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The Veterinary Journal xxx (2005) xxx–xxx
The Veterinary Journal
www.elsevier.com/locate/tvjl

# Saddle pressure measuring: Validity, reliability and power to discriminate between different saddle-fits

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## Abstract

Saddle-fit is recognised as an important factor in the pathogenesis of back problems in horses and is empirically evaluated by pressure measurement in clinical practice, although not much is known about the validity, reliability and usability of these devices in the equine field. This study was conducted to assess critically a pressure measurement system marketed for evaluating saddle fit. Validity was tested by calculating the correlation coefficient between total measured pressure and the weight of 28 different riders. Reliability and discriminative power with respect to different saddle fitting methods were evaluated in a highly standardised, paired measurement set-up in which saddle-fit was quantified by air-pressure values inside the panels of the saddle.

Total pressures under the saddle correlated well with riders' weight. A large increase in over-day sensor variation was found. Within trial intra-class correlation coefficients (ICCs) were excellent, but the between trial ICCs varied from poor to excellent and the variation in total pressure was high. In saddles in which the fit was adjusted to individual asymmetries of the horse, the pressure measurement device was able to detect correctly air-pressure differences between the two panels in the back area of the saddle, but not in the front area. The device yielded valid results, but was only reliable in highly standardised conditions. The results question the indiscriminate use of current saddle pressure measurement devices for the quantitative assessment of saddle-fit under practical conditions and suggest that further technical improvement may be necessary.

*Keywords:* Horse; Pressure; Back; Saddle; Saddle-fit

## 1. Introduction

In recent years, several pressure measurement devices for the objective evaluation of saddle-fit have become available. These systems have been used for the scientific evaluation of saddle pads (Harman, 1994, 1997; Pullin et al., 1996), different saddle brands (Werner et al., 2002) and saddles that were artificially made to be poorly fitting (Liswaniso, 2001). In equine practice and the saddlery industry, such devices are commonly used, as evaluation of saddle-fit using pressure measurement is thought to improve the quality of saddle-fit and provide a quantitative measure. Customers are prepared to pay for this, not least because bad saddle-fit is often incriminated as a cause of back problems (Harman, 1999). Moreover, there is scientific evidence that (weighted) saddles influence back and limb movements of the horse (De Cocq et al., 2004).

Nevertheless, the question remains as to whether saddle pressure systems really do contribute to better saddle-fit. The systems, which are derived from devices used in human research, are relatively new and have undergone little scientific scrutiny in the equine field. To date, the validity of only one pressure measurement device has been evaluated (Jeffcott et al., 1999). Other researchers using have reported no information about validity, variability and reliability (Harman, 1994, 1997; Liswaniso, 2001; Pullin et al., 1996), and have failed to explain the high variability found in their

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1090-0233/$ - see front matter © 2005 Published by Elsevier Ltd.
doi:10.1016/j.tvjl.2005.05.009

studies (Werner et al., 2002). These data are in contrast to work in the human field, where pressure measurement devices specially developed to test wheelchair seats have been evaluated under standardised conditions for hysteresis, creep, repeatability, response time and validity (Ferguson-Pell and Cardi, 1993; Ferguson-Pell et al., 2001; Nicholson et al., 2001). Recently, a pressure measurement device used to measure bicycle seat pressure was tested for reliability and validity under conditions that could be adapted for the equine field (Bressel and Cronin, 2005).

In the present study, a saddle pressure measurement device was tested for validity and reliability and for its effectiveness for the intended use, i.e. to discriminate objectively between different saddle-fits.

## 2. Materials and methods

### 2.1. Pressure measuring equipment

A commercially available saddle pressure measuring system was used (FSA, VERG Inc.). The system consisted of a four-way stretch Lycra fabric mat with an overall size of 79 × 106 cm and a sensing area of 66 × 96 cm. The mat contained 512 piezo-electric sensors with a size of 57 × 19 mm, arranged in a 32 × 16 pattern. The mat was 0.36-mm thick, had a maximal sample rate of 3072 sensors per second (6 Hz), and could be calibrated in the range of 0–40 kPa. The variation coefficient of the measurements was <10% according to the manufacturer.

The calibration process involved placing the pressure-sensing mat in a pneumatic test rig, which sandwiched the mat together with an air-pressurised bag between two rigid surfaces. A series of readings from the mat was taken at different pressures, both in an inclining and a declining pressure range (steps of 4 kPa). The system's software uses the values that are generated to define for every individual sensor the exact pressure and establishes creep and hysteresis values, after which these errors are corrected for. In this study, a variation coefficient of 5% (instead of the 10% recommended by the manufacturer) was deemed acceptable. The mat was calibrated at the beginning of every measurement day. The calibration set-up was also used for the over-day sensor variation measurements.

### 2.2. Procedure for validity testing

The validity of the pressure measurement device was tested before the saddle-fit experiment. Validity was tested in the same way as described by Jeffcott et al. (1999). Measurements were taken using one Warmblood horse (mare, 17 years, 654 kg, 1.65 m) and one standard 43 cm (17 in.) dressage saddle without stirrup and leathers, weighing 7 kg in total. The saddle was weighed with the girth, but without stirrup and leathers and placed directly on the pressure-measuring device. A pressure measurement was taken with a loose girth and a tightened girth before and after the measurements with the riders. The measurements with the riders took place without removing the saddle or the pressure pad and without loosening the girth.

Twenty-eight different riders (21 females and 7 males, mean ± SD age 28 ± 9 years, mean ± SD weight 72 ± 13 kg, mean ± SD height 1.76 ± 0.09 m) were weighed and asked to mount the horse from a portable stepladder. Pressure measurements were performed for 5 s with a frequency of 2 Hz (10 readings in total) with the horse standing squarely. The total pressure for each of the 10 pressure readings was determined and the mean of these values calculated. Pearson's correlation coefficient between the riders' weight and the mean total pressure was calculated. A correction for the weight of the saddle and the pressure caused by tightening the girth was made by adding the weight of the saddle to the weight of the rider and subtracting the difference in total pressure between the measurements with a loose and a tightened girth from the total measured pressure. This was done to verify the assumption made by Jeffcott et al. (1999) that the weight of the saddle and the tension of the girth caused the curve representing the correlation between pressure and weight not to pass through the origin.

### 2.3. Comparison of saddle-fitting methods

#### 2.3.1. Horses

Twenty-five Dutch Warmblood horses were used (18 mares and 7 geldings, mean ± SD age 10.1 ± 4.7 years, weight 596.3 ± 52.5 kg). The horses were clinically sound and in daily use by students of the Veterinary Horse Riding School.

#### 2.3.2. Saddle

A saddle with a flexible and adjustable tree was used (Jes Elite Dressage, Schleese Saddlery Service Ltd.). The tree could be adjusted with help of a specially developed tree-machine (Fig. 1), which changes tree size and angle by putting pressure on the inner side of the tree. The panels of the saddle were not filled with conventional filling material, but featured a special air system (Flair, First Thought Equine Ltd.) consisting of four air-bags that could be filled separately. These were a left and a right front air-bag, and a left and a right back air-bag.

#### 2.3.3. Experimental design

Thirteen of the horses were first tested with a symmetrically fitted saddle (similar air-pressure in the air-

Fig. 1. The tree machine used to adjust tree size and angle by putting pressure on the inner side of the tree.

bags in the panels), followed by testing with a saddle that was adjusted based on previously taken back conformation measurements. In the remaining 12 horses, the two conditions were tested in reverse order. Conditions were changed in-between measurements with the saddle on the horse and the girth tightened in order not to change the position of the saddle with respect to the pressure measurement device.

*2.3.4. Saddle-fitting procedure*

For each horse, measurements were taken with help of back gauges that were fitted on the back at the highest point of the withers and over the 18th thoracic vertebra (Figs. 2a,b). At both positions, the gauge was adjusted to the shape of the back and the left–right differences were used to assess the horse's asymmetry (Fig. 3). In addition to the gauge measurements, the saddle-fitter evaluated the conformation of the horse. Based both on gauge measurements and conformation, the saddle-fitter determined the tree-size for each individual horse, which was not changed during the measurements. In the symmetrical condition, the air chambers of the saddle were filled to a similar extent, i.e. the same air-pressure at the right and left side. To adjust and actually fit the saddle, the saddle-fitter adapted the pressure in the chambers to correct for any asymmetries in the back of the individual horse.

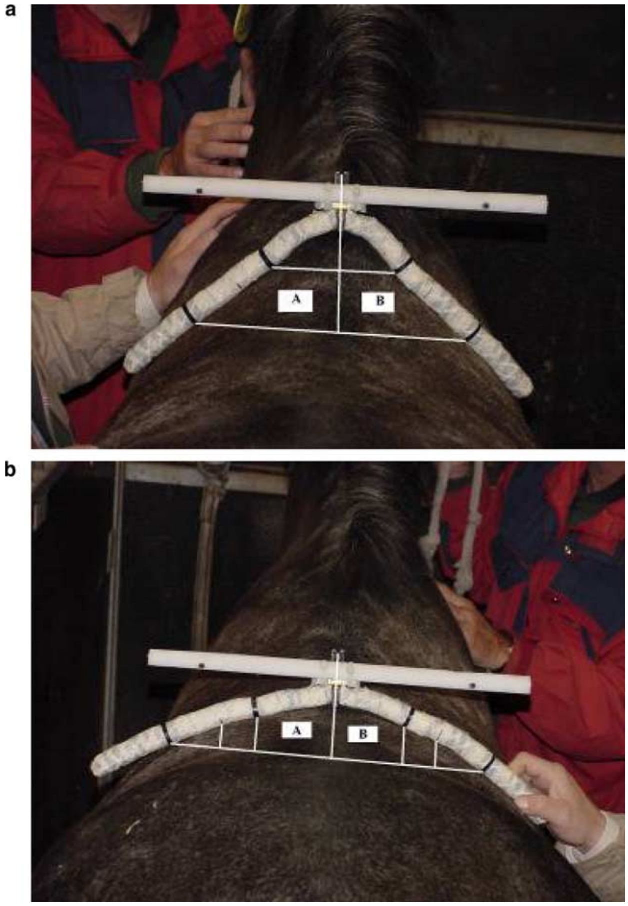


Fig. 2. Back gauge, used for taking measurements at the withers (a) and in the thoracolumbar area (b).

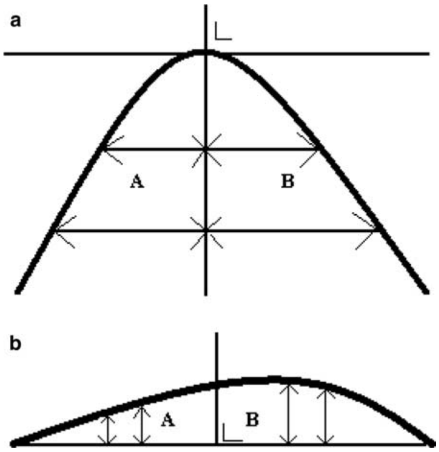


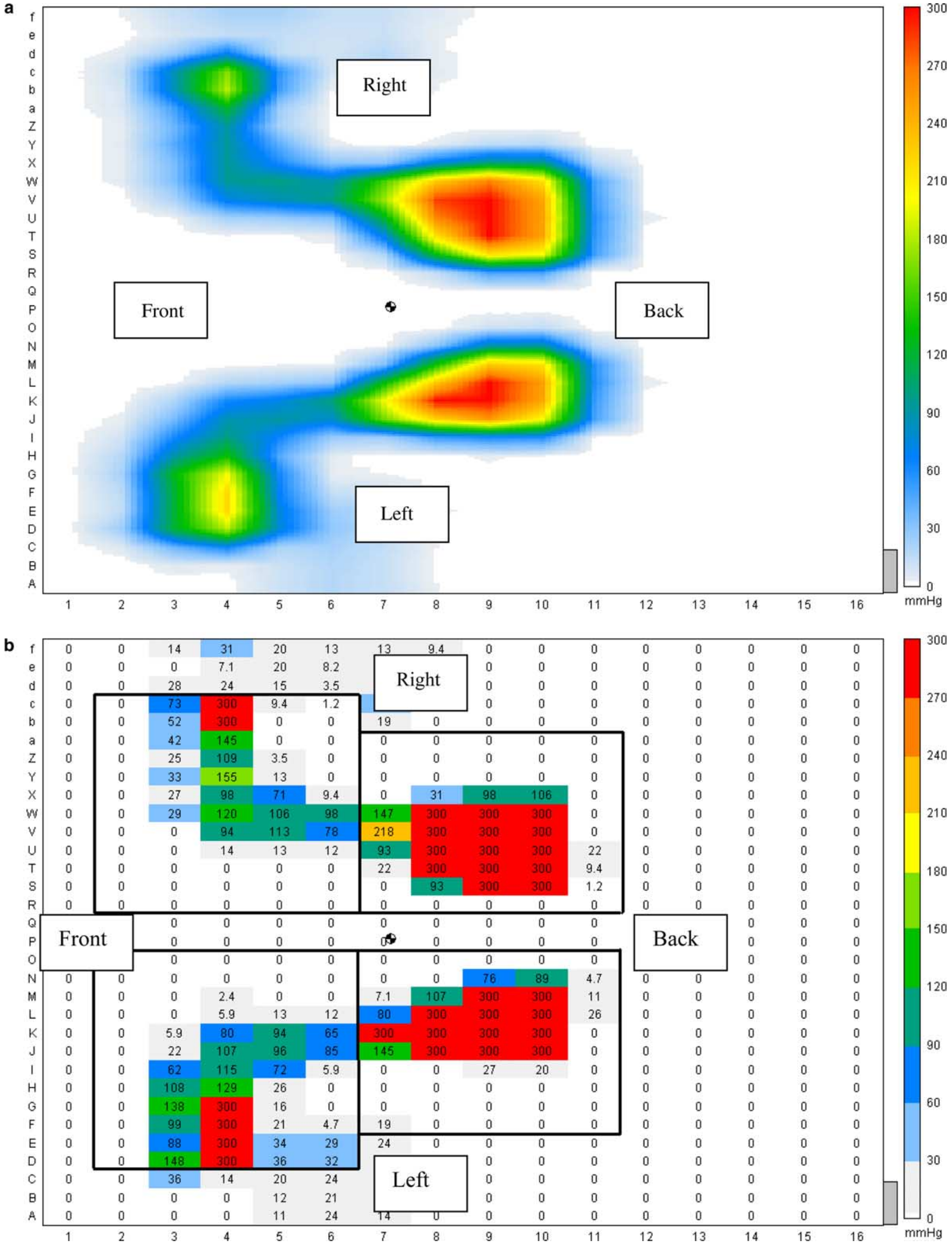
Fig. 3. Diagrammatic representation of back gauge measurements at the withers (a) and in the thoracolumbar area (b) that served for the individual adjustments of the saddle. (The length of the ↔ was measured at both right and left side. The side with the shortest ↔ is the hollow/low/concave side.)

Air-pressure in the saddle panels was measured with a sphygmomanometer (AMG, Century Medical Distributors Ltd.) by an independent assessor and in the standing horse without a rider. This information was not given to the saddle-fitter. Measurements with the saddle pressure measurement device were taken in the square standing horse mounted by one experienced rider (female, 23 years, 56 kg, 1.67 m). We tried to keep all environmental factors as stable as possible and so used an experienced rider who was presumed to have a more stable posture.

Each measurement took 5 s at a frequency of 2 Hz and was repeated three times. In this way, three sets of 10 readings were obtained for each horse, before and after fitting the saddle.

### 2.3.5. Data analysis

The data were exported to Excel (Microsoft Corporation) and for each reading the mean, standard deviation, variation coefficient, number of active sensors and



| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| f | 0 | 0 | 14 | 31 | 20 | 13 | 13 | 9.4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| e | 0 | 0 | 0 | 7.1 | 20 | 8.2 | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| d | 0 | 0 | 28 | 24 | 15 | 3.5 | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| c | 0 | 0 | 73 | 300 | 9.4 | 1.2 | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| b | 0 | 0 | 52 | 300 | 0 | 0 | 19 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| a | 0 | 0 | 42 | 145 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Z | 0 | 0 | 25 | 109 | 3.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Y | 0 | 0 | 33 | 155 | 13 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| X | 0 | 0 | 27 | 98 | 71 | 9.4 | 0 | 31 | 98 | 106 | 0 | 0 | 0 | 0 | 0 | 0 |
| W | 0 | 0 | 29 | 120 | 106 | 98 | 147 | 300 | 300 | 300 | 0 | 0 | 0 | 0 | 0 | 0 |
| V | 0 | 0 | 0 | 94 | 113 | 78 | 218 | 300 | 300 | 300 | 0 | 0 | 0 | 0 | 0 | 0 |
| U | 0 | 0 | 0 | 14 | 13 | 12 | 93 | 300 | 300 | 300 | 22 | 0 | 0 | 0 | 0 | 0 |
| T | 0 | 0 | 0 | 0 | 0 | 0 | 22 | 300 | 300 | 300 | 9.4 | 0 | 0 | 0 | 0 | 0 |
| S | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 93 | 300 | 300 | 1.2 | 0 | 0 | 0 | 0 | 0 |
| R | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Q | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | 0 | 0 | 0 |
| P | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | 0 | 0 | 0 |
| O | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | 0 | 0 | 0 |
| N | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 76 | 89 | 4.7 | 0 | 0 | 0 | 0 | 0 |
| M | 0 | 0 | 0 | 2.4 | 0 | 0 | 7.1 | 107 | 300 | 300 | 11 | 0 | 0 | 0 | 0 | 0 |
| L | 0 | 0 | 0 | 5.9 | 13 | 12 | 80 | 300 | 300 | 300 | 26 | 0 | 0 | 0 | 0 | 0 |
| K | 0 | 0 | 5.9 | 80 | 94 | 65 | 300 | 300 | 300 | 300 | 0 | 0 | 0 | 0 | 0 | 0 |
| J | 0 | 0 | 22 | 107 | 96 | 85 | 145 | 300 | 300 | 300 | 0 | 0 | 0 | 0 | 0 | 0 |
| I | 0 | 0 | 62 | 115 | 72 | 5.9 | 0 | 0 | 27 | 20 | 0 | 0 | 0 | 0 | 0 | 0 |
| H | 0 | 0 | 108 | 129 | 26 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| G | 0 | 0 | 138 | 300 | 16 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| F | 0 | 0 | 99 | 300 | 21 | 4.7 | 19 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| E | 0 | 0 | 88 | 300 | 34 | 29 | 24 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| D | 0 | 0 | 148 | 300 | 36 | 32 | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| C | 0 | 0 | 36 | 14 | 20 | 24 | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| B | 0 | 0 | 0 | 0 | 12 | 21 | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| A | 0 | 0 | 0 | 0 | 11 | 24 | 14 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Fig. 4. Pressure pictures. (a) Typical example of a computer generated pressure picture (first frame of the first measurement taken on one horse with a symmetrical saddle-fit). (b) Pressure picture with model of the numbered values used for data analysis. The same frame as in Fig. 4a, now showing the individual sensors with the measured pressures in mmHg (1 mmHg = 0.1333 kPa).

the individual reading of each sensor were recorded. The pressure readings were divided into four separate areas (left front, right front, left back, and right back). Left and right areas were separated by two rows of sensors not subjected to pressure (the gullet). The front areas consisted each of 12 rows and five columns of sensors. The back areas consisted each of 10 rows and five columns of sensors (Fig. 4). The total pressure was calculated as the sum of the four areas. To overcome the fact that some horses were hollow on the left

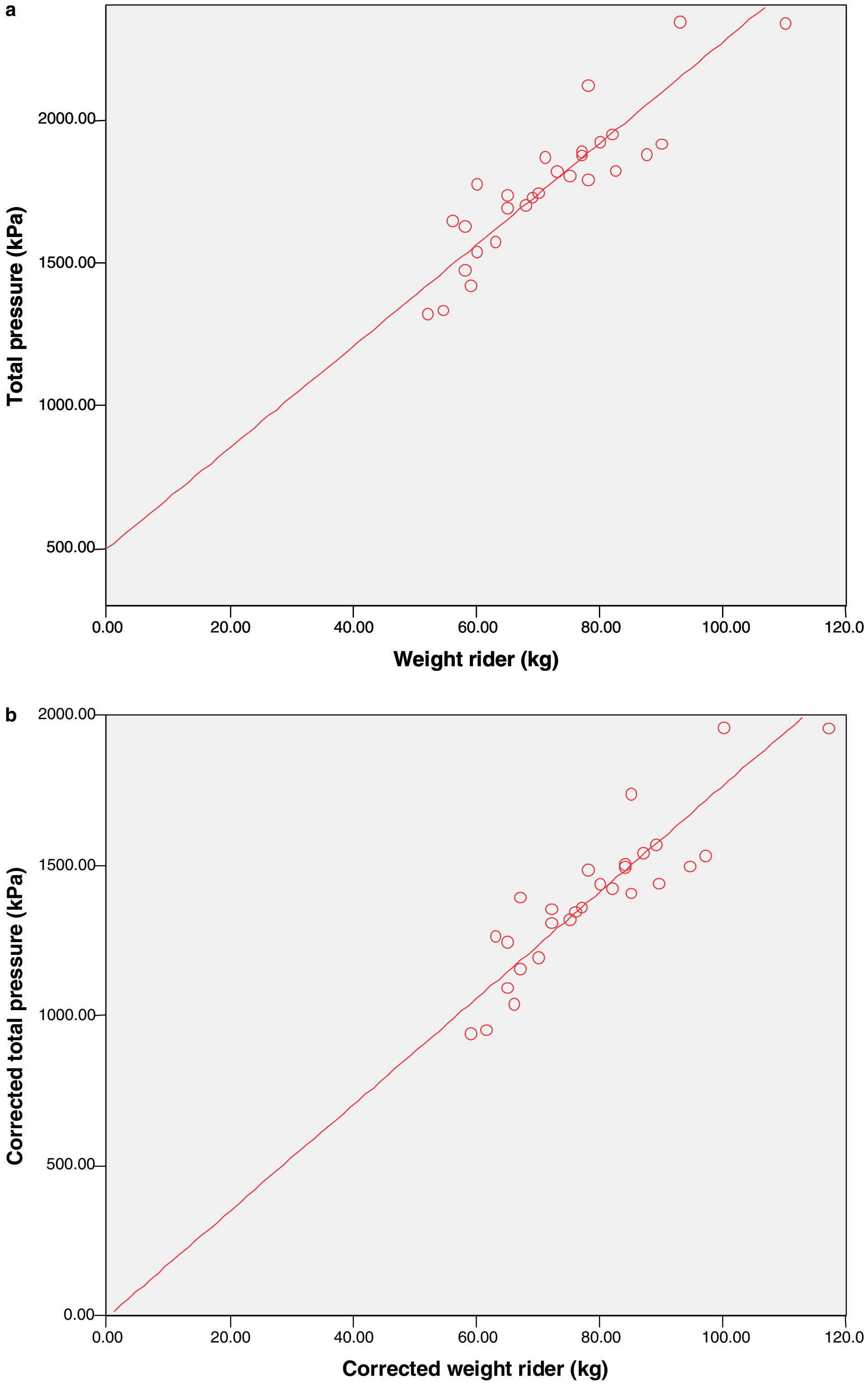


Fig. 5. Correlation between rider weight and total pressure: (a) without correction for saddle weight and pressure due to tightening of the girth; (b) with correction for saddle weight and pressure due to tightening of the girth.

side and others were hollow on the right side, data were grouped as 'high' (convex) and 'low' (hollow/concave) instead of right and left side.

### 2.3.6. *Over-day sensor variation*

Variation coefficients of the pressure measured by all sensors at 4-kPa pressure intervals in the calibration rig were calculated. The measurements took place directly after calibration and at the end of the measurement day. From these variation coefficients, a mean variation coefficient was calculated. The mean variation coefficients at the beginning and at the end of a measurement day were compared using a Students' paired *t* test. A *P*-value of <0.05 was considered significant.

### 2.3.7. *Within and between measurement intra-class correlation coefficients (ICCs)*

Reliability within one measurement of 10 readings and between the three repeated measurements, in which the saddle and saddle pressure measurement device remained on the horse, was tested with the method proposed by Bressel and Cronin (2005). The within measurement ICCs were calculated using values collected at 1.5, 3.0 and 4.5 s from measurement 1. The between measurement ICCs were calculated using values at 1.5 s from measurement 1, 2 and 3. Reliability was designated as poor with ICCs < 0.700. ICCs between 0.700 and 0.800 were classified as fair and between 0.800 and 0.900, and 0.900 and 1.000 as good and excellent, respectively.

### 2.3.8. *Evaluation of saddle-fitting*

Measurements of the air-pressure in the four panels were compared before and after saddle fitting using a Students' paired *t* test.

For the analysis of measurements by the saddle pressure measurement device, the number of active sensors, total pressures, pressures at the high and low sides at the front of the saddle and at the back of the saddle, the total high-to-low difference, and the high-to-low differences in front and back parts of the saddle were also compared between before and after saddle fitting using Student's paired *t* test. For this comparison, the mean values of the 30 readings from each horse in both the symmetrically fitted situation and the adjusted saddle situation were used. *P*-values <0.05 were considered statistically significant.

## 3. Results

The correlation coefficient between the total measured pressure and the weight of the riders was 0.96 ($P < 0.001$) when uncorrected for the weight of the saddle and the pressure caused by the tightening of the girth (Fig. 5a). When corrected for these factors, the correlation coefficient was 0.97 ($P < 0.001$) and the line of pressure against weight passed through the origin (Fig. 5b).

Over-day sensor variation increased from 3.9 to 15.4 ($P = 0.012$) and within trial ICCs ranged between 0.936 and 0.996. Between trial ICCs ranged between 0.687 and 0.971 (Table 1).

The air-pressure measurements showed that the adjustment process carried out by the saddle-fitter increased the air-pressure at the low or hollow side. The air pressure in the right and left saddle panels was virtually equal in the symmetrically fitted saddle before and had a high-to-low difference of −2.3 kPa in the front part and of −3.2 kPa in the back part in the adjusted saddle after saddle fitting (Table 2).

The measurements with the saddle pressure measurement device showed that the number of active sensors, total pressure, and pressure differences between the high and low side at the front of the saddle did not differ significantly between the symmetrical and adjusted saddle fittings. However, there was a significantly higher pressure at the hollow side at the back of the saddle after the saddle adjustment proce-

Table 1
Within and between measurement intra-class correlation coefficients before and after saddle fitting

| Variables | ICC within before | ICC between before | ICC within after | ICC between after |
|---|---|---|---|---|
| Total number of sensors/surface | 0.967 | 0.829 | 0.936 | 0.784 |
| Total pressure | 0.988 | 0.927 | 0.990 | 0.889 |
| Pressure high side front | 0.982 | 0.924 | 0.983 | 0.911 |
| Pressure low side front | 0.991 | 0.971 | 0.996 | 0.911 |
| Pressure high side back | 0.987 | 0.868 | 0.982 | 0.831 |
| Pressure low side back | 0.989 | 0.846 | 0.990 | 0.687 |
| ΔPressure underneath saddle front | 0.981 | 0.794 | 0.955 | 0.792 |
| ΔPressure underneath saddle back | 0.986 | 0.860 | 0.973 | 0.749 |
| ΔPressure underneath saddle total | 0.986 | 0.818 | 0.967 | 0.803 |

ICC, intra-class correlation coefficients.
Δ, difference between high/concave and low/convex side.
ICCs <0.700 were designated as poor reliability, 0.700–0.800 as fair reliability, 0.800–0.900 as good reliability and 0.900–1.000 as excellent reliability.

Table 2
Differences in air-pressure inside the panels of the saddle between before and after saddle fitting

| Variables | Before saddle fitting | After saddle fitting | *P*-value |
|---|---|---|---|
| Air-pressure high side front | 6.6 ± 1.6 | 6.2 ± 1.4 | 0.257 |
| Air-pressure low side front | 6.5 ± 1.7 | 8.5 ± 3.1 | 0.002* |
| Air-pressure high side back | 5.4 ± 1.0 | 5.1 ± 1.3 | 0.233 |
| Air-pressure low side back | 5.2 ± 0.9 | 8.2 ± 2.1 | <0.001* |
| ΔAir-pressure front panels | 0.1 ± 0.3 | −2.3 ± 2.1 | <0.001* |
| ΔAir-pressure back panels | 0.2 ± 0.3 | −3.2 ± 1.7 | <0.001* |

All variables are expressed as means ± SD in kPa.
ΔAir, difference between high and low side.
* Significantly different at $P < 0.05$.

Table 3
Differences in pressure measurements under the saddle between before and after saddle fitting

| Variables | Before fitting | After fitting | *P*-value |
|---|---|---|---|
| Total number of sensors/surface | 160 ± 17 | 159 ± 16 | 0.378 |
| Total pressure | 1720 ± 389 | 1760 ± 407 | 0.242 |
| Pressure high side front | 417 ± 152 | 425 ± 174 | 0.536 |
| Pressure low side front | 391 ± 182 | 407 ± 177 | 0.182 |
| Pressure high side back | 470 ± 137 | 445 ± 165 | 0.143 |
| Pressure low side back | 442 ± 121 | 484 ± 106 | 0.030* |
| ΔPressure underneath saddle front | 26 ± 94 | 18 ± 97 | 0.563 |
| ΔPressure underneath saddle back | 29 ± 133 | −39 ± 129 | 0.016* |

All variables are expressed as means ± SD in kPa.
Δ, difference between high and low side.
* Significantly different at $P < 0.05$.

dure (Table 3). Therefore, the pressure differences between the high and the low side at the back of the saddle differed significantly before and after saddle fitting.

## 4. Discussion

The high correlation coefficient between total pressure and mass of the rider confirmed earlier work by Jeffcott et al. (1999), who found a correlation coefficient of 0.98 in a similar set-up. However, in our study total pressures were higher, which may be explained by differences in technology. The sensors in the mat we used had a bigger surface and the reading they gave was not an average over the sensor, but the maximal pressure read by the sensor.

The increase in variation coefficient during one measurement day was not expected. The manufacturer recommended re-calibration of a new mat after 50 uses and an older mat after 200 uses. Recalibration is advised because the sensitivity of the sensors changes over time during use, which would be especially true for new sensors (manufacturer's guide). The pressure mat used in our study was a mat that had been used before and on one measurement day 36 measurements (6 horses × 6 measurements) were performed on average. As the manufacturer's guide gave a variation coefficient of <10% as acceptable, the pressure mat exceeded this limit within one measurement day. The high variation coefficient means that not all sensors will measure the same pressure when subjected to the same loading. A high variation in pressure patterns can be expected if the mat is slightly moved, in which case the same sensors measure different areas. In our study, we avoided this problem by performing these measurements in both conditions (before and after saddle-fit) without removing the saddle and/or the pressure measurement device. This approach is, however, only possible in an experimental set-up with the horse standing squarely. Thus, for objective pressure measurement this device should preferably be calibrated between every measurement.

The intra-class correlation coefficients indicated that the reliability of the pressure measurement device was excellent within one measurement and ranged from excellent to poor between measurements. This decrease in reliability can only be caused by a change in the position of the horse or in the position of the rider, as all other factors remained the same in-between the measurements. These positions had been standardised as much as possible by only measuring a horse standing squarely with one experienced rider, who sat in a similar position on all horses under both saddle-fitting conditions. Apparently, small changes in the horse's or the rider's position will have a big impact on the pressure pattern measured. This emphasis the need for highly standardised conditions when using saddle pressure measurement devices.

The air-pressure measurements indicated that the differences between the symmetrical fit and the adjusted fit mainly resulted from increasing the pressure (filling) of the panel on the hollow, concave side of the back of the horse. In the front part of the saddle, the pressure on the hollow side was increased by 23%, but in the back part the pressure was increased by 58%. This would translate to considerable differences in filling if using conventional flocking material. This is a new observation adding to our understanding of saddle-fitting.

The saddle pressure measurement device could discriminate between the two fitting conditions in the back part of the saddle, but not in the front area, notwithstanding the significant air-pressure difference in the front chambers. This lack of discriminative power may be related to the facts that the relative pressure increase in the back panels was more and that the inflatable panels accounted for the total contact surface in the back part of the saddle, whereas the contact surface in the front part consisted of both the inflatable panels and a part in which the pressure could not be altered (sweat flap). Therefore, a difference in filling of the front panels would affect overall pressure distribution beneath the saddle less than a difference in filling of the back panels.

The variation in saddle pressure measurements was high. The overall variation coefficient was 23%. High variation coefficients have been found in other saddle pressure measuring studies too. In a study that also focused on a standing horse with a rider Werner et al. (2002) found a variation coefficient of 35%, using a different pressure measuring system. Total pressure should theoretically be identical in all horses, as one single rider with constant weight was used and because there is a linear relationship between mass of the rider and total force. Total force translates directly to total pressure if the total pressure-sensing area is constant. The high variation encountered in different studies is an indication of the sensitivity of the measurement system for slight changes in position of the pressure mat, thus emphasising the necessity for the use of standardised conditions.

Saddle pressure measurement devices used for the evaluation of equine saddle pressure are however derived from human saddle pressure devices. More criteria are necessary when measuring pressures in saddle fitting than are required in wheelchair or bicycle seat pressure measurement. For the evaluation of saddles for horses, measurements should be performed in a more dynamic way, i.e. during riding as well. For pressure changes caused by the back-movements in trot, a frequency of 4 Hz can be expected; so, according to current measurement protocols, a sample frequency of >8 Hz is necessary in order to establish a correct pattern. A higher frequency would further improve the data collection.

The sensors of the pressure-measuring device we used had an upper limit of 40 kPa. Even without weight with a tightened girth, this maximal pressure of 40 kPa can be reached. This maximum pressure did not have a major influence in the validity experiment, as it did not affect the linear relationship of weight against pressure, nor with the heavier riders. However, during movement this maximal pressure will become a greater problem and note should be taken that the pressure measurement device used in this study measured the maximal pressure on the sensors and not the average pressure. With the relatively large sensors (57 × 19 mm), the actual pressure can, therefore, be easily overestimated. Apart from raising the maximum pressure limit of the sensors, the use of sensors with a smaller surface would thus further improve performance of the pressure measuring device.

The problem with the maximal pressure was especially seen in the caudal thoracic region. In another study (Liswaniso, 2001), the principal pressure points were located at either side of the withers and not beneath the saddle panels in the caudal thoracic region. This difference can probably be explained by a difference in tree-fit. A general accepted means of fitting a tree is parallel to the horse, but the saddle fitter in this study preferred a wider tree-fit at the top (heel) that becomes tighter towards the bottom (toe) of the tree. As the tree was fitted identically in both the symmetrical and the adjusted fit, this alternative tree fit did not influence our study. However, the difference in site of maximal pressure seen between our study and Liswaniso's demonstrated that tree-fit may indeed change the location of pressure points. To confirm this, a study in which different tree fits are compared, should be performed.

Another improvement of the pressure measurement device would be to shape the mat more according to the anatomy of the horse. The rectangular shape makes wrinkling unavoidable. As the mats are very sensitive to folding, this will probably cause a big part of the high variability seen in this study. Moreover, it would be easier to standardise the position of the mat if the mat was shaped like a saddle or saddle pad.

## 5. Conclusion

The saddle pressure measurement device tested in this study could be classified as a valid system for measuring total saddle pressures, but its reliability in practice and the power to discriminate between saddle fits remain questionable. Differences in pressures before and after fitting saddles could only be demonstrated in the back of the saddle under noticeably standardised conditions, which included the location of the mat beneath the saddle and the position of the horse and rider.

The future of saddle pressure evaluation lies in improving the technology. Ideally, both saddle-fit adaptation devices and pressure measurement technology could be incorporated in a saddle, including perhaps a display on which the rider can see the measurements on line during performance. In this way, changes in saddle fit could be quantified in terms of saddle pressure and used in a practical way. The question as to which pressure patterns are optimal is of another order and will only be answered with help of studies integrating pressure measurements and kinetics and/or kinematics of the entire horse.

## Acknowledgements

The authors thank Professor Leo B. Jeffcott for his help in the set-up phase of the research and for his valuable editorial comments on the manuscript, and Danny Kroetch (DK Saddlery, www.dksaddlery.com) for his contribution in fitting the saddles. We give special thanks to Andries Klarenbeek for his invaluable technical support.

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