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1 **Infrared thermography of agonistic behaviour in pigs**

2

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15

16 **Declarations of interest:** none.

17

18 **Highlights**

- 19 • Thermal images of pigs in dyadic contests were related to physiology and behaviour
- 20 • Temperature dropped at contest resolution, regardless of fight duration
- 21 • Results are in line with the hypothesis of a thermal response to emotional state
- 22 • Winners and losers did not differ in thermal profile, suggesting both are affected
- 23 • The possibility of emotional arousal rather than valence deserves further research

24

25 **Abstract**

26 Infrared thermography (IRT) or thermal imaging is increasingly being used as a non-invasive method
27 to gain information on animals' physiological and emotional state. IRT has the potential to serve as a

28 non-invasive quantitative assessment method but few studies have examined its utility in predicting
29 welfare-relevant outcomes of dynamic scenarios relevant to commercial farming. This study used
30 1,284 thermal images taken from 46 pigs in a controlled test environment while they engaged in an
31 agonistic encounter (dyadic contest) at 13 wk of age. Images were taken of the complete body from a
32 dorsal perspective. A pilot study indicated that a rectangular thermal window on the back region was
33 the most suitable and reliable area for obtaining temperature data in this situation. From this thermal
34 window, the average, minimum and maximum temperature, standard deviation and coefficient of
35 variation (CV) were obtained. These were analysed in relation to contest phase (from non-contact
36 assessment, through escalated fighting to retreat), fight occurrence, contest duration, contest outcome
37 (winner / loser status) and changes in blood glucose, blood lactate, and skin injuries. Variables
38 showed a strong change in response to the moment of contest resolution (retreat of the loser);
39 temperatures reduced sharply and CV increased, but did not differ between winners and losers.
40 Contests that included a fight showed lower temperatures. Contest duration, body weight and sex only
41 had minor influences on the temperatures. As the drop in temperature at contest resolution was
42 irrespective of contest intensity, and the pattern was similar in winners and losers, this data potentially
43 reflects vasoconstriction as a result of psychological stress rather than solely a physiological change.
44 The study shows that peripheral temperature, as recorded by IRT, responds to the intensity and phases
45 of a contest and may allow new insight into the physiological and welfare outcomes of aggressive
46 behaviour.

47

48 **Keywords.** Thermography; emotion; pig; aggression; physiology; contest

49

50 **1. Introduction**

51 Infrared thermography (IRT) or thermal imaging is a non-invasive method that uses specialised
52 imaging cameras to capture infrared (heat) radiation emitted from the surface of an object. It then
53 produces a thermograph that allows visualisation and quantification of the temperature distribution
54 (Gade & Moeslund, 2014; Vollmer & Möllmann, 2017). This thermograph or thermogram can be
55 used to detect physiological and behavioural changes in endotherm animals (Luzi et al., 2013).

56 In the animal and welfare science fields, IRT has initially been applied as a method to measure
57 changes in body temperature in response to injury, disease, handling, transportation, and fatigue
58 (Mitchell, 2013). As such, IRT as a health and welfare assessment tool has been used in a wide variety
59 of animals including livestock, companion and wild animals (Cilulko et al., 2013; Nääs et al., 2014;
60 Foster & Ijichi, 2017). More recent studies have also used IRT to make inferences about the
61 individual's emotional state, in particular in response to situations likely to cause stress, rather than
62 rely on more traditional physiological measures. For example, IRT has been used to assess the
63 relationship between facial surface temperature and emotional states in rhesus monkeys concluding
64 that a decrease in nasal temperature was correlated with a negative emotional state (Nakayama et al.,
65 2005). Similar approaches have thereafter been applied to other non-human species and circumstances
66 (primates: Kano et al., 2016; Chotard, Ioannou & Davila-Ross, 2018; dogs: Travain et al., 2016;
67 rabbits: Ludwig et al., 2007). The use of IRT to study emotions has been more widely used in humans
68 (Clay-Warner & Robinson, 2015), for example to study emotions in infants (e.g. Esposito et al.,
69 2015).

70 IRT has been applied to treatment comparisons in which animals have been exposed to an acute stress
71 treatment, but its sensitivity in detecting individual differences in behavioural and physiological
72 response to stress has only been sparsely tested. The objective of this study was to test whether
73 peripheral temperature as measured by IRT is associated with variations in behavioural and
74 physiological responses of pigs in a situation with strong emotional valence and arousal, namely
75 agonistic encounters. More specifically, we hypothesized that IRT response is associated with the
76 physiological and behavioural changes occurring during dyadic contests. In addition, given the
77 potentially different emotional state in winners and losers (Camerlink et al., 2016a), we also
78 hypothesize that contest outcome will influence IRT responses. Pigs were selected as an ideal species
79 since hair coverage is minimal and IRT studies have identified different thermal windows that
80 correlate to some extent with core body temperatures (Soerensen & Pedersen, 2015). The pig body,
81 rather than only the eye, is therefore very suitable for IRT. Furthermore, aggression between pigs is a
82 common occurrence on farms and is a considerable animal welfare issue (Peden et al., 2018).

83 Obtaining insight into this welfare issue through a non-invasive measure may improve understanding
84 of the physical and potentially emotional outcomes of aggression and of winning and losing.

85

86 **2. Material & Methods**

87 This research was part of a larger trial on aggression in pigs and all tests were carried out for the
88 purpose of multiple research questions. The project was carried out in accordance with the European
89 Guidelines for accommodation and care of animals, the ASAB/ABS and ARRIVE guidelines and UK
90 Government DEFRA animal welfare codes. The project received ethical approval by SRUC's Animal
91 Ethics Committee (ED AE 40-2014) and the UK Government Home Office under the Animals
92 Scientific Procedures Act 1986.

93

94 *2.1 Animals and housing*

95 In total, 46 pigs with suitable thermal image data were sampled out of a population of 134 growing
96 pigs (Large White × Landrace dam × American Hampshire sire). Entire males (not castrated) and
97 females and were studied over two batches at the SRUC pig research unit (Easter Howgate, UK). Tail
98 and teeth were kept intact. Pigs were housed by litter group in solid floor, straw bedded pens
99 measuring 1.9×5.8 m (ca. 1.0 - 1.1 m² / pig) which were cleaned and replenished daily. Pigs had *ad*
100 *libitum* access to water and dry pelleted feed suitable to their age and growth. The room temperature
101 was kept at 16.1 ± 0.3 °C with a humidity of $53.5 \pm 0.1\%$ using Dicom© monitoring and ceiling vents
102 and heat sources. From 5 – 7 weeks of age the pigs were gradually habituated human handling and the
103 test situation, including ear touching, weighing, time spent in the sampling crate, movement to the
104 contest staging area (but not the contest arena itself) and diminishing group size in order to reduce
105 potential fearfulness.

106

107 *2.2 Test situation*

108 Thermal images (explained in section 'Thermal images') were captured during 69 dyadic contests
109 between pigs. Contests were staged between two pigs who were unknown to each other, were all 13
110 weeks of age, and had a weight difference varying between 0 – 20%. Dyads were composed of male-

111 male, female-female, and male-female contests. Contests were held in a solid sided arena measuring
112 2.9×3.8 m with a solid floor covered by a thin layer of wood shavings (Figure 1). At either side of
113 the arena were $2.9 \text{ m} \times 1.9 \text{ m}$ holding pens to temporarily house each pig prior to the test starting. The
114 room was lit by nine overhead fluorescent strips providing 80-110 lux, and no natural light could
115 enter. The room in which the arena was situated had an ambient temperature of on average $16.1 \pm$
116 0.03°C (range 15-17.5 $^\circ\text{C}$) with a humidity of $53 \pm 0.1\%$ (range 50 – 58). The contest started as soon
117 as the two pigs entered the arena simultaneously from opposite sides. A contest was terminated when
118 a) a winner was apparent (loser retreats and does not retaliate within 1 min after retreat); b) after 20
119 min (time-out); or c) due to an end-point such as fear behaviour or mounting. The total contest
120 duration and the fight duration (time spent in mutual aggression) were recorded for this study.

121



122

123 **Figure 1.** Opponents showing agonistic behaviour in the contest arena. The silver dot on the rear of
124 the left pig can be distinguished on a thermal image due to difference in emissivity, and therefore
125 enables individual identification. Copyright: M. Farish.

126

127 *2.3 Blood glucose, blood lactate and skin lesions*

128 Blood values were measured within 2 min before and within 5 min after the contest by obtaining a
129 drop of blood from the ear vein of each pig. This was done using a small flat blade lancet to make a

130 tiny prick in the ear vein while the pig was standing in a sampling crate. The drop of blood was
131 directly applied to a blood glucose meter (iDia monitor; IME-DC, Germany) and a blood lactate meter
132 (The Edge; Apex Biotechnology Copr, Taiwan). The meters instantly provide a read out value in
133 mmol/ml. The measurement range for the glucose meter was 0.6 – 33.3 mmol/ml and for the lactate
134 meter 0.7 – 22.3 mmol/ml. Monitors were calibrated before each session with the appropriate
135 calibration fluids. The pre-contest value was subtracted from the post-contest value to obtain the
136 change in glucose and lactate which was used for further analyses.

137 Skin lesions, scratches on the skin due to the receipt of bites during an aggressive encounter, were
138 counted by an experienced single observer in the home pen pre-contest and directly after the contest
139 in the holding pens. The number of fresh skin lesions (bright red, with no scab formation) was
140 counted separately for the front, middle and rear of the body on the left and right side. The number of
141 skin lesions pre-contest was subtracted from the number post-contest to obtain the actual number of
142 lesions gained during the contest.

143

144 *2.4 Thermal images*

145 A FLIR SC620 thermal camera with wide angle lens ($45^\circ \times 34^\circ / 0.1 \text{ m}$) was used to collect
146 thermographs at 10 s intervals for the full duration of the contests. To distinguish the two pigs on the
147 thermographs, a silver mark (Aluspray[®], an aluminium wound spray for veterinary purposes) was
148 sprayed on the back at the base of the tail of one of the two pigs before entry into the arena (Figure 1).
149 Due to the different emissivity of the spray compared to the skin (pig skin emissivity 0.94-0.98;
150 Soerensen et al., 2014) the spray mark showed up differently on the thermograph despite having the
151 same temperature. The rear of the pig was chosen as this area receives fewest bites and would
152 therefore have least chance of fading during the course of a fight. The thermal imaging camera was
153 positioned, approximately 5 m above the ground at an angle of 30° , using a Manfrotto[®] adjustable
154 arm and clamp, providing an overhead view of the full contest arena. A Kestrel[©] 4000 weather meter
155 was used to log the atmospheric temperature and relative humidity (RH) of the contest room with
156 changes greater than 1°C or 1% RH inputted to the object parameters throughout the sampling period.

157 The distance between the camera and the pigs was constant throughout, emissivity set to 0.98, and
158 reflective temperature 15-20 °C.

159

160 *2.5 Selection of the region of interest (ROI)*

161 A pilot study was performed to determine the best area of interest, using a sub sample of 533 images
162 from 36 pigs. Using FLIR ThermaCAM Researcher 2.10 Pro (FLIR Systems, Inc.), a polygon was
163 drawn around the whole pig. From the polygon, the location of the pixel with the highest temperature
164 was assessed. To do this the thermal scale was modified by focusing on the highest temperatures until
165 only one visible spot remained. Then, a mark was placed on this pixel using the function ‘flying spot
166 meter’. The location of the spot was then identified by re-adjusting the image to the normal thermal
167 scale. The location could be categorized into one of the body regions: ears; eyes; back (excluding
168 spine); spine; rear; front leg; and hind leg. Observations on the eye (n = 3) were excluded because of
169 poor visibility from the aerial view. The results, provided in Table 1, show that the ear most often had
170 the highest temperature, followed by the back. Due to the difficulty of imaging the ear during active
171 motion of the pigs (e.g. during a fight), the possibility of saliva and blood on the ear due to bites, and
172 in this case extra blood flow due to blood sampling from the ear, it was decided that the ear was not
173 feasible nor reliable under the current conditions. Therefore, the back region was chosen as the ROI.
174 Previous research has also suggested that this ROI could be a thermal window in piglets (Tabuaciri et
175 al., 2012). Thermal windows are characterised as heat exchange body areas, perfused with blood and
176 operating as windows into core body temperature (Mitchell, 2013; Mortola, 2013; Soerensen &
177 Pedersen, 2015).

178

179 **Table 1.** Location of the highest temperature observed over 533 thermal images of 36 pigs.

Location	N observations	%
Ear	338	63.4
Back	113	21.2

Rear	44	8.3
Spine	15	2.8
Hind leg	20	3.8
Front leg	3	0.6

180

181

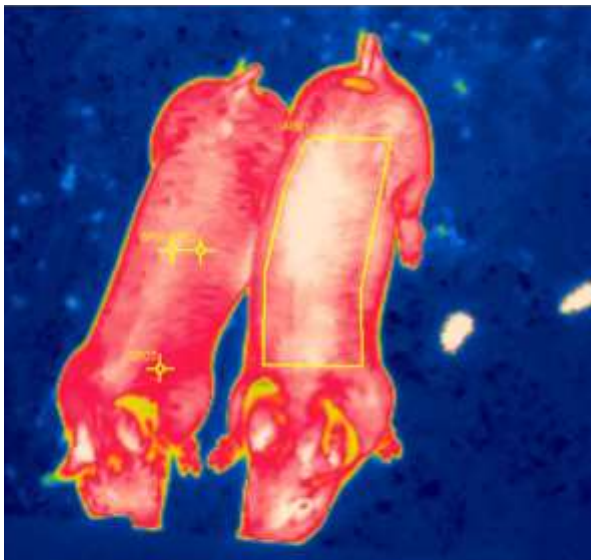
182 *2.6 Extraction of data from thermal images*

183 Contests with <17 raw images (n = 29 contests) commonly had too few usable images and were
 184 therefore excluded. Contests with >80 images (~3 times the duration of an average contest; n = 14
 185 contests) were also excluded as the behavioural repertoire in these contests typically deviated too
 186 much compared to the average contest. One contest was excluded due to too low image quality (low
 187 in pixels). Images were excluded when the two pigs appeared on the image as merged (e.g. because of
 188 mounting) or when the image was not sharp due to fast movements. Eventually, from the 67 contests
 189 23 were analysed, resulting in 1,284 suitable images for 46 pigs. Of the 46 pigs, 37% were female
 190 (n=17) and 63% were male (n=29). Dyads were composed of 48% males against males (n=22), 33%
 191 females against males (n=16), and 19% females against females (n=8). Of the 1,284 images 50.2%
 192 belonged to winners (n=645) and 49.8% to losers (n= 639).

193 In the software FLIR ThermaCAM Researcher 2.10 Pro (FLIR Systems, Inc.) images were set to the
 194 ‘rain900’ pallet for colouration (from warm to cold: white, red, orange, green, blue, dark blue). The
 195 polygon tool was used to isolate the ROI. Specifically, a rectangular area (Figure 2) was selected on
 196 the back of each pig, starting just behind the shoulder blades and ending at the start of the rump. The
 197 area did not include the belly as this appears as a warmer area due to the organs being located closer
 198 to the skin. The area excluded any object from the environment and excluded cool edges (i.e. lines
 199 around an ellipse shaped figure that give a lower radiation value due to an angle and therefore do not
 200 reflect temperature; for example in Figure 2 the cool edge is the yellow-blueish line around each pig).
 201 Each ROI had between 4,000-5,000 pixels, depending on the orientation of the pigs. The minimum,
 202 average, and maximum surface temperature and the standard deviation for each ROI were extracted.
 203 For each image the time (hh:mm:ss) was noted to assess the temperature change over time.

204 Henceforth, “temperature” refers to skin surface temperature unless otherwise stated as
205 environmental.
206 Temperature was assessed for three key time points and two phases, providing five temperature values
207 per animal: 1) start of the contest (first image in which the pig was fully visible); 2) agonistic phase
208 (average during the phase in which agonistic behaviour was shown); 3) retreat (single image closest to
209 the moment that the loser signalled its final submission to the winner; 4) post-retreat phase (average
210 of the images after retreat until the last image), and 5) end of the contest (last image, 1 minutes after
211 retreat).

212



213

214 **Figure 2.** Screenshot of a thermal image from the software *FLIR ThermoCAM Researcher 2.10 Pro*.
215 The rectangular area on the back of the pig marks the region of interest (ROI). On the rear of the right
216 pig, at the base of the tail, the silver spray mark for identification can be seen. Copyright: SRUC.

217

218 2.7 Data analysis

219 Data were analysed with SAS 9.3 (SAS Institute Inc., Cary, NC, USA). Each pig was considered as
220 statistical unit ($n = 46$), but was nested within dyad to correct for dependence between two pigs within
221 the same contest. Pearson correlations were used to assess relationships between the various contest
222 measures (skin lesions, contest duration, fight duration, glucose and lactate), and between these

223 measures and temperature variables averaged by pig. The contest measures correlated moderately
224 with each other ($r = 0.33-0.63$, average $r = 0.51$). To reduce redundancy in the subsequent modelling,
225 only skin lesions and contest duration were retained as they showed the strongest correlations with the
226 other variables.

227 The dependent variables were the average temperature (avgT), minimum temperature (minT), and
228 maximum temperature (maxT), recorded for each image. To measure the degree of variation in
229 temperature, the Coefficient of Variation (CV) was analysed as a dependent variable. These
230 dependent variables were used in a generalized linear model (MIXED Procedure). Initially, all
231 explanatory variables were included in the model. These were: contest outcome (winner / loser), sex
232 (male / female), gender composition of the dyad (MM / FF / MF), body weight at 13 weeks age,
233 weight difference between the opponents, contest duration, number of skin lesions, fight (yes / no),
234 timing (first image / average of the agonistic phase / retreat / average of the post-retreat phase / last
235 image), and test date (5 dates). Variables with the highest non-significant P -value were step-wise
236 removed from the model and the model was reassessed for goodness of fit using the Akaike
237 information criterion (AIC) and Bayesian information criterion (BIC). The variable was omitted only
238 if this improved model fit (lower AIC and BIC). The random effects included pig ID nested within
239 dyad (to indicate that the two opponents in a contest were not independent), and batch number (batch
240 1 or 2) and pig ID was specified as subject to account for repeated observations per animal (resulting
241 in 46 subjects with five observations each, one for each time point in the contest). The four models
242 showed a normal distribution of the residuals. Values are presented as LSmeans with SE. A P -value
243 <0.05 was considered significant, whereas P -values >0.05 but <0.10 were reported with their exact
244 value as tendencies.

245

246 **3. Results**

247 The average temperature (avgT) was $31.6^{\circ}\text{C} \pm 0.3$ (range 28.0 – 34.2) with a coefficient of variation
248 (CV of $2.75\% \pm 0.03$ (0.91 – 7.39%). The mean minimum temperature (minT) was $28.0^{\circ}\text{C} \pm 0.5$ (16.4
249 – 32.2) and the maximum temperature (maxT) $33.5^{\circ}\text{C} \pm 0.2$ (30.7 – 35.9). The date of observation did
250 not significantly influence these variables.

251

252 *3.1 Temperature changes over time*

253 The avgT, maxT and minT all showed a sharp and significant reduction at the moment of contest
 254 resolution, when the loser began to retreat from the winner by making a head-tilt movement (Table 2).
 255 After this retreat, the average temperature slightly increased again until the contest was ended one
 256 minutes later. The contrast is stronger when the moment of retreat is reflected as the change from an
 257 individual's average temperature (Figure 3).

258

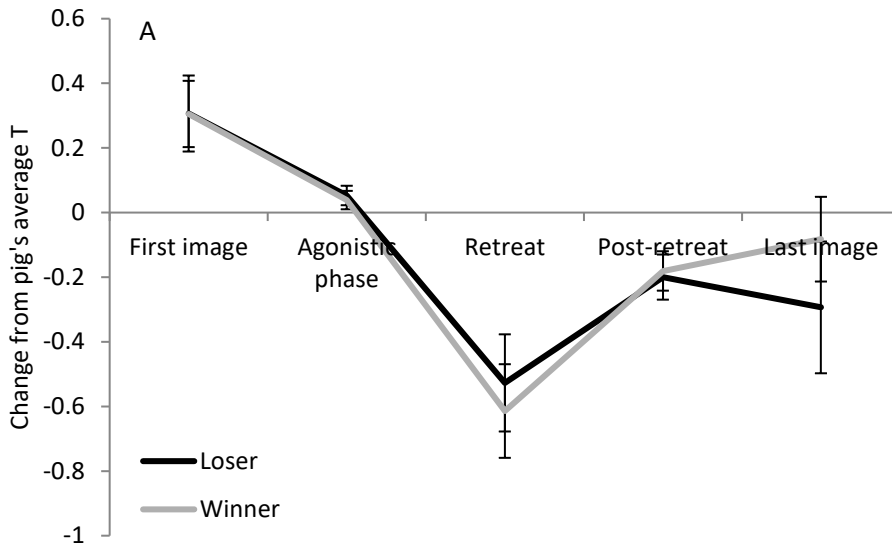
259 **Table 2.** Temperatures (in °C) and coefficient of variation (CV; in %) at different contest stages (n =
 260 1,284 images). The first image in the contest, the image at retreat of the loser, and the last image are
 261 values from a single image whereas pre and post reflect the average of all images in between the fixed
 262 time points, i.e. the agonistic phase and the post-retreat phase. Values are LSmeans.

Temperature	First	Pre	Retreat	Post	Last	<i>F</i> statistic	<i>P</i> -value
Minimum	29.12 ^a	28.89 ^a	27.98 ^b	28.19 ^b	29.10 ^b	$F_{4,172} = 14.41$	< 0.001
Average	31.85 ^a	31.73 ^a	31.20 ^b	31.43 ^c	31.39 ^{bc}	$F_{4,172} = 14.28$	< 0.001
Maximum	33.43 ^a	33.42 ^a	33.13 ^b	33.46 ^a	33.39 ^a	$F_{4,171} = 3.86$	0.005
CV (%)	2.31 ^a	2.48 ^a	2.95 ^b	3.03 ^b	2.97 ^b	$F_{4,171} = 17.11$	< 0.001

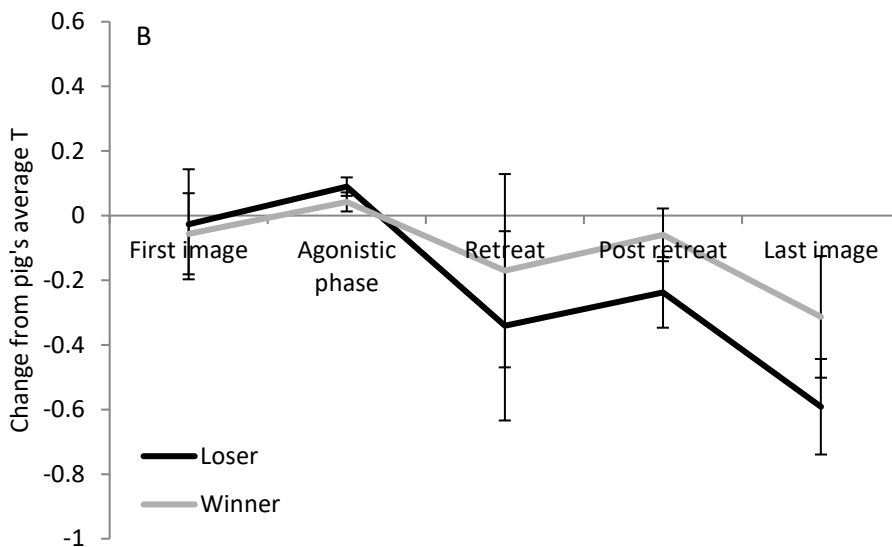
263 ^{a,b,c} Values lacking a common superscript letter differ by $P < 0.05$.

264

265



266



267

268 **Figure 3.** Average change from each individual's average temperature at various contest stages for
 269 contests A) with a fight (n = 32 pigs: 16 winners and 16 losers) and B) without a fight (n = 14 pigs: 7
 270 winners and 7 losers).

271

272 *3.2 Contest intensity*

273 The contest duration was on average 7 minutes (424 ± 0.5 s), with an average fight duration of $55 \pm$
 274 1.7 s. Contest duration and fight duration were unrelated to the avgT, maxT, minT, and CV.

275 Not all contests involved a fight as some were resolved merely by a unilateral attack from the winner
 276 (73% of the contests included a fight, 27% did not). The duration of contests with a fight was on

277 average longer than contests without fight (with fight: 450 ± 6 s; without fight: 354 ± 9 s; $P < 0.001$).
 278 Temperatures did not significantly differ between contests with or without a fight, which may be
 279 partly due to the large SE in the contests without a fight as the number of contests in this category
 280 were few (Figure 3b). Figure 3 reveals that the drop in temperature during retreat is mainly related to
 281 contests with a fight, as the different contest phases only tend to differ from each other in contests
 282 without a fight (winners and losers analysed together: $F_{4,49} = 2.45$; $P = 0.058$). In contests without a
 283 fight a significant reduction in temperature was only observed in the last image as compared to the
 284 first image ($P = 0.03$) and the agonistic phase ($P = 0.006$), and the value of the last image tended to be
 285 lower than in the post-retreat phase ($P = 0.09$) (Figure 3b). The temperature at retreat tended to be
 286 lower than the temperature in the preceding agonistic phase ($P = 0.07$).

287

288 3.3 Physiological parameters and skin lesions

289 Pigs accumulated on average 72 ± 10 skin lesions due to the receipt of bites. Temperatures were
 290 significantly related to the number of skin lesions on the pig's body. Animals with many skin lesions
 291 had a lower minT ($F_{1,172} = 4.68$; $P = 0.03$) and a greater CV ($F_{1,171} = 21.92$; $P < 0.001$), which was
 292 also clear from the initial correlations (Table 3). The number of skin lesions did not significantly
 293 relate to the avgT ($F_{1,172} = 2.55$; $P = 0.11$) and maxT ($F_{1,172} = 0.01$; $P = 0.93$).

294 Blood glucose and lactate increased on average during the course of the contest (glucose: 1.04 ± 0.22
 295 mMol/L increase (min-max: 3.2 – 10.9); lactate: 5.8 ± 0.87 mMol/L increase (min-max: 0.6 – 22.3).

296 The change in blood glucose and blood lactate did not differ between winners and losers (both $P >$
 297 0.10) and was unrelated to the temperature values, except that a relative increase in blood lactate
 298 related to a lower minT ($b = -0.073 \pm 0.036$ °C per mMol/L increase; $F_{1,171} = 4.09$; $P = 0.04$).

299

300 **Table 3.** Correlations between fixed effects and temperature variables averaged by pig (n = 46).

	Lesions	Contest duration	Fight duration	ΔGlucose	ΔLactate
AvgT	-0.44*	-0.25	-0.03	-0.35	-0.22
MaxT	-0.27	-0.02	0.10	-0.36	-0.19

MinT	-0.51*	-0.40*	-0.23	-0.32	-0.49*
CV	0.62*	0.50*	0.38	0.18	0.26

301 **P*-value <0.001.

302

303 *3.4 Individual characteristics*

304 Winners and losers did not significantly differ in avgT, minT, maxT or CV (all *P* > 0.10). They also
305 did not differ in their temperatures depending on the stage of the contest. For example, winners and
306 losers had a similar temperature at the moment of retreat (Figure 3).

307 The CV tended to be lower in pigs with a higher body weight ($b = -0.028\% / \text{kg}$; $F_{1,171} = 2.91$; $P =$
308 0.09) but body weight did not relate to avgT, minT or maxT (all $P > 0.10$). A larger weight difference
309 between the two opponents increased the minT ($b = 0.04 \text{ } ^\circ\text{C} / \text{kg}$; $F_{1,171} = 5.75$; $P = 0.02$) and tended to
310 and reduce the CV ($b = -0.016\% / \text{kg}$; $F_{1,171} = 3.53$; $P = 0.06$) as compared to pigs in dyads of similar
311 body weight. Body weight difference did not influence the avgT ($F_{1,172} = 2.50$; $P = 0.12$) and maxT
312 ($F_{1,172} = 1.75$; $P = 0.19$). Sex and the gender composition within a contest (MM / FF / MF) did not
313 influence any of the observed temperature variables (all $P > 0.10$).

314

315 **4. Discussion**

316 The use of infrared thermography (IRT) for assessing animal welfare shows promise but is still in
317 development. To date, IRT has been shown to associate with acute stressors with an indication that at
318 least part of the thermal response reflects the emotional reaction to the stressor in addition to changes
319 in activity, physiology and metabolism (rabbits: Ludwig et al., 2007; dogs: Travain et al., 2015; cattle:
320 Stewart et al., 2008; horses: Valera et al., 2012). However, the association between peripheral
321 temperature and individual differences in stress response has only been marginally explored.
322 Furthermore, the sensitivity of peripheral temperature to time-dependent phases of a highly dynamic
323 stress situation has not been examined. Here we made a step forward by assessing over one thousand
324 IRT images of pigs during an agonistic encounter and examining how temperature was related to
325 individual behaviour and contest outcomes and how sensitive the temperature changes were to the
326 phase of the contest. The main determinant of the peripheral temperature in an ambient temperature-

327 controlled environment was the moment at which the loser retreated. Other parameters such as sex
328 and body weight only played a minor role. Whilst the number of skin lesions was associated with
329 temperature changes, other aspects of the contest situation were not, including the occurrence of an
330 escalated fight, the duration of this fight and the contest as a whole, the change in blood glucose and
331 lactate and whether the animal was a winner or loser. This strengthens the overall concept that the
332 reduction in temperature at the moment of retreat of the loser is only partially related to the
333 physiological intensity of the fight, and is in addition potentially influenced by psychological factors
334 such as emotional state.

335 Mitchell (2013) suggests that infrared thermography applications can be divided into four broad
336 functional categories: a) for monitoring changes in body temperature due to environmental pressures
337 such as high ambient temperature; b) for monitoring the effects on body and skin surface temperature
338 due to transport and handling; c) for monitoring injuries, pathology and inflammatory responses and;
339 d) for monitoring the cardiovascular responses to a stressful event or state. We discuss the current
340 results in light of the two latter applications.

341

342 *4.1 Injury and fatigue*

343 Injury involves a local temperature increase and can be detected by IRT. During reciprocal aggression
344 pigs deliver bites mainly to their opponents' front side of the body (head and shoulders) including the
345 ears (Turner et al., 2006). The underlying metabolic vasoconstriction or vasodilatation that acts as
346 thermoregulation mechanisms may also influence body surface temperature of other areas. Skin
347 injuries itself, which are easily detected from distance on a normal RGB camera, are in general not
348 detectable on the infrared image unless skin injuries are numerous and bleeding. However, the
349 temperatures on the ROI, the dorsal area, did relate to the number of skin lesions. In fact, skin lesions
350 were a better predictor of skin temperature than contest duration or fight duration. Pigs with many
351 lesions showed a reduction in skin temperature rather than an increase. Before the onset of an
352 inflammatory response, which would result in an increase in temperature, there may first be a cooling
353 of the surface temperature due to evaporation from fluids on the skin such as blood from the wound
354 and saliva from the biter (e.g. Luzi et al., 2013). Also a temporary capillary constriction may occur at

355 the injury site. Moreover, skin lesions correlate with contest duration, and thus more skin lesions
356 indicate a longer time spent in the contest arena. In this particular situation, the temperature in the
357 contest arena was lower than the temperature in the home pen causing pigs to gradually cool down.
358 As most contests were short the skin lesions did show a stronger relationship to the IRT than the
359 contest duration.
360 IRT can be used to detect muscle fatigue (Bartuzi, Roman-Liu & Wiśniewski, 2012), which is also
361 reflected in lactate. An increase in blood lactate here related to a lower minimum temperature.
362 Fatigue, reflected by the increase in lactate, may have resulted in lower surface temperatures due to
363 associated physiological and psychological stress (e.g. Nakayama et al., 2005; Ludwig et al., 2007;
364 2010). Other than the abovementioned, the thermal images did not reveal differences in the animal's
365 change in blood glucose or blood lactate level.

366

367 *4.2 Psychological response*

368 The most prominent finding in this study is the sharp drop in temperature at the moment of contest
369 resolution, i.e. the loser's retreat. Existing studies have demonstrated a link between reduced surface
370 temperature and a negative emotional state (e.g. Nakayama et al., 2005; Ludwig et al., 2010). Moe et
371 al. (2012) also found a drop in temperature during a positive emotional state, relating the decreased
372 temperature to emotional arousal rather than emotional valence.

373 When unfamiliar pigs encounter they need to establish a dominance relationship (Meese & Ewbank,
374 1973). The subordinate pig signals its submission by a sharp turn away from the opponent, also called
375 a head-tilt (Jensen, 1982). The time of the final head tilt was recorded in each contest and the thermal
376 image within 5 seconds of the head-tilt was used to reflect this moment. In contests with a fight the
377 temperature is reduced compared to the agonistic phase beforehand, and a similar reduction was found
378 to be a tendency in the contests without a fight. This shows that even in the contests without much
379 physical activity (i.e. no fight), and therefore also without much skin lesions, there was a thermal
380 response to the moment that the contest outcome was settled, with both winners and losers showing a
381 drop in temperature. However, we interpret this finding with some caution given that the results of
382 contests without a fight are based on a limited sample size. Social defeat is well-known to be a

383 powerful stressor (Blanchard, McKittrick & Blanchard, 2001). In other IRT studies of acute stress,
384 including social stress, a decrease in surface temperature was also observed (Ludwig et al., 2007;
385 Stewart et al., 2008). Furthermore, repeated social defeat has been shown to induce chronic
386 hyperthermia in rat's core body temperature (Keeney et al., 2001). In this condition, it could cause
387 long term temperature modification in response to a mild stress. Commercial pigs are regularly
388 regrouped during the production phases (Peden et al., 2018) and therefore the possibility of negative
389 effects of repeated social defeat on their thermoregulation should not be disregarded. However,
390 winners and losers did not significantly differ in their thermal response at any phase during the
391 contests, including the moment of retreat. This may imply that the moment of defeat equally triggers a
392 response in the winner as in the loser. Although winners and losers show different emotional
393 responses after the fight as assessed through Qualitative Behaviour Assessment (pigs: Camerlink et
394 al., 2016a), the moment of retreat might indicate a climax in physical and psychological effort in
395 which both opponents compete to their maximum capacity.

396 Whereas in contests with a fight the temperature increased again after retreat, the temperature in
397 contests without fight significantly decreased towards the end of the contest. This might be due to a
398 higher level of bullying behaviour (16% more) in contests that are concluded without a fight
399 (Camerlink et al., 2016b). Bullying, in which the loser is being chased by the winner, is by farmers
400 perceived to be more stressful for the pigs than the actual fight (Peden et al., 2019). Less aggression at
401 the first encounter may result in more aggression at a later stage (Turner et al., 2017) and this may
402 thus result in more chronic stress.

403 These observations suggest that the physical effort committed to the contest was not the primary
404 driver of peripheral temperature changes, suggesting that injury and the emotional response to stress
405 might have been responsible for the drop in temperature during the contest.

406

407 *4.3 Selection of the region of interest*

408 For the measurement of emotions the eyes are often the targeted body area (e.g. Stewart et al., 2008).
409 Imaging pig eyes does have its difficulties due to the small surface and eye lashes obstructing the
410 image. Moreover, during situations of aggression and pain pigs may naturally squint their eyes

411 (DiGiminiani et al., 2016; Camerlink et al., 2018). Here we have demonstrated that in pigs the dorsal
412 plane can also be imaged for assessing responses to strong stressors such as agonistic encounters. This
413 has huge benefits as it is more feasible to image the dorsal plane from overhead cameras. A similar
414 conclusion was made earlier by Tabuaciri et al. (2012) when imaging piglets. For future applications,
415 data from thermal images could be extracted with algorithms that detect the shape of the animal
416 (Franco et al., 2019), as has been done for automatic recording of behaviour. Combining novel
417 technology, for example using tracking to obtain data and algorithms to extract data, will facilitate the
418 use of IRT to assess physiological and emotional responses to various welfare conditions in livestock.

419

420 **5. Conclusions**

421 Using infrared thermography, a drop in temperature was observed during agonistic encounters
422 between pigs at the moment of retreat of the loser. The drop in temperature, as compared to the
423 agonistic phase, also tended to be present in contests without a fight, indicating that the thermal
424 response was not solely due to physical activity or skin injuries. The data suggest that the moment of
425 retreat, or contest resolution, is the most stressful moment of the encounter and indicates a similar
426 arousal in both the winner and loser. The results show that in pigs the dorsal plane can be used to
427 detect responses in surface temperature to stressful situations. Imaging the dorsal plane rather than the
428 eye or ear greatly facilitates the ease of using IRT for research and practice, and can be used as a non-
429 invasive measure to obtain additional measures of welfare.

430

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439

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