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Original Research

"Feel the Force"—Prevalence of Subjectively Assessed Saddle Fit Problems in Swiss Riding Horses and Their Association With Saddle Pressure Measurements and Back Pain

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ABSTRACT

Ill-fitting saddles can impair the well-being and performance of horses. Saddle fit is generally assessed subjectively by a trained professional or with an electronic saddle pressure mat, but little is known about the agreement between both methods. The study aims were (1) to assess the prevalence of saddle fit issues in a riding sound Swiss horse population, (2) to investigate how well the subjective assessment correlates with objectively measured pressure magnitude and distribution under the saddle during riding, and (3) how well both correlate with back pain of the horse. Only 10% of the saddles were free of the assessed problems. Pressures exceeded clinically relevant thresholds in 15% of the horses. There was no clear correlation between back pain and pressure magnitude, but back pain was associated with certain subjectively assessed fit problems. Statistically significant associations between fit problems and the expected pressure patterns were found for panel angles, curvature of the saddle, width of the panel channel, and the waist of the saddle. There was no or limited association of pressure patterns with the balance of the saddle, width and angle of the tree head, or the symmetry of the panels. The results revealed that certain fit problems were reflected in the electronically measured pressure distribution and that the subjective assessment can therefore provide relevant information. Pressure magnitude showed only limited association with back pain, which indicates that there are other factors involved in the development of back problems in horses.

1. Introduction

A well-fitting saddle is considered a prerequisite for optimal performance of equine athletes and prevention of equine back problems [1]. There is general agreement and scientific evidence that an incorrectly fitting saddle can cause the horse discomfort and pain, and impair muscle development and movement of the back and the limbs [1–4]. Despite these well-known consequences, recent studies in different populations have identified considerable proportions of ill-fitting saddles among riding horses (43% in a study by Greve and Dyson [5] or 74% in a study by Dittmann et al [6]), indicating a suboptimal management of saddle fit. Mismanagement may either be because of owners not having their saddles checked and adjusted on a regular basis or because the saddle (or its adjustment) is inadequate for the horse or the rider.

In the industry, saddle fit for the horse is traditionally evaluated by manual and visual assessment of the saddle on its own and when it is placed on the horse's back [3,7]. Despite published guidelines on which parameters to assess [3,7,8], the evaluation of fit is still subjective, and there is large potential for disagreement, even between experienced qualified saddlers [9].

To evaluate saddle fit objectively, electronic saddle pressure mats have been used since the 1990s to quantify the forces acting on the horse's back [10]. Evidence suggests that certain fit problems identified during the subjective assessment are linked to higher pressures or different pressure patterns [2,4,11] and that clinical

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signs of saddle pressure (dry spots, soreness) are associated with high pressures [12].

Using both assessment methods in combination can have advantages. During the subjective assessment, the saddle's fit is assessed manually and visually on the horse. The former can only be performed in the standing horse and is often done without the rider in the saddle. In contrast, the electronic measurement yields data from the ridden situation where the horse is moving at different gaits. The electronic mat enables the identification of areas of high pressure on the horse's back, whereas the manual assessment is necessary to identify which part of the saddle is likely to cause the problem. Nonetheless, the validity of electronic saddle pressure measurements has been questioned [13], and there is only limited knowledge on how fit problems identified during the subjective assessment are reflected in pressure distribution.

The aims of this study were to (1) quantify the prevalence of commonly found saddle fit issues, which can be identified during the subjective assessment in a population of owner-sound horses in Switzerland, (2) test if electronically measured saddle pressure values and patterns reflect subjectively assessed fit issues, and (3) determine if pressure magnitude or fit problems are associated with equine back pain to identify which one is of greater relevance for the horses' well-being.

2. Materials and Methods

2.1. Study Population and Design

The analyzed data were based on the same population, as previously described in studies by Gunst et al [14] and Dittmann et al [6]. In short, the study was announced in several Swiss horse–related media, and interested participants fulfilling the inclusion criteria were invited to an examination day after they had completed an online survey. On the examination day, horses and saddles were assessed by two experienced veterinarians. Subsequently, the horse–rider pair (HRP) performed a standardized riding test in an indoor arena, during which pressure below the saddle was measured with an electronic pressure mat (details described below).

For this part of the study, only HRP with English saddles were included. This resulted in 196 HRP, 44% with dressage (DR) saddles, 37% with show jumping (SJ) saddles, and 18% with general purpose (GP) saddles. Of these saddles, 64% had been produced by local brands in Switzerland. The pressure measurements were performed with the riders' own saddle pads because many Swiss saddlers consider the type of pad used by the rider when fitting a saddle to a horse. Of these pads, 57% were sheepskin pads, 31% were thin, nonpadded saddle blankets or numnahs, and 11% were pads made of specific materials. The latter included synthetic foam (5%), roe deer fur (2%), gel (2%), or other materials (each <1%).

The riders were aged, on average, 37 ± 12 years, weighed 67 ± 11 kg, and 94% were female. The horses were aged, on average, 10 ± 3 years, had a withers height of 165 ± 7 cm, 40% were mares, 56% were geldings, and 4% were stallions. Of the study horses, 76% were European Warmbloods, whereas the remaining 24% consisted of different breeds such as Franches-Montagnes (6%), Iberian breeds (5%), Arabians (3%), and others (each <1%).

2.2. Subjective Assessment of the Saddle

The manual and visual assessment of the saddle followed the principles applied by saddlers certified by the Swiss Leather and Textile Association (SLTA), which are generally in line with guidelines published by other authors [3,7,8,15]. The assessed variables along with definitions of the fitting and ill-fitting situations are listed in detail in Supplementary Item 1. Saddle fit was assessed by a veterinarian with specialist training in evaluating saddles by the SLTA and 13 years of practical experience in assessing saddle fit in thousands of patients. Before the saddle was placed on the horse, it was assessed subjectively for obvious defects, issues, and asymmetries. One saddle was excluded from the analysis owing to a broken tree; the remaining saddles (n = 196) were free of major defects. The panels were assessed for symmetry, quality (homogeneity and consistency of the filling material), and the narrowest width of the panel channel (also referred to as gullet width) was determined and measured. This was deemed inadequate if it was below 6 cm, a measure often proposed in practice to ensure clearance of the spine. Although this value has never been validated experimentally, it is proposed in several saddle fit guidelines [8,15] and corresponds approximately to the width of four fingers as suggested by the SLTA.

One feature of the saddle that is considered important for rider comfort is the so-called waist (also referred to as twist; different definitions are used among saddle professionals, and the terms are often used interchangeably). Many riders prefer a narrow waist because it makes them feel closer to the horse and because it is more comfortable: a narrow waist requires less spread of the rider's legs than a saddle with a wide waist. A narrow waist is generally achieved by using a tree, which has bars that show a strong mediolateral curvature or steep angles in the area of the waist. It was expected that a narrow waist of the saddle increases pressure at the base of the horse's withers, which can be uncomfortable for the horse. Previous research demonstrated that reducing pressure below the saddle in the area of the 10th to 13th thoracic vertebrae (where the waist of the saddle is located) can improve stride kinematics [16]. The saddles waist was therefore subjectively assessed by looking at the panels and the underlying tree in the region of the waist (see Supplementary Item 1 for definitions).

After the subjective assessment of the saddle's waist, it was placed on the horse, and the following aspects were evaluated from both sides. The bars of the tree head or gullet plate should be parallel to the horse's back behind the scapulae [7,8,15]. This variable—further referred to as angle and width of tree head—was assessed by sliding a hand in the dorsal to ventral direction between the most cranial aspect of the saddle (where the gullet or head plate is located) and the horse's back. It was deemed adequate if the pressure felt even along the bars [8].

The curvature of the tree and the panels should follow the curvature of the horse's back ([7,8], see illustration in Supplementary Item 1) to ensure even contact of the panels along the horse's back. A saddle with a curvature that is too small tends to rock on the horse's back, whereas a saddle with a curvature that is too big bridges (the center of the panels have no contact with the horse's back) [8]. This variable was assessed by sliding a hand in the cranial to caudal direction along the panels, between the saddle and the horse's back, along with an attempt to rock the saddle on the horse's back. The angle of the panels in the caudal third of the saddle should correspond to the shape of the horse's back in this area [8]. Panel angle was evaluated visually by the assessing person standing behind the horse. The balance of the saddle was assessed visually from the side. A saddle was considered balanced if the seat was level and the lowest point of the seat was located in its middle [8].

2.3. Back Pain Score

Before the riding test, the back of each horse was palpated by an experienced veterinarian, and the horse's reaction was recorded. The following muscles were palpated on both sides of the back: *M. latissimus dorsi*, *M. longissimus thoracis*, *M. spinalis thoracis*, *M. trapezius* (thoracic part), and *M. glutaeus medius*. The horse's reactions on the application of digital pressure were defined as none (no reaction), mild (muscle twitching and mild hypertonicity of the muscles of the back), moderate (aversive reactions, such as pinned back ears, evasive behavior, head tossing, tail swishing, obvious contraction and moderate hypertonicity of the muscles of the back, slight hollowing of the back), and severe (extreme aversive reactions, such as biting, kicking, vocalization, severe hypertonicity of the back muscles, marked hollowing of the back), and they were transformed into ranks of 0–3. Local reactions on the back and behavioral responses were based on Girodroux et al [17], but the scoring system was specifically developed for this study. To derive a back pain score (BPS), the individual ranks determined for each of the 10 palpated locations of the back (five muscles on both sides) were summed up. The BPS could range from 0 (no reactions in any location) to 30 (severe reaction in all locations).

2.4. Saddle Pressure Measurements

The method for the saddle pressure measurement is described in detail in a study by Gunst et al [14]. In summary, a pressure mat (Pliance Saddle System, Novel GmbH) was placed below the saddle and the pad the riders would normally use. Before pad and saddle were placed on the mat, it was set to zero. The HRP were allowed a 10-minute self-prescribed warm-up, including walk, trot, and canter on both reins. For the measurements, HRP performed a predefined riding test in a 20 $\times$ 60 m indoor arena. The test was approximately 9 minutes long and consisted of walk, rising trot, sitting trot, and canter on the left and the right rein. At walk and trot, pressure data (in kPA) were recorded when the HRP was on a straight line along the long side of the arena (approximately 20 seconds on each rein). At canter, data were recorded for 20 seconds while the HRP was riding on a 20-m circle.

To exclude irrelevant data from the pressure measurements (e.g., caused by the parts of the saddle blanket sticking out from underneath the saddle, which are not loaded by saddle or rider), a digital mask was created for each saddle to include only relevant sensors of the mat. The mask was created based on data recorded at sitting trot (detailed description in Supplementary Item 2). The two most lateral sensor rows in the caudal area where the pressure mat was not loaded, and cells with a mean peak pressure <4 kPa were excluded. For more accurate spatial partitioning, data were linearly interpolated by a factor 4. To identify the most loaded region, the four adjacent sensors with the highest mean pressure (hMP) were detected automatically, and their mean was calculated (37.5 cm^2, adapted based on the study by Von Peinen et al [12]). Within each gait, the hMP on the left and the right rein were averaged to create one value per gait per horse.

For the correlation of pressure data and manually assessed saddle fit problems, specific pressure ratios were calculated. For this purpose, active sensors for each half of the mat were partitioned longitudinally into two or three transverse zones (depending on which fit issue the ratio was associated with), which were further divided into a medial and a lateral zone. Averaging the mean pressure (MP) of all sensors within the respective zone resulted in one value per zone, which was then used to calculate the pressure ratios assumed to be correlated with manually assessed fit problems (formulas in Supplementary Item 3).

2.5. Statistics and Hypotheses

For statistical analysis, the categorical data (fit problems) from the manual saddle assessment were transformed into a binary code: absent (0) or present (1). These values were additionally summed up to create an overall score of fit problems from 0 (no problem present) to 7 (all problems present). For variables with several levels (e.g., too big, adequate, too small), data were further transformed into ranks (described in Supplementary Item 1).

Initially, it was tested if there was a difference in hMP, BPS, and the prevalence of fit problems between saddle types and pads. For continuous outcome variables (hMP, BPS), linear models or analyses of variance were applied. Where the outcome variable was binary (fit problem present or absent), logistic regression models were applied. In the same manner, the data were tested for associations between hMP, BPS, and fit problems, expecting that saddles with problems have higher hMP and BPS values compared with saddles without problems and that there would be a positive correlation between hMP and BPS. Based on previous research, which could show that a fur pad reduces the overall force below the saddle [18], it was further expected that the use of a sheepskin pad would result in lower hMP values compared with other pads.

For each of the manually identified fit problems, a hypothesis was developed how this problem would affect the pressure distribution below the saddle, and a specific pressure ratio was calculated based on MP in the zones of interest (Supplementary Item 3). It was then tested if there were differences in these ratios between saddles with and without the manually identified problem by applying linear mixed models, including data from all gaits and horse as a random factor. All ratios differed significantly between gaits ($P < .001$), and where the overall finding was not consistent, mixed models were followed by separate linear models for each gait, using the binary or ranked variables as a fixed factor. For panel channel width, the hypotheses were tested on the binary variable (>6 cm/<6 cm) as well as on the continuous variable (minimal panel channel width in cm). In cases where a specific direction of the relationship between outcome variable and predictor was hypothesized, the reported P values were based on one-tailed tests. All statistical analyses were carried out in R Studio (version 1.1.442, 2019). Significance levels were set to alpha of 0.05.

3. Results

3.1. Descriptive Results

In the online survey, 95% of participants responded that their saddle was an ideal fit for their horse. Fifty-three percent of the participants stated that their saddle was regularly checked by a qualified professional, whereas 47% did not have their saddle checked on a regular basis. On average, saddles had last been checked by a qualified professional 9.8 $\pm$ 10.5 months ago (range: 0–80 months). The actual prevalence of subjectively assessed fit problems is listed in Table 1. Overall, the three most prevalent issues were a narrow panel channel, inadequate angle and width of the tree head, as well as inadequate panel consistency. The majority of saddles showed a narrow waist. Only a minority of the saddles (10%) presented without any of the assessed fit problems (Table 1, Fig. 1A).

Of the investigated horses, 29% showed moderate or severe reactions to palpation in at least one of the assessed locations of the back. The median BPS was 2 (standard error: 0.24; range: 0–16; Fig. 1B). The absolute hMP showed an overall increase from walk to canter (Table 2). In 14.8% of HRPs, the hMP values exceeded previously published values associated with clinical signs of saddle pressure [12] in at least one gait.

3.2. Differences Between Saddle Types and Pads

3.2.1. Manually Assessed Fit Problems

Compared with SJ saddles, DR saddles had a higher frequency of asymmetric panels ($P = .019$) and inadequate panel angles ($P = .044$). Compared with SJ saddles, there was a higher frequency of

Table 1
Prevalence of subjectively assessed fit problems in the evaluated saddles (n = 196) in percent.

	Adequate	Inadequate
Panel symmetry	Symmetric: 77.4%	Asymmetric: 22.6%
Panel quality	Adequate: 51.0%	Inadequate: 49.0%
Minimal width of panel channel	>6 cm: 58.4%	<6 cm: 41.6%
Angle of panels	Fitting: 80.7%	Not fitting: 19.3% (Too steep: 8.9%, too shallow: 10.4%)
Angle and width of tree head	Fitting: 58.6%	Not fitting: 41.4% (Too wide: 17.8%, too narrow: 23.6%)
Curvature of saddle	Fitting: 78.6%	Not fitting: 21.4% (Too big (bridging): 14.6, too small (rocking): 6.8)
Balance	Balanced: 75.6%	Imbalanced: 24.4% (Tipping forward: 13.0%, tipping backward: 11.4%)
Overall	None of the above issues: 10.3%	At least one of the above issues: 89.7%
Waist of saddle	Wide: 26.7%	Narrow: 73.3%

Details on the subjective saddle assessment are given in Supplementary Item 1.

inadequate angle and width of the tree head in GP saddles (P = .034). GP saddles more frequently had an inadequate balance when compared with DR and SJ saddles (P = .001, P = .005). Compared with DR saddles, there was a higher frequency of a narrow waist in SJ saddles (P = .023) and GP saddles (P = .050). No difference was found between saddle types in the prevalence of inadequate panel quality, the minimal panel channel width, or an inadequate curvature (P > .18).

3.2.2. Highest MPs and BPS

hMP showed a significant positive correlation with rider weight (BM) in all gaits (P < .0015; R^2: 0.05–0.09). To control for this relationship, hMP was divided by BM (hMP_BM) for further analyses. In all gaits, SJ saddles had higher hMP_BM values than DR saddles (P = .002–0.046). In all gaits, hMP_BM values for HRPs using a sheepskin pad were significantly lower compared with those with thin, nonpadded saddle blankets (P < .003). There was no significant difference in BPS between saddle types or saddle pads (P > .11).

3.3. Correlations Between hMP, BPS, and Fit Problems

At walk, hMP_BM was slightly higher in saddles with inadequate panel quality (P = .045). At trot and canter, hMP_BM was higher in saddles that were rocking, compared with saddles deemed to have an adequate curvature (P = .006–0.027). In all gaits, hMP_BM was higher in saddles with a narrow waist, compared with saddles with a wide waist (P = .028–0.05). The magnitude of the mentioned differences between saddles with and without these fit problems (inadequate panel quality, rocking, narrow waist) was in the range of 0.01–0.05 kPA/kg rider BM. For an average rider of 67 kg and an average saddle pressure of 12 kPA, this corresponds to a 6%–28% increase in absolute pressure or, in other words, an increased force of 2.5–12.6 N acting on the area of interest (37.5 cm^2; the four most loaded sensors). There were no significant associations between hMP_BM and any of the other fit problems or the overall number of fit problems.

The BPS was not correlated with hMP (Fig. 2A) or hMP_BM in any of the gaits nor with body weight of the rider (P > .7). BPS values for horses with saddles with asymmetric panels were (based on least square means), on average, 1.4 scores higher than for horses with saddles with symmetric panels (P = .009). BPS values for horses with saddles that had an inadequate curvature were not higher than for those with saddles with an adequate curvature (P = .99). In fact, horses with saddles deemed as having an inadequate curvature had lower BPS values than those with saddles with an adequate radius (on average, BPS were 3.9 for adequate curvature, 2.7 for rocking, and 2.4 for bridging). BPS values were, on average, 1.1 scores higher for horses with saddles with an ill-fitting tree head (too narrow or too wide; P = .016). BPS was not significantly increased in horses with saddles showing any of the other fit issues or a narrow waist, and it did not increase significantly with an increasing number of fit issues (Fig. 2B).

3.4. Correlation of Pressure Patterns With Individual Fit Problems

The calculation of the pressure ratios assumed to be affected by different manually assessed fit problems, along with an illustration of the respective data, are presented in Table 3 and Supplementary Item 3. In none of the gaits, there were statistically significant associations between the MP patterns and the balance of the saddle (P > .09) or the angle and the width of the tree head (P > .06). For these fit problems, the hypothesized pressure distributions could not be confirmed. At walk, saddles with asymmetric panels showed a more asymmetric distribution in MP between the two halves of the mat than symmetric saddles (P = .008), but this difference was

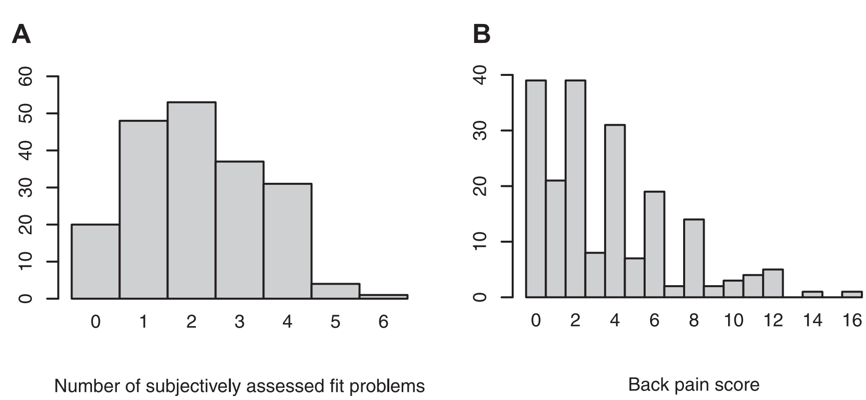


Fig. 1. Histograms of (A) the overall number of manually assessed saddle fit problems per saddle and (B) of the back pain score per horse. The scale on the y-axis denotes the number of saddles or horses.

Table 2
Absolute highest mean pressure (hMP in kPA) below the saddle in the different gaits and proportion of horses where this value exceeded previously published thresholds linked to clinical symptoms of saddle pressure.

Gait	Mean ± SD (minimum; maximum)	Proportion of horses with hMP exceeding critical values[a]
Walk	11.0 ± 3.5 (3.7; 21.7)	11.7% (>15.3 kPA)
Sitting trot	11.6 ± 3.8 (4.6; 24.2)	5.6% (>18.1 kPA)
Rising trot	12.4 ± 4.1 (4.6; 24.8)	9.2% (>18.1 kPA)
Canter	14.2 ± 4.2 (4.9; 26.0)	6.1% (>21.4 kPA)

[a] Critical values linked to clinical symptoms of saddle pressure are based on a study by Von Peinen et al [12].

not significant in any of the other gaits ($P > .28$). Compared with saddles with adequate panel angles, in saddles with panels deemed too steep, the pressure ratio in the caudal two-thirds of the mat showed a shift to the lateral area in all gaits ($P < .02$); in saddles with panel angles deemed too shallow, the pressure ratio in the caudal two-thirds of the mat showed a significant shift to the medial area at walk ($P = .048$) but not at trot or canter ($P > .18$).

The hypothesized pressure distributions for narrow panel channels, an inadequate curvature, and a narrow waist were confirmed in the linear mixed models, including data from all gaits. In saddles with a panel channel width <6 cm, the pressure ratio in the caudal two-thirds of the mat was shifted toward the medial area compared with saddles with a panel channel wider than 6 cm ($P = .011$). Furthermore, there was a negative correlation between this ratio and the minimal panel channel width ($P = .009$). Compared with saddles with an adequate curvature, saddles that were deemed as bridging showed a pressure ratio shifted to the caudal and cranial thirds of the mat ($P = .001$), whereas saddles that were deemed as rocking showed a pressure ratio shifted to the central third of the mat ($P = .004$). In saddles with a narrow waist, the pressure ratio in the two cranial thirds of the mat was shifted toward the medial area compared with saddles with a wide waist ($P = .001$).

4. Discussion

4.1. Descriptive Results

Overall, there was a high prevalence of saddle fit issues despite most owners stating that they considered their saddle an ideal fit for their horse. This finding is in line with other studies, indicating that horse owners have a limited ability to recognize saddle fit issues [19], and it underlines the need for regular saddle checks by professionals (something which almost half of the participants forwent) and education of owners to enable them to recognize problems on their own.

4.2. Limitations

This study was based on field data, where the effect of horse and rider could not be controlled. This approach was necessary to investigate the prevalence of saddle fit–related problems and to test if manually assessed problems were associated with saddle pressure measurements under field conditions. Therefore, the detected correlations between certain fit problems, saddle pressure, and back pain should be interpreted with caution, as some of them could be the result of unknown confounding factors and they should therefore be validated under experimental conditions.

The proportion of saddles with only one subjectively assessed fit problem in this population was limited (25%), some problems occurred more frequently than others, and most saddles (65%) had more than one problem, which could have influenced one another. The working hypotheses only focused on individual problems, but most of the analyzed saddles had additional problems, which might have affected pressure patterns or magnitude.

The described method to manually and visually assess saddle fit reflects the normal procedure applied by saddlers or saddle fitters in Switzerland. It is subjective and depends on training and experience of the person carrying it out. Although there are guidelines on what to assess [3,7,8,15], the evaluation whether a certain aspect is (ill-)fitting still depends on the subjective perception of the assessor. In this study, some subjectively assessed variables were reflected by the pressure measurements, but the outcome of the analyses might have been different if another person had evaluated the saddles. Having all saddles assessed by a second qualified observer could have provided information on the interobserver agreement for the subjective assessment. Furthermore, as the aim of this study was to assess the prevalence of saddle fit issues, there

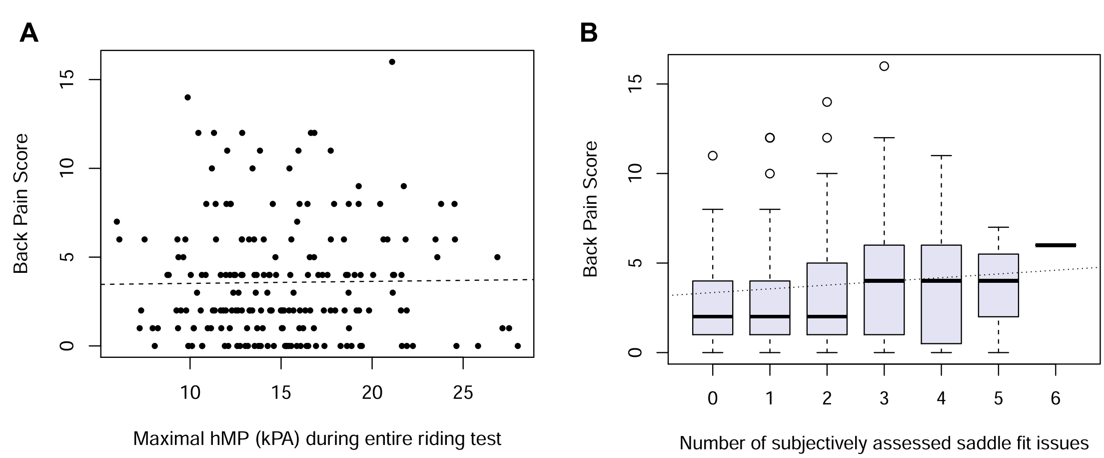


Fig. 2. Association of back pain score (BPS) with (A) the highest mean pressure (hMP) during the entire riding test and (B) the number of manually assessed saddle fit issues. Neither of the correlations were statistically significant.

Table 3
Mean pressure ratios in relation to manually assessed fit problems.

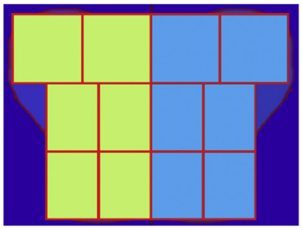
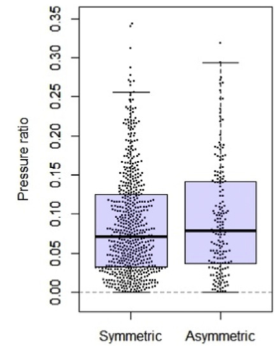
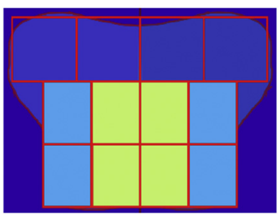
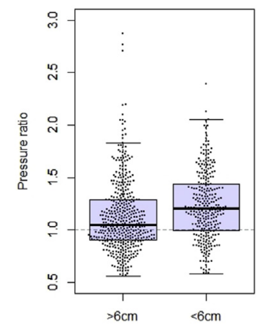
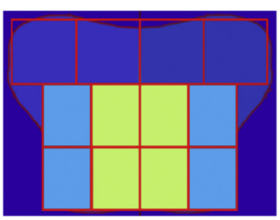
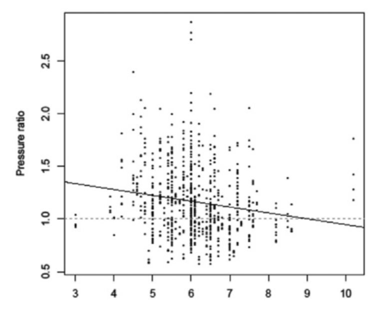
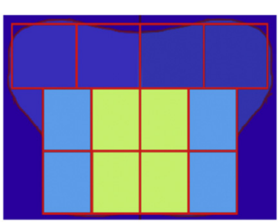
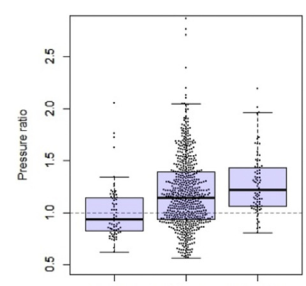
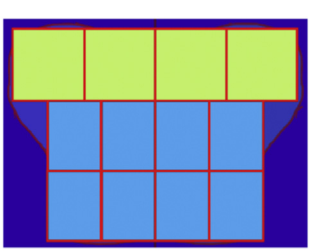
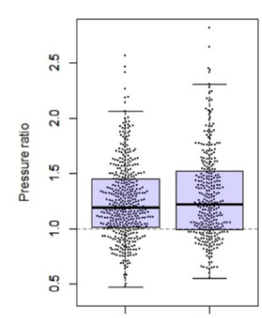
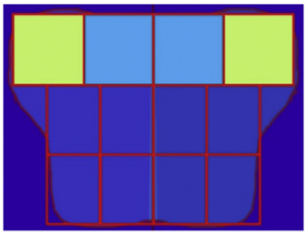
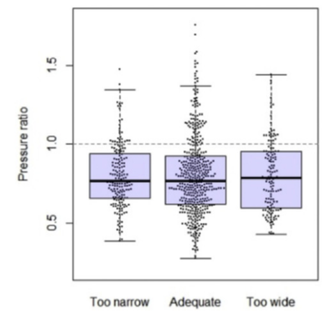
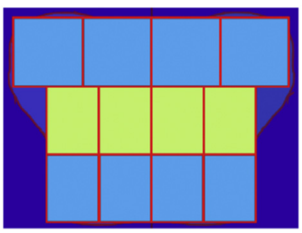
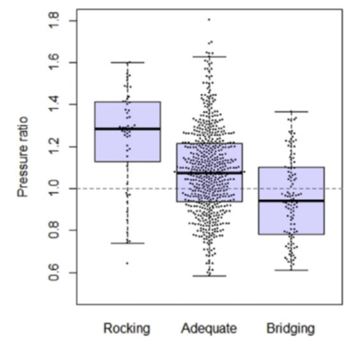
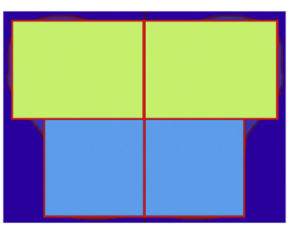
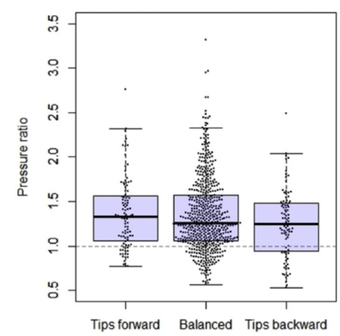
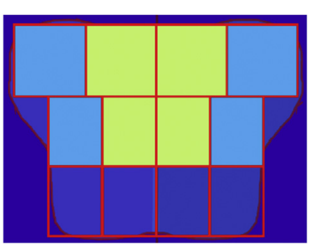
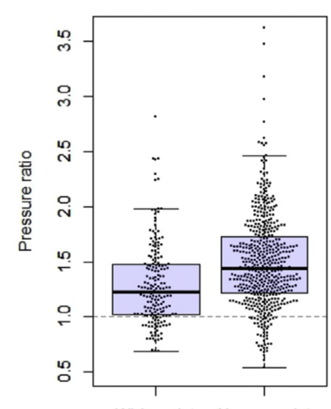
Calculation of pressure ratio (green:blue)	Hypothesis	Outcome
	Panel symmetry The difference in mean pressure between saddle halves is higher in saddles with asymmetric panels compared to saddles with symmetric panels. Confirmed only at walk ($P = .008$, all other gaits: $P > .28$)	
	Panel channel width (binary) The ratio is higher in saddles with panel channels <6 cm compared with saddles with panel channels >6 cm Confirmed for all gaits ($P = .011$)	
	Panel channel width (continuous) The narrower the panel channel, the higher the ratio. Confirmed for all gaits ($P = .009$)	
	Panel angles Compared with adequate panel angles, the ratio is smaller in panels deemed too steep and bigger in panels deemed too shallow. Partly confirmed (too steep vs. adequate: $P < .02$ in all gaits; too shallow vs. adequate: $P = .05$ at walk but $P > .18$ at trot and canter)	
	Angle and width of tree head—general Compared with saddles with adequate angle and width of the tree head, the ratio is higher in saddles with ill-fitting tree heads. Not confirmed ($P > .06$ in all gaits)	

Table 3 (*continued*)

Calculation of pressure ratio (green:blue)	Hypothesis	Outcome
	Angle and width of tree head—specific Compared with saddles with adequate angle and width of the tree head, the ratio is lower in saddles with a tree head deemed too wide and higher in saddles with a tree head deemed too narrow. Not confirmed ($P > .5$ in all gaits)	
	Curvature of the saddle Compared with an adequate curvature, the ratio is smaller in saddles, which are rocking, and bigger in saddles which are bridging. Confirmed in all gaits (rocking vs. adequate: $P = .004$; bridging vs. adequate: $P = .001$)	
	Balance Compared with balanced saddles, the ratio is bigger in saddles tipping forward, and smaller in saddles tipping backward. Not confirmed (in all gaits $P > .09$)	
	Waist Saddles with a narrow waist have higher ratios than saddles with a wide waist. Confirmed in all gaits ($P = .001$)	

The illustrations represent the saddle pressure mat (top—cranial, bottom—caudal); for each of the problems, the mean pressure value in the light green sections was divided by the mean of the light blue sections. For panel symmetry, the absolute difference between pressure under the left and the right panel was calculated. In the second column, the hypothesis regarding the association of the pressure pattern with the manual fit problem is stated, along with information on whether the hypothesis was confirmed or not. The boxplots show data of the respective ratio in relation to the manually assessed fit problem (data from all gaits).

might have been an observer expectancy effect, that is, the person performing the manual assessment might have been overly stringent in detecting issues, which might not have been considered relevant under different circumstances.

Palpation is a standard procedure used in clinical practice to assess back pain in horses [20]. However, the observed behavioral responses and individual sensitivity levels were highly variable between horses, which made the interpretation of the BPS somewhat difficult. This interindividual variability could explain the limited degree of correlation of BPS with the objective measurements.

4.3. Differences Between Saddle Types and Pads

Wheareas DR saddles more frequently had inadequate (too steep) panel angles or asymmetric panels, SJ saddles more frequently had a narrow waist. A panel angle, which is steeper than the horse's back could be a functional advantage in DR saddles, for example, as a means to elevate the caudal part of the seat to create a deep, forward tipped seat for the rider, which would position him/her closer over the stirrup bars and thereby allow a long straight leg, as required for the dressage seat. However, this finding might also be a side effect of the way DR saddles are built. In SJ saddles, the narrow waist presumably contributes to a more stable position of the saddle during jumping and would therefore be a desired feature of SJ saddles. A higher prevalence of a narrow waist in SJ saddles might also be the reason why they had higher hMP_BM values than DR saddles. Furthermore, a narrow waist was associated with increased pressure in the medial cranial area of the mat. It has previously been shown that reducing pressures in the area of the 10th to 13th thoracic vertebrae of the horse—which is where the saddle's waist is located—can improve limb kinematics (i.e., by inducing greater forelimb and hindlimb protraction and greater carpal/tarsal flexion) and thoracolumbar expansion [16] and impact thoracolumbar kinematics [4] as well as the kinematics of approach and take off when jumping [21]. It is therefore in the best interest of the industry to understand which aspect of the waist (e.g., the shape of the tree, the angulation of the bars, the curvature of the panels, or their combination) can be altered to produce saddles, which create a narrow waist to optimize rider comfort without creating areas of increased pressure on the horse's back.

The hMP_BM values were lower in HRPs using a sheepskin pad compared with those using a thin, nonpadded saddle blanket or numnah. This finding is in line with previous research: Kotschwar et al [18] could show that a reindeer fur pad significantly reduced the maximum overall force below the saddle, and MacKechnie-Guire et al [22] found that a wool half pad can reduce MPs in the caudal region during sitting trot and canter. Taken together, these results indicate that sheepskin pads can help to improve the pressure distribution below the saddle.

4.4. Associations of Fit Problems With Back Pain and Saddle Pressure

There was no significant association between BPS and the hMP (absolute or normalized to the rider's BM) in any gait. This could partly be because of the generally low magnitude of hMP values: only 15% of the HRPs showed values, which were previously described critical pressure values linked to clinical signs of saddle pressure (i.e., dry spots in the sweat pattern underneath the saddle, muscle soreness, skin trauma of various degrees, including swelling or heat) [12], whereas almost one-third of the horses showed moderate to severe signs of back pain. This indicates that other factors than the absolute magnitude of saddle pressure are involved in the development of back pain. The frequency and intensity of riding in the assessed saddle (e.g., hacking at walk vs. jumping), skill and balance of the rider, the posture of the horse during movement, and underlying diseases might just be some of the factors that determine whether a horse develops back pain. Also, the critical pressure values published in a study by Von Peinen et al [12] were associated with clinical signs of saddle pressure, not with back pain as quantified in this study. Ultimately, the distribution of the pressure under the saddle might be of more relevance to the development of back pain than the overall pressure.

4.4.1. Panel Symmetry and Consistency

Horses with saddles with asymmetric panels had higher BPS values than those with symmetric saddles. Furthermore, they only showed a more asymmetric pressure distribution than symmetric saddles at walk, and no statistically significant association was found between asymmetric panels and pressure magnitude. It is possible that asymmetric panels are a consequence of an asymmetric rider, which causes a shift in pressure [14] or of a horse, which moves asymmetrically, possibly because of back pain or (subclinical) lameness. Greve and Dyson [23] showed that hind limb lameness can induce saddle slip, which on the long run, could lead to asymmetrically shaped panels. It is therefore difficult to tell if asymmetric panels are an indicator of or a cause for back pain. Taken together, these findings indicate that pressure distribution could be more relevant in the development of back pain than pressure magnitude. To better understand the association between asymmetric panels, pressure, and pain, it would be imperative to know the origin of the panel asymmetry. Are the panels shaped by functional or anatomical asymmetries of the horse, by a crooked rider, or were they purposefully flocked asymmetrically by the saddler? Unfortunately, this information was not available in this study.

Inadequate panel quality appeared to have no effect on BPS, and a positive association with hMP_BM was found at walk only. On the one hand, this lack of correlation could be explained by this variable being very subjective and combining different aspects of panel quality (e.g., softness, homogeneity). On the other hand, the shape of the panels could ultimately have a bigger impact on pressure magnitude and distribution than the quality of their filling. Furthermore, panel consistency might have been somewhat masked where thicker saddle pads were used.

4.4.2. Panel Angle and Channel Width

Inadequate panel angles and minimal panel channel width were not associated with hMP_BM or back pain. Nonetheless, they showed the expected pressure pattern below the saddle: the medial-to-lateral pressure ratio increased with decreasing minimal panel channel width, and there was a tendency for an increase in this ratio in panels deemed too shallow, whereas the ratio was decreased in saddles with steep panels. This demonstrates that both fit problems affect the pressure distribution below the saddle and should be considered during saddle fitting.

4.4.3. Angle and Width of the Tree Head

The manual evaluation of the adequacy of the tree head was not clearly associated with pressure magnitude or distribution. This finding is in contrast to previous experimental studies. Two studies report an increase in pressure in the caudal area in saddles with trees/gullet plates deemed too narrow [4,11]. Both studies further report an increase in pressure in the cranial/central area in saddles with trees deemed too wide. These results could not be replicated in this study, which may be because of the experimental design where each horse was measured with only one saddle and not with different saddles of varying width.

There is evidence that the shape of the back (e.g., the area behind the scapulae where the tree head/gullet plate should sit) can undergo considerable change during exercise [19]. This difference in shape between the static and the ridden situation could be another reason, why a tree head deemed unfitting during the manual assessment was not reflected by a particular pressure pattern during riding. For example, the tree head might be deemed too wide in the static situation where the horse does not activate the muscles of the shoulder girdle and the area behind the scapula is hollow. In the ridden situation, the horse may activate its trunk muscles and fill out the area behind the scapula, in which case the same tree may yield an even pressure picture. Despite the lack of association with pressure magnitude and distribution, BPS values were higher in horses with saddles with an ill-fitting tree head. It is therefore possible that an ill-fitting tree head causes the horse pain but also impacts the pressure distribution in a way that is not consistent between saddles. For example, an ill-fitting tree head may impact the balance and the contact area in some saddles, whereas it could only have a localized effect in others: a tight tree head might elevate the cranial area of the saddle, thereby causing bridging and four-point pressure (bilaterally in the cranial and the caudal part of the saddle area), whereas in another saddle, a tight tree head might occur without bridging, thereby only causing increased pressure in the cranial area.

4.4.4. Curvature

The expected pressure patterns (Table 3) were confirmed for bridging (more pressure in the cranial and caudal third of the mat) and rocking (more pressure in the central third). Saddles that were rocking also showed higher hMP_BM values compared with saddles with adequate curvature. Surprisingly, horses that had saddles deemed as having inadequate curvature during the manual assessment showed lower BPS values than horses with saddles deemed to have an adequate curvature. It is possible that a saddle deemed as bridging during the manual assessment allows the horse to dorsiflex its spine during riding. In contrast to the neutral posture of a standing horse, a low head—neck position has been linked to increased distances between the dorsal spinous processes of adjacent thoracic vertebrae [24], which could be beneficial for the horse's back health. This speculative explanation requires verification under experimental conditions and does not explain why BSP values were lower in rocking saddles, too. Nonetheless, it is supported by the recommendation of some practitioners to fit saddles with a slight bridge to allow the horse to dorsiflex its back [8].

4.4.5. Balance

There was no statistical evidence that a saddle tipping forward or backward had an impact on back pain, the magnitude of hMP, or the craniocaudal distribution of MP. Although the saddle's balance should not be disregarded during a saddle check, it might be that the posture of the horse and the stability of the rider during movement are more important to balance the rider's weight and to achieve an even pressure distribution. Furthermore, the saddle's balance can be influenced by other aspects of saddle fit (e.g., angle and width of the tree head, curvature, shape of the panels), which might have had a bigger impact on the pressure distribution than the position of the seat.

5. Conclusion

There was a high prevalence of subjectively assessed saddle fit problems, some of which were reflected in the electronically measured pressure patterns. This demonstrates that the subjective assessment can yield valuable information on saddle fit. Absolute pressure magnitude was not correlated with back pain, indicating that the distribution of pressure may be of greater importance in the development of back problems. The limited associations between back pain, saddle fit, and absolute pressure indicate that additional factors are involved in the development of equine back problems. The lack of association between certain manually and visually identified problems and pressure magnitude and distribution could be because of the subjectivity of the manual assessment, which underlines the importance of electronic saddle pressure measurements as a complementary tool. The industry would benefit from clear quantitative criteria to define saddle fit. These can only be developed based on experimental studies focusing on individual aspects (e.g., specific characteristics of the tree) where there is no risk of different fit problems influencing each other.

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Supplementary data

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