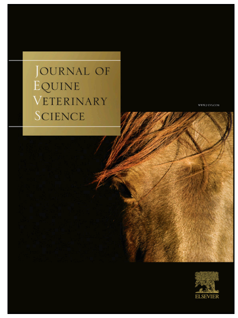
Accepted Manuscript



A photographic methodology for analysing bit position under rein tension

Caroline C. Benoist, Graham H. Cross

PII: S0737-0806(17)30626-3

DOI: 10.1016/j.jevs.2018.03.017

Reference: YJEVS 2501

To appear in: *Journal of Equine Veterinary Science*

Received Date: 18 September 2017

Revised Date: 27 March 2018

Accepted Date: 27 March 2018

Please cite this article as: Benoist CC, Cross GH, A photographic methodology for analysing bit position under rein tension, *Journal of Equine Veterinary Science* (2018), doi: 10.1016/j.jevs.2018.03.017.

A photographic methodology for analysing bit position under rein tension

Authors: Caroline C. Benoist[1*] and Graham H. Cross[2]

[1] NS Academy, Momentum, 30 Ellerbeck Court, Stokesley TS9 5PT UK

[2] University of Durham, Department of Physics, South Road, Durham DH1 3LE, UK

[*]**Corresponding author.**

E-mail address: caroline.benoist@gmail.com

Abstract

Bits are a common and invasive piece of equipment used in equestrian sports. A bit should be carefully chosen to suit the individual horse according to the pressure points it is willing to accept. Bit pressure is poorly understood due to a lack of accessible research instruments. The objective of this study was to describe a method to estimate pressure points from the bit on the tongue without the need for radiographs. The method employs photographic images of horses under static rein tension. Using design features on the bit, the angle at which these features press into the tongue were calculated. Ten riding school horses wearing a snaffle bridle without a noseband, were used to measure the degree to which a bit rotates under 2 kg of static rein tension for a: Turtle Top snaffle bit, French Link snaffle bit, HS single-jointed snaffle bit and ported Weymouth bit. Six dressage and eventing horses were used to measure the effect of rein tension, in 0.5 kg increments, on the degree of rotation of the bit. The bit rotated, but not significantly ($P > 0.008$), over the rein tensions used (up to 2kg). The reliability of the proposed method was confirmed by comparing anatomical reference lines in photographs with those in radiographs. The findings provide a reliable estimate to determine pressure points from a bit on the tongue, under rein tension without the need for invasive techniques and in the absence of technologically adequate equipment.

Keywords: Radiography, Rein Tension, Horse, Bit, Tongue, Pressure

1. Introduction

Controlling the ridden horse's speed and direction is commonly achieved by using a bit inserted into the horse's oral cavity. Reins are attached to the cheeks of the bit, allowing the rider to apply pressure to various points on the horse's head, in addition to the oral tissues [1–3]. The horse learns to respond to the release of pressure by the rider who does so to acknowledge a correct response from the horse. This form of learning, known as negative reinforcement, is commonly used for controlling horses [4].

The snaffle, Pelham and curb, or Weymouth, are the three most common types of bits used in riding and are classified according to the cheeks, mouthpiece, and mechanism of action [5]. The snaffle bit can have an unjointed, single-, double- or multi-jointed mouthpiece with either loose, or fixed rings on either end to which the cheekpieces of the bridle and the reins attach. However, a large variety of bit cheeks can be attached to this type of mouthpiece that can add or negate pressure on the area between and directly behind the ears, known as the poll [1]. The cannons and joint of a single-jointed snaffle can be regarded as a pair of class 2 levers with the joint on the centre of the tongue acting as the fulcrum. The inwards-directed component of the bilateral rein tension exerts a squeezing action on the commissures of the lips [3,6]. In the double-jointed bit there are two fulcrum points (one for each joint) that lie to either side of the centre of the tongue. Shifting the effective position of the fulcrum towards the edges of the mouth will reduce the inwards-directed component of the rein tension thus reducing the squeezing force. In multi-jointed bits the effective fulcrum position is ill-defined, but we can assume that the squeezing effect is reduced further still. An unjointed snaffle bit mouthpiece has no lever mechanism and simply converts a unidirectional bilateral rein tension into pressure applied onto the tongue and the commissures of the lips [2].

The Weymouth mouthpiece is unjointed and can range from having a lightly arched tongue groove to a narrow port, the direction of which can be vertical or angled 45˚ in caudal or rostral directions. Shanks of varying lengths extend above and below the mouthpiece, the lengths of which determine the amount of poll pressure applied [1]. Poll pressure is created by the pulling down of the headpiece of the bridle onto the poll of the horse as the shanks below the mouthpiece rotate anti-clockwise (as viewed from the left-hand side of the horse) in response to rein tension. The cheek pieces of the bridle, which attach to rings on the upper shanks, are pulled forward. A curb chain is fastened to hooks on rings attached to the upper shank. The function of the curb chain is to restrict the degree of rotation of the shanks, which serve as lever arms. Engagement of the curb chain therefore puts pressure on the chin groove. This type of bit can therefore apply pressure to the poll, the tongue, the bars, the chin groove and quite possibly the palate depending on the oral dimensions of the individual horse [7,8].

The Pelham is a combination of the snaffle and Weymouth, having a snaffle-type mouthpiece and shank cheeks that apply a lever action. This bit is also best employed with a curb chain. The curb chain is traditionally fitted to allow the lever arms (shanks) to rotate to an angle of ± 45° to the line of the lips.

The bit has been in use since 3500 BC [9], but recorded evidence of a scientific approach to analysing this influential and invasive item for control of the horse has only been accessible since the early 1980s [1,3,5,10–13]. These academic studies have been available to inform the equestrian professional of its mechanism of action on the oral tissues. However, perhaps because the methods described involve high level clinical techniques such as x-ray fluoroscopy, these have not trickled down to the everyday rider. Where the mechanical operation of bit cheeks has been previously described [1], the effects of mouthpiece features, such as joint-loops, links, and ports on the tongue and palate remain poorly understood by the everyday rider. A horse that seeks relief from pressure points, produced by design features on a bit, is likely to use his tongue to do so [12] yet tight nosebands, which are a common occurrence throughout the equestrian sport [14], make it difficult for the horse to open the mouth, and hinder oral behaviours. Therefore, it is important to understand pressure points from the bit that affect the tongue.

The absence of a simplified analysis was recently tackled by Doherty *et al.* [15] by examining patterns of wear by the horse on the mouthpiece. The patterns were examined and interpreted to reflect locations of pressure on the horse's tongue. Marked signs of wear were observed on medial areas of the cannons that lie directly on the tongue. Fewer marks were observed on the lateral ends of the cannons where the mouthpiece passes through the lips. According to the study, and as evidenced by examining oral behaviour in response to static rein tension [3], the bit is pulled in a caudal, ventral, or caudo-ventral direction. Caudo-ventral movement is readily observed in radiographs [11], as is rotation due rein tension [3,10,16]. It is also evident that the tongue compresses upon insertion of the bit [7,11]. Doherty et al. conclude that the use of micro-electromechanical pressure sensor arrays embedded in the mouthpiece could more accurately identify locations of pressure on the tongue when the bit is under rein tension [15]. This rather ambitious solution to the problem could be an important tool for research purposes. In the interim, an alternative practical solution is provided here.

The purpose of this study was to examine the use of a straightforward method to determine to what degree a feature on the mouthpiece of a bit is pressing into the horse's tongue when it is under rein tension, without the need for radiography and sedation of the horse. The method described here relies on full-profile photographs of the bitted horse with and without rein tension, and a third photograph of the bit used. From these, two-dimensional geometrical constructions of angles formed between anatomical landmarks within the sagittal plane of the horse's head and chosen features on the mouthpiece of the bit, can be produced. These constructions, which highlight regions of high pressure on the tongue produced by the mouthpiece under rein tension, are a good first approximation to what is otherwise often inaccessible information regarding what is pressing on the bitted horse's tongue under ridden conditions. The method relies on simple tools such as a camera on a mobile phone, a protractor and spring balance.

2. Materials

2.1 Subjects

Ten riding school horses (1-10) from a riding centre in the UK of various ages (mean 10.9 ± 1.2 years), heights (mean 154.4 ± 8.6 cm), breeds (two Thoroughbreds, one Welsh section D cob, two Clydesdale crosses, and four Cobs), sex (six mares and five geldings) were recruited to the study and fitted with a snaffle bridle with the noseband removed, and bits 1-3. The order of horses and bits was randomized.

One 16-year-old Oldenburg gelding (11), used for leisure riding was used to obtain radiographic images. This horse was fitted with a snaffle bridle, with the noseband removed, and bits 2 and 4.

Six dressage and eventing horses (12-17), from the Presidential Military Sports Center in Mexico, of various ages (mean 9.33 ± 1.4 years), heights (162.5 ± 5.62 cm), breeds (three Warmbloods and three S. Gertudis), sex (four geldings and two mares) were recruited into the study. These horses were fitted with snaffle bridles and a French crank-style cavesson and bit 5. One horse (12) was fitted with a flash strap (a thin leather strap attached to the cavesson to keep the mouth closed) with enough space for 1 finger between the skin of the horse and the leather strap. The order of horses was randomized.

2.2 Bits

Four bits with obvious design features such a links and loops, were evaluated for a broad representation of structures that press into the tongue (Fig.1). Each bit was fitted to the individual horse and in every case the bit was at the very least lightly touching the commissures of the lips and, at most, produced one wrinkle at the commissures. The length of the mouthpiece was measured from bore hole to bore hole, the diameter of the mouthpiece was taken at the borehole, and the ring size was measured as the inner diameter of the ring to which the cheekpiece of the bridle attaches (Fig.1). Characteristics of the bits used are as follows and described as if in the horse's mouth. Features on the mouthpiece are described in reference to the axis of the bore (Fig.1). The order of bits was randomized.

1. Turtle Top loose ring **(TT)**

A double-jointed, solid mouth piece whose cannons each possess an arched and flattened face. The loops of the cannons are aligned parallel to these faces. The loops attach to a central lozenge has a flattened and widened surface that lies parallel to the flattened face of the cannons. These flattened surfaces and loops are set at a 55° angle to the cannon bores. The rings are free to rotate through the bore holes of the cannons and through any attached leather work such as the cheekpieces and reins. The length of the mouthpiece = 15 cm and diameter of the mouthpiece = 12 mm. The inner-diameter of each ring = 70 mm. The mouthpiece is made of a copper alloy and the cheeks are stainless steel. N = 5

2. French Link eggbutt snaffle **(F)**

A hollow, double-jointed mouthpiece with loops that are at 90° to the bore axis and connect to a dog-bone shaped flat plate link. The cannons articulate with the rings to which the reins and cheek piece attach. These rings are free to rotate through the attached leatherwork to the extent that the fixed cheek design allows. The length of the mouthpiece = 14 cm and diameter = 15 mm. The inner long diameter of each ring = 70 mm. The mouthpiece and cheeks are made of stainless steel. N = 4

3. HS single-jointed eggbutt snaffle **(SJS)**

A solid, single-jointed mouthpiece with loops connecting to directly to one another. One loop is oriented at 90° to the cannon bore and the other is parallel to the cannon bore. The cannons articulate with the rings to which the reins and cheek piece attach. These rings are free to rotate through the attached leatherwork to the extent that the fixed cheek design allows. The length of the mouthpiece = 13 cm and its diameter = 16 mm. The inner long diameter of each ring = 55 mm. The mouthpiece is made of a copper alloy and the cheeks are stainless steel. N = 5

4. Weymouth (curb) bit **(W)**

A solid mouthpiece with a 7 cm wide tongue port angled 45° to the shanks which articulate directly with the mouthpiece. The upper shanks are 5 cm long and have small fixed rings to which the cheekpiece of the bridle attach. Hooks attach to the fixed upper rings allowing for the placement of a curb chain. The lower shanks are 7 cm long and have small moveable rings to which the rein attaches. The mouthpiece length = 13 cm and diameter = 16 mm. The mouthpiece is made of a copper alloy and the cheeks are stainless steel. N = 1

5. KMSS Single-Jointed Loose Ring Snaffle

A solid, single-jointed bit as described above (SJS). The length of the mouthpiece was 13 cm. The diameter of the mouthpiece = 20 mm and the inner diameter of each ring = 65 mm. The mouthpiece is made of a copper alloy and the cheeks are stainless steel. This bit was used for the rein tension analysis. N = 6

2.3 Bit Classification

Bits were classified according to the direction of rotation of the bores, or cheeks, when rein tension is applied. For Class I bits (bits 1-3, 5 - Fig.1) the cheekpieces and reins of the bridle work attach to the same ring on the bit and rotation occurs in a clockwise direction (as viewed from the left-hand side of the horse). Class II type bits (bit 4, Fig.1) rotate in an anticlockwise direction (as viewed from the left-hand side of the horse) and the cheekpieces attach to a ring sited above the mouthpiece while the reins attach to a separate ring either directly level with, or below, the mouthpiece.

3. Methods

3.1 Cheekpiece tension

Cheek piece pre-tension (Table 1), for the photographs under static rein tension, was measured using a 1 kg/10 N spring balance (IS-VET, England) inserted into the cheekpiece of the bridle and attached to the bit cheek. Pre-tension readings were taken when the horse appeared to be quiet in the mouth (not chewing on the bit) and the numbers stabilized to a value that fluctuated to no more than ± 0.5N.

3.2 Rein tension

A 5 kg spring balance (Salter Super Samson, OurWeigh, UK) was inserted into the left rein and used to measure rein tension. 2 kg of static rein tension was used to measure the degree of rotation of the bit due to applied rein tension.

Rein tensions of 0.5 kg gradations were used to measure differences in bit rotation at varying rein tensions for the KMSS loose ring single-jointed snaffle bit (5). A photograph was taken at each 0.5 kg increment. Measurements above 2 kg were deemed unnecessary in the spirit of maintaining as light a contact as possible whilst also representing most riding conditions.

3.3 Photographs

An initial photograph was taken of each horse with the bit in place and without reins attached.

For the initial angle (IA) a full-profile photograph of the bridled and bitted horse was taken from the left-hand side for consistency of approach. The photograph is intended to act as a para-sagittal plane. Wherever possible, for safety reasons, the image was taken without reins to determine the initial position of the mouthpiece on the tongue (Fig.2A). It was at this point that the cheekpiece pre-tension was recorded.

A second full-profile photograph was taken to obtain the working angle (WA) of the bit. This photo was again taken from the left-hand side of the horse in full profile. The horse was bridled and bitted with reins attached and a 5 kg spring balance inserted into the left rein (Fig.2B). A mounted rider tensioned the reins 2 kg at which point the photograph was taken and cheekpiece tension was again recorded.

A photograph was taken of each bit stretched out on a flat surface and taken in a direction along the mouthpiece long axis to capture design features of interest (Fig.2C).

3.4 Initial Angle construction

To obtain a reference angle for the bit in the resting position, without rein tension, an anatomical reference line was defined along the nose. This reference line, call the nose line, was intended to lie within the midsagittal plane of the horse's head in the first photograph taken (Fig.3A) as an externally visible reference line, and as a good approximation to an internal reference of the tongue [17]. An anatomical correction of 10° clockwise is applied to the nose line to find a more accurate estimate of the orientation of the tongue (Fig.3A dashed line). Examination of several equine skulls shows that a naturally occurring angle of approximately 10° lies between the nasal bone and palatine process of the maxilla, thus the accuracy of the analysis will generally be improved by applying this correction [18,19]. This corrected reference line is called the tongue line (*TL*).

A second reference line, called the bore axis (BA) was defined by drawing a line on the photograph corresponding to an axis through the bore hole in the cannon in the case of a loose ring cheek, or along a line parallel to a similar bore hole used to attach a fixed cheek to the mouthpiece (Fig.3 and

7). The angle lying between the BA and the TL, measured anti-clockwise from BA to TL in degrees, thus represents the initial angle of the bit in the absence of rein tension.

3.5 Working Angle construction

The degree of bit rotation due to rein tension was determined by creating the same reference lines in the second photograph, in which the bitted horse is under rein tension (Fig.3B). A mounted rider applied 2 kg rein tension and kept the hand-height as consistent as possible among horses. The same reference lines were drawn. One along the nose and shifted by 10°, and the BA. The angle between them is again measured anticlockwise in degrees from BA to TL.

3.6 Feature Angle construction

Features in the design of the mouthpiece that may be of interest or concern to the equestrian professional practitioner, or horse owner, were examined from photographs taken of the bit. A feature angle (FA) was obtained by first drawing a reference line through the cannon bore for the Turtle Top (Fig.4A and inset), along the bore for the French Link and SJS (Fig.4B and C) or along the shank of the Weymouth (Fig.4D). A second reference, the feature line (FL), was drawn along the plane of a feature of interest. For bit 1, the Turtle Top, the near (left) loop, was taken as the feature of interest (Fig.4A and inset) and FL drawn across its plane. For bit 2, The French Link, two features were of interest. FL_1 was drawn across the width (not its length or thickness) of the central link. FL_2, the near (left) loop, was taken as the second feature of interest and FL drawn across its plane (Fig.4B). Both loops of the SJS (3) were taken as features. FL_1 is the off-side loop and FL_2 the near (left) loop (Fig.4C). For the Weymouth, bit 4, the 45° angled port was the feature (Fig.4D) and FL drawn along it. The angle, (FA), between the feature of interest and BA, was measured anticlockwise from BA to FL.

3.7 Tongue Angle

The tongue angle (TA) was calculated as follows:

$$TA = WA - FA \qquad [1]$$

TA was calculated for each bit (Table 2) and drawn onto each WA photograph from FL to TL (Fig.6A-D) to display the angle at which the chosen feature is aligned to the tongue.

3.8 Radiographs

The horse (11), fitted with a snaffle bridle without a noseband, and a surcingle, was placed in stocks and sedated with 4.2 ml Romifidine 10 mg/ml solution and 0.7 ml Torphasol 10 mg/ml solution. All radiographs were taken with an output of 72kV and 1.8 mAs with the source at a distance of 60 cm from the left side of the horse's head with the imaging plate held on the right side of the head by a technician wearing a protective apron. Radiographs and photographs without reins were taken subsequently and the bits were in randomized order. The same procedure was followed for radiographs and photographs of the horse under rein tension. For these images the horse was fitted with long reins passed through the top loops of the surcingle to mimic a rider's hands. A 5 kg spring balance was inserted into both reins (Salter Super Samson, OurWeigh, UK). The researcher, wearing a protective apron stood behind the horse, outside the stocks, and applied 2 kg tension to both reins. The horse's head required support from a rope to maintain a position of ±20° to the vertical. The bits were again randomized, and the radiographs and photographs taken in subsequent order. Data is shown only for the French Link and Weymouth bits. Radiograph images were rotated to align to the photographs (Fig.7) and the two were taken no more than 1 minute apart.

4. Statistical Analyses

The relationship between working angle and rein tension for each bit was analysed using the Pearson's correlation method and the Wilcoxon signed-rank test with Bonferroni correction as *post hoc*. Statistical analysis of data was undertaken in IBM SPSS Statistics version 21 and Excel 2016 (Microsoft Office, Redmond, WA).

5. Results

5.1 Working Angle and Tongue Angle

FA and TA for each bit (Table 3), were calculated and measured according to equation [1] and Fig.4. TA varies according to bit design and the feature chosen. The Turtle Top bit (1) has loops (and co-aligned flattened cannon faces and flattened link surface) aligned at FA = 125° (Fig. 4A). The mean TA at 2 kg rein tension is -5.2° ± 9.0 and they therefore lie at a very shallow angle to the tongue (Fig.6A data shown for horse 2). The French Link bit design with both loops perpendicular to the bores has a mean TA_1 of -53.25° ± 5.5 for the dog-bone shaped central link which lies parallel to the bores and a mean TA_2 of 36.75° ± 5.5 for the loops (Fig.4B, data shown for horse (9) and Fig.7B, data shown for horse (11)). The loops of the French Link bit therefore lie at an angle that is somewhat shallow to the tongue while the link presses more acutely into the tongue. The SJS (bit 3), on which the near (left) loop lies perpendicular to the bore and the offside loop lies parallel to the bore (Fig.4C), has a mean TA for the near loop of 39.8° ± 7.7 and mean TA for the offside loop of -50.2°± 7.7. Both loops therefore lie at an acute angle to the tongue but in opposite directions. The near loop (TA_2) is acutely angled dorso-ventrally in a caudal direction. The offside loop (TA_1) is also acutely angled in a dorso-ventral direction but rostrally facing (Fig.6C, data shown for horse 2). The tongue-relief port of the Weymouth bit (4) has FA = 45° (Fig.4D) and TA of 46° (Fig.7D). The mouthpiece of this bit rotated rostrally and the cheeks caudally. The port therefore presses into the tongue at position rostral to the resting position (pre-rein tension) which was at an initial angle of 167° (Fig.7B).

5.2 Rein tension

The *WA*, for the KMSS loose ring single-jointed snaffle (5) increases when rein tension increases from 0.5 kg to 2.0 kg: $r = 0.97$ (*df* = 2). Mean values ± SD are shown in Table 2. Post hoc analysis with non-parametric Wilcoxon signed-rank tests of all 6 pairs of means was conducted using Bonferroni correction of an assumed parametric level of significance of 0.05, resulting in a corrected level of significance of 0.008. No statistically significant difference in the *WA* was seen between 0.5 kg and 1.0 kg of rein tension (Z = 2.21, P = 0.03), 0.5 kg and 1.5 kg (Z = 2.21, P = 0.03), 0.5 kg and 2.0 kg (Z = 2.00, P = 0.05), 1.0 kg and 1.5 kg (Z = 2.20, P = 0.28), 1.0 kg and 2.0 kg (Z = 1.7, P = 0.03), 1.5 kg and 2.0 kg (Z = 0.95, P = 0.34). The WA increases with increasing rein tension until a limit to the rotation is reached at 2kg rein tension where the WA variation falls within a narrow statistical range (Fig.5E).

5.3 Radiographs

Radiographs taken of the French Link (2) and Weymouth (4) bits (N = 1) were used to correlate angles on photographs (Table 3 and Fig.7). The WA for the French Link bit was 140° on the photograph and 136° on the radiograph (Fig.7B). TA_1, the link, is shown to be -40° to TL on the photograph and -44° on the radiograph. TA_2, the loop, is 50° on the photograph and 46° on the radiograph. The WA for the Weymouth is 91° on the photograph and 105° on the radiograph (Fig.7D). The TA is 46° and 60° respectively.

6. Discussion

6.1 Working Angle and Tongue Angle

Without rein tension, the mouthpiece is held against the horse solely by the forces in the cheekpieces of the bridle. These forces are balanced by the reaction forces of the horse's mouth and poll against the bit and headpiece of the bridlework. The bit therefore adopts a static orientation relative to the horse and when rein tension is applied the bit rotates. Rotation of the bit is caused by unbalanced torques acting on the mouthpiece when rein tension is applied to the bit cheeks. This new orientation of the bit also reaches a state of balanced forces, but the overriding action/reaction force pairs are directed along the line of action of the rein force rather than along the cheekpieces of the bridle. This is because the rein tension now exceeds the cheek-piece tension by a significant margin (Table 1). Due to the torques produced, *BA* has noticeably rotated relative to *TL*, opening the angle between them and indicating the rotation of the bit mouthpiece (Figures 6 and 7). This new angle, the WA, was used to determine the degree to which a feature on the mouthpiece of a bit presses into the tongue.

When measured in a perspective view, with the mouthpiece long axis lying perpendicular to the plane of the photograph, an angle of a chosen feature between *BA* and a reference line defined on the feature of interest (*FL*) was measured (Fig.4). This angle, *FA,* when viewed strictly from this perspective, remains constant when the bit takes up the bent conformations that result from rein tensioning and it is thus a reliable parameter for all practical applications.

By correlating constructions made on these two photographs it then becomes an exercise to find the relative orientation of the feature to the tongue under rein tension (Fig.6). The re-orientation due to rotation of a relatively sharp mouthpiece feature presented onto the tongue thus specifies a region of high pressure. The Turtle Top bit, with a curved design, for which the loops are parallel to the lozenge and angled at 125° to BA, the angle to the tongue is very shallow and the features present low pressure points on the tongue (Fig.6A). In contrast, the two remaining snaffle bits (French Link and SJS) have regions of high pressure on the tongue. The link of the French Link lies parallel to BA and therefore presses acutely into the tongue as the bit reaches its WA. The loops attaching the link however, lie at a 90° to BA and thus are presented at a shallower angle to the tongue (Fig.6B). Single-jointed snaffle bits have loops that lie perpendicular to one another, with one loop at 90° to BA and the other at 180° (Fig.4C). In this case, both loops press acutely into the tongue but do so in opposite directions, with one loop in a caudal direction and the other in a rostral direction (Fig.6C) therefore, both loops present points of high pressure to the tongue.

6.2 Rein tension effects on the methodology

The strong support for a positive correlation between rein tension and working angle given by the Pearson test over the range of 0.5 to 2.0 kg of rein tension is not supported by the Wilcoxon non-parametric test for significance of paired groups across this range. In view of the strong indication of correlation however, further study using larger samples so that parametric methods may be used is justified. The data suggest that the method should be undertaken at rein tension levels of around 2 kg where the standard deviation drops appreciably (see Table 3). In normal riding a typical average rein tension is certainly within the range of 2 kg but it is a dynamic, rather than static, situation. In that case we should consider the relaxation times for the bit under tension against the known instantaneous rates of change of rein tension. The instantaneous rein tension fluctuates rapidly at frequencies related to the stride frequency [20–22] with peak to valley time scales of around 0.7 – 0.3 seconds but resistive frictional forces between the bit and the mouth probably prevent the mouthpiece from following this movement. On longer time scales however, the average rein tension may fluctuate due to other riding conditions such as a loss of balance in the horse over a few seconds and in such circumstances, it is possible that the bit mouthpiece may have time to re-orient. Currently, only static measurements at varying degrees of rein tension can be taken at the halt and it might be interesting to extend the study to dynamic conditions, perhaps using high speed motion capture and video-graphic methods.

6.3 Radiographs

Curb bits such as the Weymouth (Fig.4D), are class II bits. The extent of rotation of a class II bit depends on the pre-existing lever arm, the length of the shank below the mouthpiece, and reaches its rotation limit for one or both of two possible reasons. First, it may be that the line of action of the reins finally passes through the axis of the mouthpiece and the lever effect of the rein force vanishes, thereby effectively removing the possibility of producing torque and establishing the working angle is established at this point. Second, the lever arm that creates the torque may remain finite at the limit of rotation (the lever arm persists) but it is balanced by the tightening of the curb chain on the chin and the headpiece of the bridle on the poll, again establishing the working angle. The working angle can therefore vary greatly according to shank length and curb chain tensioning.

The Weymouth bit has a wide 45° forward-facing port, oriented rostrally at a shallow angle to the tongue producing minimal or no interference to the palate (Fig.7D) under the conditions of this study. The WA for this bit was larger than is usually recommended and resulted from the curb chain being fitted more loosely than is usual. However, had the curb chain been tightened to restrict the rotation to 45° then WA would have been ±137 and TA ±90° whereupon interference of the tongue relief port to the palate might have occurred. Allowing the shanks to rotate to 90°, the port, which rotated rostrally (anticlockwise) was situated at an acute angle on the tongue and did not interfere with the palate.

The IA for horse 11 in the French Link bit is smaller compared to horses 4, 8, and 9, and the WA is also much larger in comparison (Table 3). This may have been an effect of the sedation that caused the muscles to relax, thereby altering the degree of rotation of the bit due to a lack of resistance in the oral tissues. Variations in the WAs and TAs among horses (Tables 2 and 3) could be due to resistance to the bit. Horses may be producing tension in the tongue in response to static rein tension or conduct any variety of the oral behaviours described by Clayton et. al [12].

While variations in the WA are bound to exist, the robustness of the method was confirmed by radiography of the French Link and Weymouth bits (Fig.7). Reference lines in the photographs correspond to the reference lines in the radiographs. The nasal bone, clearly visible in radiographs, was used as a landmark for the nose line. The reference line for the nose line on the radiograph corresponds to the nose line on a full-profile photograph. The nose line in the image pairs were rotated by 10° and, as can be seen on the radiographic images, clearly follow the plane of the tongue where it is not deformed by the presence of the bit. The differences in the WA in this horse are likely caused by the inability to take photographic images and radiographic images simultaneously. Differences in the WA and TA for the Weymouth in the photograph and radiograph can be due to the horse swallowing or mouthing the bit at the moment either image was taken. This is evident from the tongue protruding through the incisors on the IA radiographs (Fig.7A and C) but not in the WA images (Fig.7B and D). This highlights the dynamic nature of the bit in the horse's mouth which is clearly not caused by rein tension alone.

Regardless of variations in the data, the method described here presents a useful estimate of bit design features pressing into the horse's tongue at a known rein tension, using accessible tools. The information obtained is static in nature but can be viewed to reflect riding conditions during rein tensions similar to those used in the photograph taken. In fact, previous observations [3,11,12][3,11,12][3,10,11]

of rotation and translation of the bit under rein tension, using radiography, are confirmed here and thus provide horse owners with a simple technique to solve any question on the physical action of a bit that lies within its wide scope of applicability (see Appendix for a typical worked example).

6.4 Limitations

Limitations to the method exist, and certain considerations should be taken into account. For example, the horse's oral behaviour may cause a difficulty in taking reliable readings because a horse chomping the bit, in response to rein tension, will cause varying deformation of the oral tissues upon which the rotation relies and thereby alter the measured WA. A quiet mouth is therefore necessary for the most accurate measurement.

Different types of nosebands, and perhaps noseband tensions, may affect the WA should they physically interfere with the bit. Also, cheekpieces that are over-tensioned can potentially affect the degree of rotation of the bit, unless sufficient rein tension is applied to overcome this pre-tension.

Some breeds have distinct nose lines, such as the so-called Roman nose of Iberian and draft horses, and the dish-face of some Arabian horses. Also, horses in general, are likely to have varying elasticity of the lips, any of these parameters may affect the WA, and perhaps be of further research interest.

The accuracy in the method however, relies on the precision of taking a full-profile photographs, since a photograph taken at an angle will naturally produce a parallax error. Knowing the exact design specification of a bit increases the accuracy of the method as drawing FL can be subjective. Where possible, the FL must be drawn by locating a top and bottom edge of feature, if visible, otherwise a best estimate of both starting and ending points should be used. Lozenges are not useful features to analyze as they are broad and distribute pressure over a large area and therefore do not represent points of high pressure.

7. Conclusion

The methodology described here, using photographs to measure the angle of rotation of the bit under rein tension, can be employed to determine, within reason, the pressure points applied by features on a bit while the horse is under rein tension. This approach, which requires no more than a camera, protractor and a spring balance, negates the need to take radiographs of the bitted horse under rein tension. Further studies examining the elasticity of oral tissues amongst horses and the effect of oral behaviours on the WA would be useful. The effect of curb chain tension and interference of ported bits with the palate are certainly warranted. This method, in the absence of a bit capable of measuring pressure on the tongue, serves as a good analysis tool in the interim.

Acknowledgements: The authors would like to thank Tracy Bye of Bishop Burton College, Beverley, UK for her review of the draft manuscript and help with statistical analyses, James Marshall, NA, VetMB, NRCVS of Hambleton Equine Clinic for the radiographs, Jose Casado, head of the Technical Commission of the Dressage committee of the Mexican Equestrian Federation and FEI Steward, for his contribution to the rein tension data, Kari Grundvig for her case study described in the Appendix, and Miranda Jupp for her technical assistance. We also thank Kirklevington Riding Centre for the kind use of their horses and facilities.

Ethical considerations: According to UK legislation no specific ethical permit was necessary for this study.

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

References

[1] Cross GH, Cheung MKP, Honey TJ, Pau MK, Senior KJ. Application of a Dual Force Sensor System to Characterize the Intrinsic Operation of Horse Bridles and Bits. J Equine Vet Sci 2017;48:129–135.e3. doi:10.1016/j.jevs.2016.01.017.

[2] Bennett DG. An Overview of Bits and Bitting. Proc. Am. Assoc. Equine Pract., 2001, p. (47) 130-141.

[3] Clayton, HM and Lee R. A Fluoroscopic Study of the Position and Action of the Jointed Snaffle Bit in the Horse's Mouth. Equine Vet Sci 1984;4:193–6. doi:10.1016/S0737-0806(84)80141-0.

[4] McGreevy P. Punishment in horse-training and the concept of ethical equitation. J Vet Behav Clin Appl Res 2009;4:193–7. doi:10.1016/j.jveb.2008.08.001.

[5] Clayton H. A Fluoroscopic Study of the Position and Action of Different Bits in the Horse's Mouth. J Equine Vet Sci 1985;5:68–77. doi:10.1016/S0737-0806(85)80050-2.

[6] Edwards EH. The Complete Book of Bits & Bitting. 2000.

[7] Engelke, E. and Gasse H. An Anatomical Study of the Rostral Part of the Equine Oral Cavity With Respect To Position and Size of a Snaffle Bit. Equine Vet Educ 2003;15:158–63. doi:10.1111/j.2042-3292.2003.tb00235.x.

[8] Evans, R.G and Lowder M. Examination of the Depth of the Equine Hard Palate. J Vet Dent 2012;29:228–30.

[9] Anthony, D. and Brown D. The origins of horseback riding. Antiquity 1991;65:22–38. doi:10.1017/S0003598X00079278.

[10] Manfredi, J, Clayton, HM and Rosenstein D. Radiographic study of bit position within the horse's oral cavity. Equine Comp Exerc Physiol 2005;2:195–201. doi:10.1079/ECEP200564.

[11] Uhlig F. [Darstellung der Lage verschiedener Trensengebisse im Pferdemaul bei Einwirkung unterschiedlich starken Zügelzuges am gerittenen Pferd im Halten] [Presentation of the position of various snaffle bits in the horse's mouth when subjected to varying degrees]. University of Vienna, 2009.

[12] Manfredi JM, Rosenstein D, Lanovaz JL, Nauwelaerts S, Clayton HM. Fluoroscopic study of oral behaviours in response to the presence of a bit and the effects of rein tension. Comp Exerc Physiol 2010;6:143–8. doi:10.1017/S1755254010000036.

[13] Manfredi J, Clayton H, Derksen F. Effects of different bits and bridles on frequency of induced swallowing in cantering horses. Equine Comp Exerc Physiol 2010;2:241–4. doi:10.1079/ECP200569.

[14] Doherty, O.; Casey, V.; McGreevy, P.; Arkins S. Noseband Use in Equestrian Sports - An International Study. PLoS One 2017;12:e0169060.

[15] Doherty O, Casey V, McGreevy P, McLean A, Parker P, Arkins S. An analysis of visible patterns of horse bit wear. J Vet Behav Clin Appl Res 2017;18:84–91. doi:10.1016/j.jveb.2016.12.007.

[16] Clayton H. Bitting : The Inside Story. Vet Connect 2005:28–32.

[17] Kimberlin, L.; zur Linden, A.; Ruoff L. Atlas of Clinical Imaging and Anatomy of the Equine Head. 1st ed. Wiley Blackwell; 2017.

[18] Evans, K.E. and McGreevy PD. Conformation of the Equine Skull: A Morphometric Study. Anantomia Histol Embr 2005;35:221–7. doi:10.1111/j.1439-0264.2005.00663.x.

[19] Radinsky L. Ontogeny and Phylogeny in Horse Skull Evolution. Evolution (N Y) 1984;38:1–15.

[20] Eisersio, M; Rhodin, M; Roepstorff, L; Egenvall A. Rein tension in 8 professional riders during regular training sessions. J Vet Behav 2015;10:419–26.

[21] Konig von Borstel U GC. Alternatives to Conventional Evaluation of Rideability in Horse Performance Tests: Suitability of Rein Tension and Behavioural Parameters. PLoS One 2014;9.

[22] Warren-Smith, A; Curtis, R; Greetham, L; McGreevy P. Rein contact between horse and handler during specific equitation movements. Appl Anim Behav Sci 2007;108:157–69.

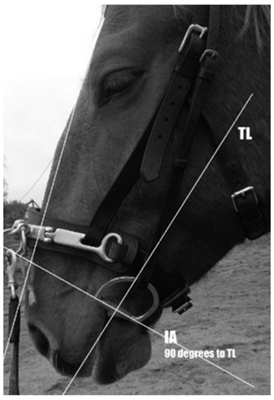
APPENDIX

Reproduction, unaltered from the source, of a Neue Schule Academy case study of a Sprenger KK Ultra D-ring snaffle, produced by a student in Norway with an interest in learning how the bit in use affects the horse.

Objective: To find the key angles of operation of the Sprenger KK Ultra snaffle bit attached to a sliphead on a lungeing cavesson, with and without rein tension.

Equipment and methods: A KK Ultra D-ring snaffle bit was photographed for determination of the Initial Angle and Working Angle with the horse at halt but under rein tension. The tongue line is assumed to be at an angle of -10^0 from an approximated line of the horse's forehead, as shown in the photos 1 and 2. The working angle (WA) is measured from photo 2, and the tongue angle (TA) calculated.

Analysis of the Initial and Working Angle



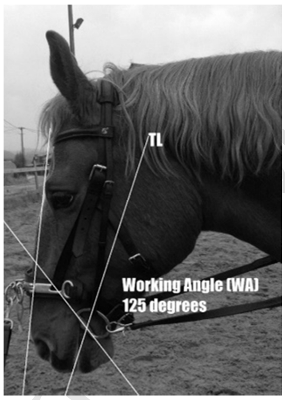


Photo 1 (left) shows the bit without reins. The Initial angle is measured with a protractor and is -90° from the tongue line, seen from the left side.

Photo 2 (right) shows the bit with side reins attached at the height of the horse's wither. Upon contact on the side reins the bit rotated clockwise to a working angle (WA) of 125^0 from the Tongue Line. The WA was the same with very light contact ("slack" side-rein), and with a firmer contact. This indicates that the weight of the side rein alone was enough to rotate the bit.

The Feature Angle between BA and the Loop Plane Axis is 45^0. The Tongue Angle (TA), Loop Plane axis to Tongue Line, is 125 - 45 = 80^0.

Conclusion: With even very little contact on the reins the bit rotated to a working angle (WA) of 125^0. The "chain links" of the loop planes protruded down into the tongue at an angle of 80^0 to the tongue line. Due to the Chain-Link principle, the middle lozenge was oriented along the tongue at an angle of -10^0.

Tables

Table 1

Bit	Horse	$CP\ FR_{0\ kg}$ (kg)	$CP\ FR_{2\ kg}$ (kg)
TT	1	2	4
TT	2	3	4
TT	3	2	3.5
TT	4	2	3.5
TT	5	3	3.8
F	4	4	2
F	8	3.8	3
F	9	3	3.5
SJS	1	2.5	3.5
SJS	2	4	3
SJS	5	3.5	2
SJS	6	4	1
SJS	7	4	1
Weymouth	11	3.5	6.5

Table 1. Cheekpiece tension values for Class I bits. $CP\ FR_{0\ kg}$: Cheekpiece pre-tension values in kg; $CP\ FR_{2\ kg}$: Cheekpiece tension values at 2 kg rein tension kg.

Table 2

RT (kg)	WA° Horse 12	WA° Horse 13	WA° Horse 14	WA° Horse 15	WA° Horse 16	WA° Horse 17	Mean ± SD
0.5	118	138	123	125	121	109	122.3±9.5
1.0	123	144	128	128	134	122	129.8±8.2
1.5	134	151	136	130	137	134	137.0±7.3
2.0	142	137	141	135	140	137	138.7±2.7

Table 2. Mean ± SD for the degree of rotation of a single-jointed loose ring snaffle bit taken at 0.5 kg increments of rein tension. The degree of rotation was not significant at 0.5 kg intervals of rein tension.

Table 3

TT	**IA°**	**WA°**	**FA°**	**TA°**		
Horse 1	74	109	125	-16		
Horse 2	62	116	125	-9		
Horse 3	80	135	125	10		
Horse 4	74	124	125	-1		
Horse 5	71	115	125	-10		
Mean ± SD	72.2±5.9	119.8±9.0	125±0.0	-5.2±9.0		
F	**IA°**	**WA°**	**FA_1°**	**TA_1°**	**FA_2°**	**TA_2°**
Horse 8	104	128	180	-52	90	38
Horse 9	99	124	180	-56	90	34
Horse 4	98	120	180	-60	90	30
Horse 11 (P)	86	140	180	-40	90	50
Horse 11 (R)	102	136	180	-44	90	46
Mean±SD	97.8±6.6	126.8±5.5		-53.3±5.5		36.8±5.5
SJS	**IA**	**WA**	**FA_1**	**TA_1**	**FA_2**	**TA_2**
Horse 1	100	121	180	-59	90	31
Horse 2	100	137	180	-43	90	47
Horse 6	96	134	180	-46	90	44
Horse 5	115	137	180	-43	90	47
Horse 7	88	120	180	-60	90	30
Mean ± SD	99.8±8.8	129.8±7.7	180.0±0.0	-50.2±7.7	90.0±0.0	39.8±7.7
W	**IA**	**WA**	**FA**	**TA**		
Horse 11 (P)	167	91	45	46		
Horse 11 (R)	181	105	45	60		

Table 3. Mean ± SD values of the WA with the NN setting. Tongue angles were calculated from WA and FA for each feature of interest for each bit. P: photograph and R: radiograph.

ACCEPTED MANUSCRIPT

Fig.1 Class I bits (1-3 and 5) and a Class II bit (6) used in the study. (A) mouthpiece length measurement (B) measurement of inner ring diameter (C) point of measurement for mouthpiece diameter (D) measurement area for port width (E) upper shank length (F) lower shank length.

Fig.2 Full profile photographs of the left-hand side of (A) an unmounted horse without reins and (B) mounted under 2kg rein tension (C) A photograph of bit 2, arranged as required for analysis of feature angles.

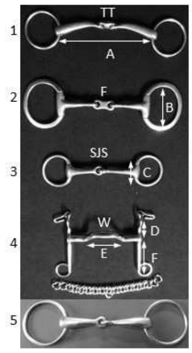
Fig.3 Defining anatomical landmarks. (A) The solid white line represents the first reference line along the nose. The dashed line represents TL, shifted 10° from the nose line. A line drawn tangent to the bore (black) establishes the angle (IA) of the bit in relation to TL (arrow). (B) The same reference lines are used on the photograph of the horse under rein tension to measure the WA (arrow).

Fig.4 Defining FL and measuring the FA. (A) FL for bit 1 (Turtle Top) was taken along the near (left) loop plane (B) Two design features were of interest on bit 2 (French Link): FL_1 (white) was taken along the plane of the central link and FL_2 (black) was taken along near loop plane (C) Two design features were chosen on the SJS: the off-side loop (FL_1, white) and the near loop (FL_2, black dashed line) (D) The design feature for bit 6, a class II Weymouth was the 45° forward facing port.

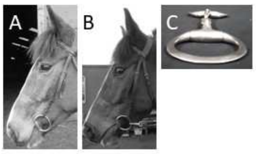
Fig.5: (A-D) Increasing degrees of rein tension applied to a single-jointed bit (5) with constructions on each figure to show the reference lines TL, BA, and the WA. (E) Plot of WA as a function of rein tension. Error bars are ± SD.

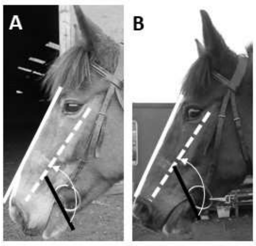
Fig.6 FLs and TAs transposed onto the photographs indicate the angle at which a feature presses into the tongue. (A) FL: near (left) loop of the Turtle Top; TA is represented by the arrow (B) French Link bit: central link = FL_1 (black) and near loop = FL_2 (white); TAs are represented by arrows of corresponding color (C) FL_1 = off-side loop (black) and FL_2 (white) the near loop of SJS; TAs are represented by arrows of corresponding color (bit 3) (D) The 45° forward-facing port was used as the feature on the Weymouth. TA was measured from BA to FL.

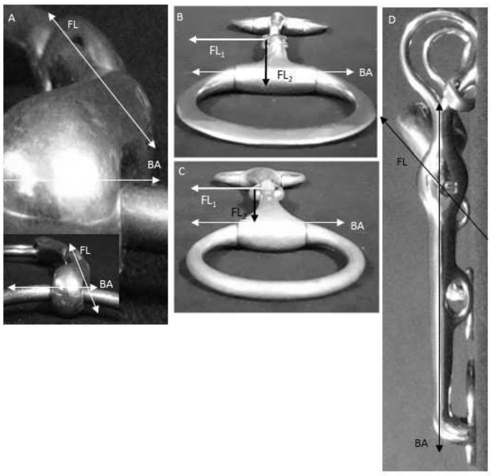
Fig.7 Photographic and radiographic images of the French Link and Weymouth bits at the IA (A and C) and WA (B and D), respectively. Radiographic images were rotated to match the head position of the photographs.

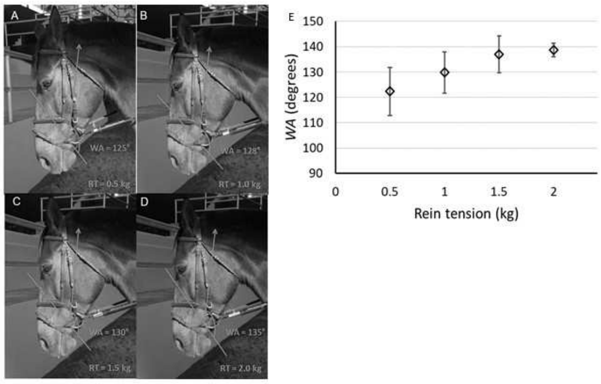


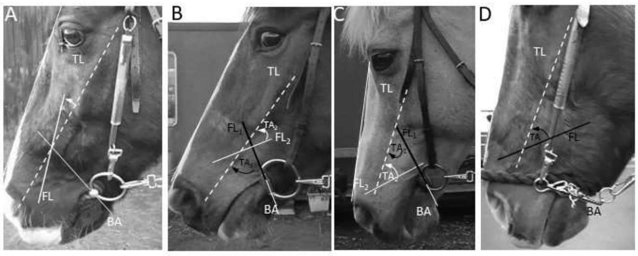
TT
1
A
2
F
B
3
SJS
C
4
W
D
E
F
5

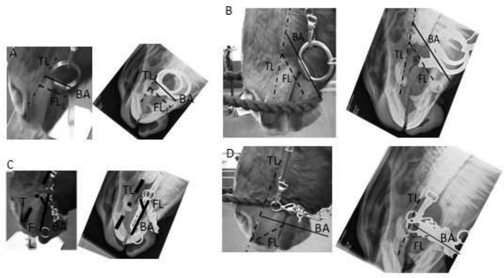

A
B
C


A
B


A
FL
BA
FL
BA
B
FL_1
FL_2
BA
C
FL_1
FL_2
BA
D
FL
BA


A
B
C
D
WA = 125°
RT = 0.5 kg
WA = 128°
RT = 1.0 kg
WA = 130°
RT = 1.5 kg
WA = 135°
RT = 2.0 kg
E
150
140
130
120
110
100
90
WA (degrees)
0
0.5
1
1.5
2
Rein tension (kg)


A
TL
FL
BA
B
TL
FL1
TA2
FL2
TA1
BA
C
TL
FL1
TA1
FL2
TA2
BA
D
TL
TA
FL
BA


A
TL
BA
FL
B
C
D

- The bit rotates in response to rein tension.
- Static photos can be used to identify key pressure points from a bit on the tongue.
- Bits create pressure points according to their design and the direction of rotation.