An Investigation into the Oro-nasal Pressures used in the Control of the Ridden Horse

A thesis submitted to the University of Limerick in fulfilment of the requirements of the degree of Doctor of Philosophy

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Declaration

I, Orla Doherty, hereby confirm that the content of this thesis is a product of my own research. Where use has been made of the work of other people, it has been fully acknowledged and referenced in accordance with University regulations. This material has not been previously submitted to any university or higher education institution for an academic award of any kind.

Signed: ________________________________  Date: 18 April 2016

Orla Doherty
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Abstract

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The control and training of horses is achieved through the application of physical pressures on the body of the horse. However, the levels of pressure exerted by most equitation equipment in use have not been measured. Welfare concerns exist regarding the levels of pressure exerted by some equipment in use, and the use of sustained pressures. Regulation by governing authorities is difficult until pressure levels and their possible consequences have been investigated.

A survey of equipment used by 861 show jumping riders identified the most popular bits, nosebands and other devices in use. A study of the type and location of surface changes to a range of bits as a result of wear identified suitable locations to place pressure-sensing technology. Noseband tightness measurements were taken of 750 competition horses in 3 countries. These data showed a strong preference by riders to use extremely tight nosebands in competition.

Two approaches to measuring sub-noseband pressures were developed. Facial curvature data and noseband force measurements generated by a strain gauge inserted into the noseband were used to predict pressures exerted by the noseband at a range of locations. Placement of pressure transducers at various locations beneath the noseband and on the bit, along with the use of wireless technology allowed data to be collected from bit and noseband sensors while the horse was being ridden. Output from sensors in both locations was pulsatile, with highest pressure peaks corresponding to a range of events including transitions, jumping efforts, head tossing and resistances. Such events resulted in pressure peaks from noseband sensors exceeding 1400 mmHg with lower pressure peaks recorded from bit sensors.

Following development of an electronic noseband force measurement probe, noseband force measurements were carried out on two groups of horses (n=23) while nosebands were at three different noseband settings. Mean noseband force measurements of 63 N were recorded from nosebands at the tightest fitting. Thermographic measurement of eye temperatures taken from the second group of horses (n=8) showed a small but statistically significant increase in eye temperature at the tightest noseband setting. This research identifies substantial pressure levels exerted by nosebands, describes methods of measuring sub-noseband pressures, and also of monitoring and regulating noseband tightness levels in competition.
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Chapter 1

Literature Review

Introduction
An increased focus on the application of principles derived from learning theory in recent years has led to a greater understanding of the ways in which the learning capabilities of the horse can be harnessed to facilitate optimal and ethical training (McGreevy, 2007, McLean, 2005a). For example, the use of classical conditioning is suggested as a means of reducing the levels of pressure required during training. A light pressure cue, immediately preceding a stronger pressure cue, will be associated by the horse with the stronger cue (McLean and McLean, 2008). After a small number of successful responses, which relieve pressure (where the trainer removes the pressure upon performance of the correct behaviour), the behaviour can be elicited by the light cue. When correctly applied, this approach can create a level of training resulting in the need for only pressure cues of a small magnitude to elicit the desired responses (McLean, 2003).

Unfortunately, learning theory is not yet widely taught. Equestrian coaches have been found to have low levels of knowledge of learning theory (Warren-Smith and McGreevy, 2008, Wentworth-Stanley, 2008, Durant, 2011) and veterinarians also receive minimal training in this area (Doherty et al., In Press). The consequence of this lack of knowledge is that those involved in the training and control of horses are less likely to achieve optimum efficacy in training. Errors in the use of negative reinforcement, such as delayed or lack of pressure release impede learning, and frequently result in the need for maintenance of sustained pressures to achieve particular responses (McLean, 2005b). One such example is the use of rein tension to elicit a head and neck posture similar in outline to that achieved through progressive training, known as collection (McGreevy et al., 2010). Development of increased muscular tone of
particular targeted muscle groups through progressive training results in an increased degree of cervical and poll flexion, bringing the frontal nasal plane of the horse into a position at, or slightly in front of the vertical. This posture is thought to consider a biomechanical advantage to the horse by resulting in increased tone of the back musculature (McGreevy et al., 2010). However, sustained or escalating rein tension can elicit a similar head and neck position as discomfort due to bit pressure levels will result in the horse drawing the head closer to the chest to reduce discomfort. This frequently results in the head being held with the frontal nasal plane behind the vertical, a posture known as hyperflexion, or in cases of extreme cervical and atlanto-occipital joint flexion, Rollkur. Achieving this posture through the use of rein tension is possible in a much shorter time period than through progressive training. However the sustained bit pressure on tongue and other oral structures used to elicit this posture has been questioned as a possible threat to horse welfare (McGreevy and McLean, 2009). In addition, as bit pressure is also used to elicit deceleration, the use of bit pressure to request two different responses is likely to lead to confusion for the horse (McLean and McGreevy, 2010). Sustained bit pressure is also thought to contribute to habituation to bit cues, resulting in reduced responsiveness to bit pressures, with the consequence of reduced performance and also rider safety.

**Pressures used in training and control of horses**

Pressures used in horse control and training are applied at various locations of the horse’s anatomy to elicit a response. Head and mouth pressures are used to control forward movement, speed, direction, slowing and stopping (McGreevy and McLean, 2010). Possibly the most salient pressure to the horse is pressure applied by a metal bit against intra-oral structures, and to a lesser extent, external oral structures (lips, cheek). Research into the levels of pressure applied by the bit and noseband is lacking. Pressures exceeding certain levels cause pain (Greenspan and McGillis, 1991). Ridden horses are exposed to pressures of varying levels and at various locations on the body during each ridden session. Horses which fail to respond to bit and leg pressures are described as ‘dead to the leg’ and having a ‘hard mouth’. This terminology suggests that horses have become desensitised to pressures exerted by riders. However, preliminary evidence in horses suggests that habituation to bit pressure during repeat exposures does not occur (Christensen et al, 2011). While further investigation into desensitisation to
rider-imposed pressures is needed, the possibility that desensitisation may not be occurring highlights the need for investigation into the levels of pressures being applied by riders.

Use of high levels of pressure in horse control is most likely when lower pressure levels do not elicit the desired response. Failure of trained responses occurs when training is flawed and also when the horse’s motivation to respond to a cue from the rider competes with other motivations (McGreevy and McLean, 2010). Some equestrian sports, particularly group situations such as hunting, involve some manifestation of the flight response. The presence of pain, discomfort or confusion in the horse may also induce the flight response (Casey, 2007). Differentiation between the causes may elude the rider, but all of them are likely to result in reduced responsiveness to bit pressure. For the rider to continue participating safely and effectively in their chosen sport, they must adopt some remedial measures. It is likely that the range of bits and nosebands available for purchase are a reflection of the riders’ requirement to enlist more powerful means of control over horses as a result of training deficits (McLean and McGreevy, 2010b).

**Pressure and force measurement in animals - Background**

Given that the use of pressure, through the form of negative reinforcement, forms the basis of the majority of horse-human interactions during equitation (McLean, 2005, McGreevy and McLean, 2010), measurement of pressures applied by the rider against various equine anatomical locations is an area of interest to equitation scientists (Holmes and Jeffcott, 2010, McGreevy, 2011). Measurement of pressure exerted against tissue has been used in both medicine and biomedical engineering to quantify various contact interactions between living tissue and inanimate surfaces, such as bandages, tourniquets (Casey et al., 2011) and support devices such as bedding and wheelchairs (Shelton et al., 1998). Pressure measurement is important because excess pressure has been shown to cause tissue and neuron damage (Klenerman, 1980, Worland et al., 1997, McEwen and Casey, 2009).

Pressure is defined as the average force per unit area (Casey et al., 2011). One of the challenges inherent in measuring tissue pressure includes the contour of the surface against which pressure is being measured. Convexity or concavity of the surface renders pressure measurement more difficult as shear forces complicate output (De Cocq et al., 2010a). Deformation of the tissue surface by the device used to measure pressure is
another complication, leading to a requirement for the pressure measuring device to conform, as far as possible, to the surface contour of the tissue subjected to pressure (O'Brien and Casey, 2002).

A more widely used approach within equitation science of estimating pressures exerted against the horse’s oral tissues by the bit has been the use of strain gauges to measure force applied via reins or other straps (Heleski et al., 2009, Clayton et al., 2011, Randle and McGreevy, 2013), discussed below. While force measurement does not allow direct inference of pressure exerted against tissues, it does provide a comparative measure which has been used to examine the relative impact of different variables such as type of bit (Potz et al., 2014), level of noseband tightness (Pospisil et al., 2014), type of rein (Randle et al., 2011) and the force required to elicit a certain behaviour or head position (Hawson et al., 2014a, Christensen et al., 2011). For example, a comparison between the amount of force required to elicit a particular head and neck position in horses, at two different levels of noseband tightness has been used to suggest that the horse is more sensitive to bit pressure when the noseband is at a particular tightness level (Pospisil et al., 2014).

The operating principle of a strain gauge is that all electrically conductive materials undergo a change in electrical resistance when deformed through stretching. By increasing the length of a material through stretch, the resultant reduction in cross-sectional area results in an increase in resistance of that material (Ó Muiris, 2014). Adaptation of the strain gauge to allow insertion into the rein has enabled rein tension studies to investigate a range of factors (Heleski et al., 2009, Manfredi et al., 2009, Clayton et al., 2011, Randle et al., 2011, Randle and McGreevy, 2013). While the rein tension studies illustrate the ranges of force exerted between the bit and the rider’s hand during a range of activities, findings fall short of clarifying exact pressure levels exerted against oral tissues, as the bit action, shape and dimensions and position in the mouth will influence the range and distribution of pressures.

An alternative approach to force measurement is the use of pressure sensors, devices which convert applied pressure into a measurable electric signal. The pressure sensor is composed of two principal components: a flexible material which will deform when placed under pressure and an electrical component which measures the level of deformation, converting the measure into an electric signal which can then be recorded (Ó Muiris, 2014). Strain gauges are used in pressure sensors, to measure the degree of
deformation, consequent on pressure. While pressure sensors have been in use in a variety of areas such as dentistry (Maness and Podoloff, 1989), orthotics (Zammit et al., 2010) and orthopaedics (DeMarco et al., 2000), use within equitation science is a relatively recent development. Placement of arrays of sensors between interfacing surfaces, such as beneath the saddle or the riders leg allow direct pressure measurement to be carried out (De Cocq et al., 2006, Greve and Dyson, 2013, Hawson et al., 2013). Challenges faced by researchers in using pressure sensors in this way include continued functionality within challenging environments. Moisture diminishes effectiveness (Jansson et al., 2013) and signal loss due to malfunction of unknown origin can confound findings following considerable expense and labour of setting up a clinical trial (Hawson et al., 2013). Calibration of sensors has also been described as a challenge during use of some pressure sensor systems (Hawson, 2014b).

An alternative approach is the use of single pressure sensors at chosen sites of suspected significant pressures. Similar challenges remain with regard to exposure of susceptible technology to an environment which is potentially hostile in terms of moisture and temperature. In addition, the required range of calibration of sensors may be difficult to predict when preparing for measurement of previously unquantified pressure levels. On the other hand, use of single sensors does not incur similar levels of financial outlay as the use of multiple sensors and can allow placement at very precise locations, with minimal intrusiveness at the tissue surface interface, due to the dimensions, with sensor height as little as 2.8mm in some cases (Casey et al., 2011).

**Strain gauge use to measure force in equitation science**

Pressure and force measurements on horses in the past have mainly followed two distinct routes. The development of purpose-built units such as the Rein Check™ (Crafted Technology, NSW, Australia) and the MLP-100™ (Transducer Technologies, Temecula, CA, USA) which integrate strain gauge units into left and right reins has led to their use in a range of studies investigating rein tension (Heleski et al., 2009, Clayton et al., 2011, Randle et al., 2011). Direct pressure measurement using pressure sensors has been carried out primarily in investigating saddle pressures (De Cocq et al., 2006, Byström et al., 2010, Clayton et al., 2010) but also pressures exerted by the riders leg (Hawson et al., 2013).
Rein tension studies

Measurement of rein tension at different gaits has been carried out by a number of researchers, with a range of findings. An early study, carried out by Clayton et al (2005), using a strain gauge inserted into the left rein only, using one horse and rider, reported ranges of rein tension of 4-43 N at walk; 19-51 N at trot and 21-104 N at canter. The higher level of rein tension at higher gaits recorded in this study is consistent with several other studies. Warren – Smith et al (2007) recorded rein tension in 22 horses being long-reined and also ridden in walk and trot, and found median rein tension of 5.1N at walk compared to 6.3N at trot. In a study using 8 professional riders, each riding 3 familiar horses, Eisersio et al (2015) recorded median rein tensions of 12N in both reins at walk, 14-19 N in left/right reins at trot and 13-24 N in left/right reins at canter. While force measurements cannot be directly converted to pressure (as pressure equals force divided by the area over which the force is distributed), 9.81 N equals one Kg of force.

It is suggested that movement of the head and neck during higher gaits may contribute to variation in rein tension measurements independent of rider input. The extent of variation contributed by the rider was suggested to be 26% compared to 21% of variation attributed to the horse by Egenvall et al, 2015 following measurement of rein tension patterns and variations at canter by 8 professional riders, each riding 3 familiar horses. This suggestion was made after taking into account significant variation in left versus right rein tensions among riders, and the lack of significance in the effects of horse laterality. The contribution of both horse and rider movements to rein tension measurement output increases the challenge of meaningful analysis of results from rein tension gauge studies.

Addressing this issue, the effect of horse input was investigated by Clayton et al (2011) where rein tensions were measured from 8 horses –with the horses trotted in hand, and the reins attached, at 3 different lengths, to the top ring on a surcingle. Minimal, maximal and mean rein tension increased significantly with each reduction in rein length, and the output showed peaks corresponding to each diagonal stance phase at trot. These peaks were also seen in an earlier study by Clayton et al (2005), where a single strain gauge inserted into the left rein recorded 2 peaks per stride in walk and trot and 1 peak per stride in canter. These peaks, attributed to the downward head movement during the stance phase of each stride result in rein tension peaks not attributed to rider action. Horse-related input was also proposed by Egenvall et al (2015) to contribute
substantially to the force measured by the rein tension gauge during peaks of pressure, and less to baseline levels. The pressure peaks identified by Clayton et al. (2005) were also described by Egenvall et al. (2015) with maximum mean tension occurring during the stance phase of the leading foreleg in canter, and minimal rein tension occurring close to the suspension phase of the canter. However, Egenvall found rider-specific differences in the timing of left and right-rein peaks, suggesting significant variation in rider input, even among experienced riders.

Elimination of horse effect has been addressed by measuring rein tensions exerted by riders sitting on a dummy horse or simulator (Randle et al., 2011, Randle and Wright, 2013, Hawson et al., 2014a). Hawson et al. (2014a) investigated the strength of rein cue used to elicit a walk–halt transition, by 12 riders, using a dummy horse. The mean left rein tension used was 8.58 N with a range of 3.14-28.92 N, and this was significantly greater than the right rein tension (mean tension, 6.24 N; standard deviation = 4.1; range = 2.27-16.17 N). Randle and Wright (2013) also used a static box fitted with reins in place of a live horse to investigate perceived severity of different bit types, by asking 10 riders to deliver a cue to elicit a walk-halt transition while the ‘dummy’ horse wore 4 different bit types, or a bitless bridle. Baseline rein tensions were also measured. No significant difference between left and right rein tensions were found, but the type of bit had a significant effect on both the baseline tension and the tension applied to elicit the halt, with significantly lower mean rein tensions (+ SD) applied during use of the gag (1.98 ± 0.52 N) and pelham bits (2.04 ± 0.64 N) and the bitless bridle (1.92 ± 0.22 N), compared to a single jointed snaffle and a double jointed snaffle bit (2.29 ± 1.11 N and 2.34 ± 1.09 N respectively). These findings are of interest as they suggest that riders perceive a bitless bridle as being as severe on the horse as the pelham and gag bits, despite the fact that they are marketed as a kinder alternative to bitted bridles. In a separate study, Randle et al., (2011) also investigated the effect of rein type on rein tension, using 13 riders and a static horse. The lowest tension found was when riders were using narrow or webbing reins and the highest rein tensions with laced leather reins. Eleven out of the 13 riders exerted higher levels of right rein tension irrespective of rein type being used. Mean rein tensions measured (+ SD) were 2.77 ± 1.51 N. These studies use rein tension to gain valuable insights into rider behaviour independent of horse input. Rein tensions measured during these studies tended to be lower than those measured during studies carried out on live horse, possibly due to the horse effect being eliminated. However the extent of the impact of such an artificial scenario on rider
behaviour, without the visual or proprioceptive feedback likely to follow administration of cues on a live horse is unknown. This renders meaningful interpretation of the findings difficult (Hawson et al., In press).

While rein tension studies can provide some insight into the ranges of force in use in equitation, they do not inform us of the horse’s perception of the resultant intra-oral bit pressure. In an effort to investigate this, Christensen et al (2011) recorded the amount of rein tension voluntarily taken up by horses during a trial run over 3 days, in order to gain access to a food reward. Mean rein tension was found to be 10.2 N on the first trial, but decreased significantly following the initial trial (mean rein tension levels: Day 2: 6.0 N, Day 3: 5.7 N), as horses declined to exert a similar level of tension on consecutive trials. This would suggest that habituation to bit pressure may not happen and that bit pressures in excess of 11 N were sufficiently aversive to the horses that motivation to avoid such pressures exceeded motivation to access the food reward.

Neurophysiological research indicates that exposure to repeated mechanical stimulation of skin in fact increases the perception of pain (Andrew and Greenspan, 1999), causing sensitisation rather than resulting in desensitisation. In a study conducted to investigate the ability of humans to perceive sharpness, pressure and to identify the pressure levels at which pressure elicited cutaneous pain, participants were subjected to probes of varying dimensions pressed against the skin. With the smallest probe used (area of probe tip: 0.01 mm²), sharpness was perceived almost immediately pressure was applied, i.e. the sharpness threshold was very close to the pressure threshold. An unexpected finding was that the larger sized probe (5.0 mm²) began to elicit a perception of sharp pain as force increased, and that the diameter of the probe influenced perception more than the area in contact with the skin. Some degree of desensitisation to pressure was shown to occur during this study, with higher levels of pressure required to reach pressure threshold but only in 27% of subjects (n=24) tested over 15 days, while only 6% showed an increased pressure or sharpness threshold over the same period, indicating that 94% of subjects (n=24) continued to experience similar sensations of pressure on repeated exposure (Greenspan and McGillis, 1994). Christensen’s findings in horses may be explained by similar neurophysiological reactions to those found in the human studies alluded to.
Concern has been expressed in recent years about the apparent usage of tighter nosebands than in the past (McLean and McGreevy, 2010b). However, the benefit of a tighter noseband, and how it might benefit the rider is poorly understood. In an effort to identify the effect of noseband pressure on reaction to bit pressure, two separate studies were carried out, one on the ridden horse (Randle and McGreevy, 2013) and one without a rider on a treadmill (Pospisil et al., 2014). In the first (Randle and McGreevy, 2013), six horses, ridden with the noseband at the normal tightness level but also at one hole looser and one hole tighter, required significantly higher levels of rein tension when the noseband was loosened by a hole, to elicit a halt. Lower levels (though not significantly so) of rein tension were required for a halt when the noseband was tightened one hole more than the normal. No significant difference was found between left and right rein tensions. This is the first study to identify a significant effect of noseband tightness on the horse’s response to bit pressure. In a study addressing the same question, using a different approach, Pospisil et al (2014) measured the amount of rein tension required to elicit a particular head position (with the head held so as the nasal plane was vertical) on 10 horses, with the noseband at a standard fitting (two fingers) and ‘tight’ (no further details of how tight the noseband was were given). Measurements were taken on a treadmill, with reins attached to a surcingle. Significantly higher mean rein tension was required to elicit the desired head position when the noseband was at the looser fitting (maximum rein tension at walk: 8.6 ± 0.9 N) than at the tighter fitting (6.7 ± 0.95 N). (The authors do not specify whether the results cited describe standard deviation or standard error of the mean). This was also found to be the case at trot (7.2 ± 0.95 N versus 5.96 ± 0.9 N). These studies throw some light on the reason for the apparent popularity of the use of tight nosebands among riders but also indicate the importance of the use of standardised noseband fitting during future rein tension studies to facilitate comparative analysis of findings between studies.

Lack of responsiveness to bit pressure frequently results in a rider using a different bit type in order to achieve improved responses (Kapitzke, 2004, McGreevy and McLean, 2010). However little is known about the mode of action of different bit types. A similar approach to that taken by Pospisil et al (2014) was used by Potz et al (2014) to investigate the effect of type of bit on the level of rein tension required to achieve a vertical head position (comparing a double jointed snaffle with a mullen mouth snaffle). Ten horses wearing side reins were assessed at walk and trot. Lower maximum rein tension (15.7 ± 1.9 N) was required with the mullen mouth snaffle bit to elicit the
desired response compared to the snaffle bit (16 ± 1.9 N). Similarly at trot the mullen mouth snaffle (10.4 ± 1.8 N) was associated with lower maximum rein tension than the double-jointed snaffle (12.7 ± 2.0 N) to achieve the desired head position. The authors do not specify whether the results cited describe standard deviation or standard error of the mean. The lower rein tension found at trot compared to walk is unusual and differs from the findings of other studies (Clayton et al., 2005, Warren-Smith et al., 2007, Eisersiö et al., 2015) in this regard. While evidence regarding the action of different bit types in the equine mouth is limited to a small number of studies using radiographic (Manfredi et al., 2005) and fluoroscopic imaging (Clayton, 1985, Manfredi et al., 2009), the use of rein tension in this way is an innovative approach to identifying motivation levels of the horse to yield to pressure exerted by different types of bit.

**Challenges associated with the use of rein tension gauges**

Advances are being made with regard to identifying rein tension ranges, patterns and the variables influencing tension exerted by riders. However, conflicting findings exist with regard to left versus right rein tension pressures. Similar left and right rein tensions were found in studies by Warren-Smith et al (2007), Edwards and Randle (2010) and Randle et al, (2013), while greater left rein tension was found by Kuhnke et al (2010) and Hawson et al (2014a). Greater right rein tension was found by Randle et al (2011) and Eisersiö et al, (2015). Significant variation in left versus right rein tensions and also within-stride variations among individual riders was found by Egenvall et al, (2015) among 8 professional riders. Data were collected while each rode 3 familiar horses at canter. Inconsistency between perceived and actual rein pressure exerted by riders was identified by Randle and Wright, (2013). All of the above findings indicate that further research is required to provide clarity regarding horse rider interaction. In addition, lack of consistency in previous studies regarding weight of device, calibration, bit type and fitting, units used and conditions under which measurements were generated confound comparison between existing findings (Hawson et al., In press). However, recommendations regarding standardisation of methodology based on a review of rein tension studies carried out to date have been made by Hawson et al (In press) and should help to guide future research in this area.
Pressure sensor use in equitation science

The use of pressure sensors in equitation science has mainly been in the area of pressure measurement beneath saddles although a more recent development has been in the measurement of pressures used in delivering leg cues by riders (De Cocq et al., 2010b, Hawson et al., 2013). The availability of integrated arrays of sensors allows the production of pressure maps indicating the levels of pressure over a dispersed area (Ashruf, 2002, Greve and Dyson, 2013). As back pain is a common problem thought to affect up to 25% of dressage horses (Murray et al., 2010) the role of saddle pressure is of interest as a possible aetiological factor. This has led to the use of pressure sensors to investigate a range of variables thought to influence saddle fit and pressures exerted by the rider.

Saddle pressure measurement studies

Meschan et al (2007) identified a link between width of the saddle and occurrence of potentially pathological levels of pressure beneath the saddle. Wider and narrower saddles resulted in significantly higher pressures being exerted by the saddle during walk and trot on 19 horses ridden on a treadmill. Mean and standard deviation of pressures exerted by the central section of the best fitting saddle while being ridden at walk by an 80 kg rider were 0.65 ± 0.10 N/cm² and 0.63 ± 0.11 N/cm² at trot. De Cocq et al (2004) measured the forces exerted by 12 riders, each riding their own horse, at the gaits of walk, trot and canter. The maximum overall force increased with increase in gait (12.1 ± 1.2 N/kg SD at walk, 24.3 ± 4.6 N/kg SD at trot and 27.2 ± 4.4 N/kg SD at canter).

Investigations into the effect of adding a saddle blanket beneath the saddle on sub-saddle pressures have been carried out. In a comparison of four different saddle pads, made of gel, leather, foam and reindeer fur, Kotschwar et al (2010) found that the reindeer fur pad reduced the maximum overall force exerted by the saddle from 1005 N to 796 N at walk and from 1650 N to 1437 N at trot. None of the other 3 saddle pads had a similar effect. This follows an earlier study by Hofmann et al (2006) who measured sub-saddle pressures on 10 horses wearing saddle pads of either rubber foam, leather, gel or reindeer fur, resulting in a similar outcome, where the maximum overall force was lowest when the reindeer fur pad was in use, and the maximum overall force in each case was reduced by the presence of a saddle pad. The material used to fill the
cushioning saddle pads, traditionally wool flocking, was compared by Byström et al (2010) to foam, as an alternative, to investigate distribution of pressure under the saddle of 6 horses, ridden by 3 riders, at trot and canter. The effect of position of girth attachment to the saddle was also investigated in the same study, comparing traditional girth attachment location with a V-system, where the girth was attached to 2 points, further rostral and caudal to the standard girth attachment point. With regard to both variables, the area under the saddle exposed to >11 kPa was lower using the traditional approach, flocking material (wool) and normal location of girth attachment. The threshold level of pressure for the stimulation of back pain was identified by Byström et al during this study as 11 kPa.

The effect of saddle type - comparing a traditional saddle with a treeless saddle, was investigated by Belock et al (2012). Comparison of total force, area of saddle contact, maximal pressure and area with mean pressure >11 kPa was carried out on data collected from 8 horses, ridden at sitting trot by one rider. While the treeless saddle is thought to give a better fit, the output showed lower total force, area of saddle contact, maximal pressure and area with mean pressure >11 kPa beneath the traditional saddle. Similarly, Clayton et al (2013) found that the pressure exerted by a bareback rider is higher, and concentrated over a smaller area than with a rider using a saddle. Clayton also investigated the influence of the shape of horse rugs on the levels of pressure exerted on sub-blanket tissues (Clayton et al., 2010). Pressures were measured on either side of the withers and over the shoulders. Comparison of 3 different rugs worn by 14 horses while walking and standing was carried out by measuring pressure for 5 seconds. A rug with a cut-away section over the prominence of the withers exerted pressures greater than 4 kPa over significantly less area than the other rug designs, one with a straight cut edge, the other with an insert over the withers. The minimal pressure required to impair capillary blood flow is 4 kPa. Pressures in excess of this, exerted on skin, may impair capillary blood flow to tissues beneath the skin, impairing oxygen supply and resulting in tissue damage. Taking into account the weight of each blanket, forces of 5.14 ± 2.78 N/Kg SD were measured at walk with the straight-cut blanket compared to 3.41 ± 1.85 N/Kg SD with the cutback rug, and 2.69 ± 1.60 N/Kg SD with the rug with the V-shaped insert. Common practice in the equestrian world is to layer more than one rug on horses during colder / wetter seasons – and in some cases, throughout the year. The forces exerted in such situations are likely to be substantial, and sustained over lengthy periods, unlike the pressures exerted by riding related
equipment. These studies begin to throw light on the merit or otherwise of a range of common practices, many of which are carried out in an effort to maintain good welfare – but may, in the light of recent findings, have the opposite effect.

**Use of pressure sensors to measure rider cues**

The pressures exerted by riders in asking for specific responses have been investigated using pressure sensors both on the ridden horse (De Cocq et al., 2010b) and on a dummy horse (Hawson et al., 2013). De Cocq et al measured the sub saddle and leg pressures exerted by 9 riders, using 11 horses, while they rode through the lateral movements of shoulder-in and travers in trot, comparing these forces with trotting straight ahead. Mean saddle force was lower in trotting straight (671 ± 143 N SD) compared to either shoulder-in (707 ± 150 N SD) or travers (726 ± 165 N SD). While the sub-saddle pressures showed a regular pattern, leg pressures were irregular, with high variations in leg forces and also variations in peak frequencies. Hawson et al (2013) measured leg force applied by 12 riders on a dummy horse as they gave the leg cue to ask for a transition from walk to trot and also found irregularities in leg pressure output, where the median cue pressure was lower (at 6.1 N) than resting calf pressure (18.7 N). This was an unexpected outcome, with the median cue pressure 66% lower than the median pressure exerted by the resting leg. Similarly, heel resting contact pressure had a median value of 0.29 N/cm² while the median heel contact pressure while applying a cue was 0.05 N/cm². The mean duration for application of cue pressure also showed substantial variation (mean 3.92 ± 5.36 seconds SD). Two riders in particular showed variation from the remainder of the riders. Removal of those scores reduced the mean cue duration to 1.79 ± 0.89 seconds SD. These studies show that the analysis of rider pressures is likely to be complex, with early research indicating unexpected patterns.

Comparison between pressure and force measurements described above are difficult. Saddle pressure measurements represent the weight of the saddle, weight and movements of the rider, and may be influenced by conformation, soundness, saddle type, flocking type and other variables. Leg cues, by comparison, measure the effects of rider position, muscle tone, voluntary and involuntary leg movements. Size and shape of an applied pressure were found by Greenspan and McGillis (1991) to be influential in determining thresholds for perception of pressure, pain and sharpness in their studies on
perception of pain in humans, and suggested that pressure (force/area) measurements alone were not sufficient to describe the animal’s perception of pressure / pain. However, the studies described begin to give an idea of the ranges of force and pressures exerted during day to day riding activities.

**Challenges associated with the use of pressure sensors**

As with the use of strain gauges, pressure sensor use in equitation science faces a number of challenges. Lack of consistency in output between trials (De Cocq et al., 2006), malfunctioning of sensors resulting in loss of data (De Cocq et al., 2010a), underestimation of shear forces (Clayton et al., 2013, Greve and Dyson, 2013), production of multi-dimensional data, incorporating input from both horse and rider and the challenges of analysis (Belock et al., 2012) mean that output does not yet clearly answer many of the questions being asked (Holmes and Jeffcott, 2010). In addition, practical challenges include keeping the sensor mat in exactly the same position during equine locomotion (Belock et al., 2012) and accounting for normal versus non-normal equine locomotory patterns (Byström et al., 2011). The movement of the equine back during gaits differs, and is also influenced by the presence of any gait abnormality such as lameness. Elimination of lameness through diagnostic analgesia resulted in altered saddle pressure measurements (Byström et al., 2011) as did rider position (De Cocq et al., 2009, Peham et al., 2010). Rider experience is also thought to impact on saddle pressure as more experienced riders synchronise their movements to a greater degree with equine locomotory pattern (Lagarde et al., 2005). Clearly, application of technology to investigation of sub-saddle pressures has raised many questions but has led the way in terms of beginning to measure pressures applied by riders and equipment.

**Noseband as tourniquet: Could a tight noseband achieve a similar effect to a tourniquet?**

Traditionally, nosebands have been fitted loosely enough to slide two fingers under the noseband when closed (Klimke, 1994). Development of the Swedish, or crank noseband, with a leveraged tightening mechanism allows the noseband to be tightened to a high degree more easily. Evidence has been found of possible impairment of vascular perfusion of the skin close to the noseband, with lower skin temperatures detected using thermography on 5 horses whose nosebands were tightened to a high...
level of tightness, compared to baseline levels (McGreevy et al., 2012). In an investigation into the impact of tight nosebands on performance in horses, the level of pressures under the section of a crank noseband covering the dorsal aspect of the horses face, while trotting in a straight line were investigated by placing pressure mats beneath the nosebands of 10 horses (Murray et al., 2015). Pressure at the poll was also measured, as were the gait characteristics of the horses. The study was carried out as part of a two-stage process, whereby a bridle, manufactured in such a way as to redistribute pressure from areas of maximum pressures, was designed, based on the findings of the preliminary sub-bridle pressures. The locations of highest pressure peaks are described as occurring to the left and right of the nasal bone, with maximum pressures of $64.2 \pm 19.6$ N SD occurring beneath the noseband, and peaks of $46.5 \pm 21.4$ N SD occurring beneath the headpiece of the bridle. Pressure peaks beneath the headpiece occurred at the approximate location of the wings of the atlas, ventral to the ear base on either side. A significant reduction in pressure peaks in both locations was found on repeated measuring with the newly designed bridle (noseband: $41.2 \pm 11.2$ N SD, headpiece: $24.5 \pm 5.8$ N SD). In addition, increased carpal and tarsal flexion angles were measured during trot while the newly designed bridle was worn. This was suggested to be as a result of greater freedom for the horse to use the head and neck for balance, and for the muscles to work more effectively, upon removal of the constraining pressures of the traditional bridle. The new bridle redistributed pressure by placing padding either side of the previous locations of peak pressures, and narrowed sections of the headpiece to reduce pressure on anatomical structures (wings of the atlas, base of the ears). The degree of tightness of the noseband of either bridle during data collection was not specified in this study, with the method of fitting described as ‘standard’. The newly designed bridle also incorporated a crank closing method to the new noseband, suggesting that it is designed to offer the same general effect on mouth opening and response to bit pressure as the traditional crank noseband.

Apart from these studies, very little research has been carried out to investigate possible pressure levels or adverse effects related to tight nosebands. Following on from the high levels of pressure exerted against sub-noseband tissues reported by Murray et al (2015), a review of the recorded effects on tissue of tourniquet pressures may help identify some possible consequences of excessively tightened nosebands on horses.
Tourniquet use in medicine
The tourniquet is a restrictive band which is tightened around a part of the body to restrict bloodflow to the area beyond the tourniquet during surgery (Worland et al, 1997). Used mainly to restrict bloodflow to the extremities (arms and legs), tourniquets are also used to prevent blood loss following injuries, such as in war situations where rapid blood loss follows trauma to arms and legs (McEwan and Casey, 2009). The effectiveness of the tourniquet in occluding blood vessels is influenced by the diameter of the tourniquet and by the tissue types underlying the tourniquet (Noordin et al, 2009). Tissues lying directly beneath the tourniquet are affected to the greatest degree by the pressure exerted by the tourniquet, while tissues lying deeper beneath the surface are subjected to lower levels of pressure (Shaw and Murray, 1982).

Adverse effects of tourniquet use
While tourniquets play a vital role in medicine and surgery, compression of tissue can result in tissue damage (Noordin et al, 2009). The findings of a range of studies have resulted in recommendations regarding the optimal tensions, duration of use and width of tourniquet, in order to minimize the deleterious effects of tourniquet usage. Adverse effects associated with tourniquet use include nerve and soft tissue damage due both to direct pressure exerted by the tourniquet but also due to ischemia (disruption of blood supply) of tissues distal to the tourniquet, and pain, both during and following tourniquet use.

It has been suggested by Klenerman (1980) that direct tourniquet pressure is the main factor responsible for nerve palsies and muscle disability. Neuron damage (increased permeability of intra-neural blood vessels and consequent neural oedema) was found to occur at compression of 50mmHg over two hours, with greater levels of damage at higher pressures (Rydevik and Lundborg, 1977). The consequence of neuron compression, particularly beneath and near the edges of the tourniquet cuff has been shown to include disruption of the node of Ranvier and damage to the myelin sheath surrounding the neuronal axis on either side of the node, resulting in disturbances to nerve conduction and subsequent muscle function (Ochoa et al, 1972). In a study investigating nerve damage following knee surgery, 71% of patients on whom a tourniquet had been used during the surgical procedure showed electromyographic and functional evidence of denervation compared to a control group on whom no tourniquet
was used during the same surgical procedure (Dobner and Nitz, 1982). Similarly, Rorabeck & Kennedy (1980) found some degree of impaired sciatic function in dogs with every tourniquet application. Kokki et al (1998) described the metabolic effects on tissues deprived of oxygen for a period of time through tourniquet compression, including depletion of oxygen stores after 20-30 mins, post ischemic hyperaemia and subsequent release of breakdown products that accumulate in ischemic tissues. Metabolic indicators of muscle damage were more pronounced with longer tourniquet time (Kokki et al., 1998).

Muscle damage beneath and also distal to the point of application of the tourniquet was found by Pedowitz et al (1991) after two hours of tourniquet pressures of 200 and 350mmHg. Compression of in vitro muscle cells results in cell deformity and death after compression at various pressure levels within 1 – 2 hours (Breuls et al., 2003). Signs of regenerative changes in muscle cells, including macrophage infiltration were found in muscle cells 24 hours following application of pressures ranging from 10 – 250 kPa or 70 – 1875 mmHg (Bosboom et al., 2001).

**Tourniquet-related pain**

In a study investigating tourniquet-induced pain, Worland et al (1997) looked at the use of different tourniquet pressures in patients undergoing bilateral knee replacement surgery and who were subjected to the use of a tourniquet for 22 – 23 minutes. Patients were 21 times more likely to experience pain the day after wearing the tourniquet at 350 mmHg than at 230 mmHg. The pain reported by human subjects following tourniquet application follows a pattern reported by several investigators, and has been described as occurring in different stages. Estebe et al (2000) described the stages of pain as occurring initially directly under the tourniquet, presumed to be caused by direct pressure. Within 2-3 minutes a tingling sensation distal to the tourniquet occurs (e.g., in the hand, where the tourniquet was applied to the mid upper arm), increases progressively and after 10-15 minutes is replaced by hypoesthesia (numbness), while the pain directly beneath the tourniquet increases to a higher level after approximately the same time span. Twenty minutes following tourniquet application the hand is completely anaesthetised and paralysed to wrist level.

Release of the tourniquet resulted in relief within seconds in the above study but this was replaced within a minute by a warming sensation which progressed to a burning or
aching sensation in the limb. As blood flow returned to the limb, a tickling feeling progressed to a throbbing sensation which was sensitive to touch and was accompanied by muscle cramps. The pain subsided within approximately 7 minutes. The pain reported by subjects is thought to be multifactorial and has been attributed to skin, muscle and nerve pathology.

While patients undergoing surgery are usually under general or local anaesthesia, an investigation into tourniquet – induced pain, subjecting 11 conscious healthy adult volunteers to thigh tourniquet pressures of 300 and 400 mmHg (Hagenouw et al., 1986) resulted in half of the experiments being terminated due to intolerable pain at the site of the tourniquet, and other related experiments being terminated due to pain distal to the tourniquet (in the calf or throughout the leg). Levy et al suggest using the lowest possible tourniquet pressure to maintain arterial closure in upper limb surgery (Levy et al., 1993), usually a tourniquet pressure of 100 mmHg plus systolic blood pressure (average 230 mmHg) with reported use of tourniquet pressure up to but not exceeding 350 mmHg as being required on patients of greater thigh circumference (Worland et al., 1997).

**Anatomy of the equine head at the location of the noseband**

The research described suggests that pressure exerted by nosebands on neurons, muscle and other tissue may result in damage to these tissues. Tissue type is an important determinant influencing the likelihood of damage caused by pressure exerted. Soft tissues (skin, muscle, nerves) are more susceptible to compression damage than bone. The equine muzzle at the level of the noseband has bony structures ventrally (left and right mandibular rami) and dorsally (nasal bone) but a significant area laterally between these bony areas comprises soft tissue, including skin and the underlying muscles (levator nasolabialis, levator labii superioris, buccinator muscle, levator labii ferioris, zygomaticus and caninus). Two important nerves provide most of the sensory and motor innervation for the areas of the horse’s head that lie immediately beneath or distal to the noseband. The facial muscles responsible for facial expression are innervated by branches of the facial nerve which run superficially forward from the cheek area (across the surface of the buccinator muscle) towards the lips and nostrils. Facial paralysis is a regular sequel to trauma of this nerve including damage caused by pressure if insufficient padding is used during surgery to support this area and protect it from the
resting weight of the anaesthetised horse’s head (Orsini and Sack, 2003). The infraorbital nerve emerges from the infraorbital foramen and provides sensory innervations to the upper cheek teeth, gums, nose and upper lip. Both of these nerve tracts run superficially on the face, directly beneath where a cavesson noseband will sit.

If the pressures exerted by a noseband result in neural damage, the possible cumulative effects include denervation, and subsequent desensitization of an area, or inflammatory change, such as trigeminal neuritis. The consequence of desensitization in equitation may be reduced sensitivity to pressures and subsequent reduced control and increased safety issues (McLean and McGreevy, 2010b). Trigeminal neuritis (inflammation of the trigeminal nerve), is implicated in headshaking in horses (Newton et al., 2000, Roberts et al., 2013). The facial nerve is a branch of the trigeminal nerve, and runs directly beneath the position of the noseband.

**Possible effects of tight nosebands**

In an investigation into the effects of tight nosebands on behaviour, Fenner et al (2016) investigated the effects of a crank noseband, worn with a double bridle, and fastened to four levels of tightness (unfastened, loose, moderately tight and very tight) on behaviour, eye temperature and cardiac responses. Treatments (different noseband tightness fittings) were continued for 10 minutes. Significant cardiac responses (reduced heart rate variability and increased heart rate) were associated with the very tight noseband fitting, suggesting a stress response. This finding was supported by a significant increase in eye temperature. Significantly reduced frequencies of swallowing, chewing and yawning compared to baseline levels occurred during the very tight noseband fitting, with a significant increase in these behaviours over baseline levels on removal of the noseband, suggesting a post-inhibitory rebound of the behaviours. While this study indicates a cardiac and behavioural response to tight nosebands, insufficient research into sub-noseband pressures at tightness levels currently in use by riders has been carried out to allow direct inference of probable sub-noseband tissue damage based on tourniquet related research findings. The findings by Murray et al (2015) of peaks of pressure as high as 83.8 N suggest that the possibility of tissue damage exists, but direct comparison of tourniquet pressures (measured in mmHg) is not possible with measures of force (measured in N). As pressure is the force per unit area, force measurements alone cannot be compared with pressure.
measurements such as those derived from tourniquet-related research. Further research into sustained pressures exerted by nosebands, over specified areas, as determined by noseband width, would produce measures which would allow comparative analysis with the tourniquet related research described.

**Regulations governing bit and noseband use in competition**

The type of equipment used in equestrian competition is controlled by the governing bodies overseeing the various equestrian sports. Show jumping, horse trials (eventing), dressage and a number of less popular disciplines such as endurance riding, polo and Western riding have dedicated governing bodies, which govern all aspects of the sports, organize competition structures within each country and in turn are governed by an international body, the Federation Equestre Internationale (FEI). Each country has a National Federation which oversees the individual governing bodies for each sport within the country, and which is a member of the FEI. International competition in each discipline is governed by the FEI, with in excess of 3500 competitions organized by the FEI annually (Murray et al, 2013).

**Regulations and Horse Welfare**

The FEI Code of conduct for the Horse mentions horse welfare in several places. Those involved in international equestrian sport are requested to

> ‘adhere to the FEI’s Code of Conduct and to acknowledge and accept that at all times the welfare of the horse must be paramount and must never be subordinated to competitive or commercial influences’.

It also states that:

> ‘At all stages during the preparation and training of competition horses, welfare must take precedence over all other demands’ and that: 'Tack must be designed and fitted to avoid the risk of pain or injury’. (FEI, 2011)

The challenge of deciding which pieces of equipment are or are not of such design in the absence of relevant research is significant. A further reference to protecting the welfare of the horse with regard to excessive tightness of nosebands is touched on in FEI Dressage Regulation 38A: ‘*Neither a cavesson noseband nor a curb chain may*
ever be as tightly fixed so as to harm the horse’. Dressage Ireland rules state that ‘Nosebands must not cause discomfort’. However, regulation of degree of tightness of noseband or curb chain is not a routine part of the FEI or national associations tack inspections carried out on competing horses.

Permitted bits and nosebands in show jumping
Regulations governing show jumping place fewer restrictions on the type of bit or noseband used in competition in comparison with other popular equestrian disciplines (Table 1).

FEI Regulations
The FEI place no restrictions on bits used in show jumping competition. While all bits are also allowed in pony competitions some specifications are made:

1) Double bridles are not permitted
2) The minimum diameter of the bit shall be 10mm.
3) All pelhams must be used with a single rein.
4) No hackamore may be used in combination with a bit.

National Federation Regulations
Show jumping Ireland (SJI), the show jumping governing body in Ireland also permits all bits, with the exception of one particular snaffle bit, the magennis snaffle, which is not permitted in pony competitions. This bit has a squared mouthpiece which is thought to have the potential to create peaks of pressure within the oral cavity where the edges of the mouthpiece come into contact with oral structures. No mention of nosebands is made in the regulations.

Riding Club and Pony Club regulations
The show jumping regulations of the Association of Irish Riding Clubs specify the use of either the snaffle bridle, pelham bridle or double bridle in show jumping competitions, with riders competing in the lowest two grades of competition (Primary, Advanced Primary) prohibited from using the double bridle (AIRC, 2012). Similarly, the Irish Pony Club permit only the snaffle, pelham and double bridle (double bridle use
is limited to intermediate level and above) during show jumping (Table 1). All noseband types are permitted in both riding club and pony club show jumping – but use of a noseband is not compulsory in either.

Table 1: Bit / bridle types specified for use in competition by governing bodies responsible for regulating show jumping competitions in Ireland and at international level.

<table>
<thead>
<tr>
<th>Permitted Bits</th>
<th>FEI Horses</th>
<th>FEI Ponies</th>
<th>SJI</th>
<th>AIRC</th>
<th>IPC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Snaffle</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes**</td>
</tr>
<tr>
<td>Pelham</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Double bridle</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes*</td>
<td>Yes</td>
</tr>
</tbody>
</table>

*Double bridle not permitted at Primary and Advanced Primary levels

** Magennis snaffle not permitted for use

FEI = International Equestrian Federation, SJI = Showjumping Ireland, AIRC = Association of Irish Riding Clubs, IPC = Irish Pony Club

Recognition of the need for updating regulations in the light of evidence surrounding the use of equipment which may threaten the welfare of horses in competition is acknowledged by the FEI as follows:

‘This Code of Conduct for the Welfare of the Horse may be modified from time to time and the views of all are welcomed. Particular attention will be paid to new research findings and the FEI encourages further funding and support for welfare studies’

(FEI, 2011).

Acknowledgment is also made by ShowjumpingIreland of the challenge of determining which bits should be permitted, particularly where the bit in question is a new product, previously unseen and therefore unfamiliar to the judges:

‘The Judges of any competition can decide whether a bit is abnormal or cruel and therefore may not be used. It is recognised that other bits may come onto the market and the owner has the right to submit any such bit to the National
Permitted bits and nosebands in dressage

The FEI stipulates the use of a double bridle with cavesson noseband in all FEI dressage competitions. Under national rules (Dressage Ireland) the snaffle bridle is permitted in competition at all levels of competition, but the double bridle is also permitted from elementary up to Grand Prix level. Nosebands are mandatory in competition, with cavesson, drop, flash and grackle permitted with snaffle bits. Only the cavesson noseband is permitted with a double bridle. Use of a noseband is mandatory in riding club dressage competitions, with no restrictions on type of noseband. The kineton noseband is prohibited by the pony club in dressage, with cavesson, flash, grackle and drop nosebands permitted (Irish Pony Club, 2016).

Given the range of bits, nosebands and additional devices available commercially, and concurrent lack of relevant research, regulation by the FEI of which bits should be permitted in competition is acknowledged to be a major challenge (personal communication, FEI sports forum, Lausanne, 2012). Acknowledgement is made in several locations in the Code of Conduct for the Welfare of the Horse (FEI, 2011) and the regulations governing show jumping of the possibility of tack design or usage causing pain or damage, but responsibility is given to the judges, ground jury or veterinarian to decide on whether a particular bit is permitted, or noseband is sufficiently loose. The FEI or national federation in Ireland do not give guidelines regarding noseband tightness, nor is any assessment of noseband tightness carried out during routine tack inspections. With a lack of supporting evidence, the making of such a decision particularly by judges or ground jury who may not have a background in veterinary medicine or equine welfare is likely to be extremely difficult.

Regulations may serve to protect the welfare of the horse in sport. However lack of research weakens the strength of authorities to uphold regulations in the face of challenges, where supporting evidence or knowledge is lacking. Research developments in the area of pressure application by the range of bits and nosebands in use will advance understanding and assist both individuals and governing bodies in making decisions which will help safeguard the welfare of the horse in equestrian sport.
Conclusion

The horse, as a sentient being, is subject to a range of rider-applied pressures each time it is ridden. In competition, regulations are in place to uphold the welfare of equestrian athletes. These regulations specify the importance of avoiding pain for the horse but allow a range of devices to be used that have the potential to cause pain or injury. Minimal research into the equipment designed to deliver pressure at sensitive anatomical locations has been carried out to date. While pressure is exerted by the bridle on several locations both within the mouth and on the head, study of actual pressures exerted at the horse-tissue interface are few, although the impact of some pressures (noseband in particular) on behaviour and physiology are being investigated.

Progress in the development of technology previously used in other areas has resulted in pressure and force measurement technology becoming available and being adapted for use in equitation science. Some advances have been made but very little with regard to direct pressure measurements of the most sensitive areas used in control of the ridden horse. Further development of existing technology is needed before heat, moisture and calibration challenges no longer hamper use of sensors and reliability of output. Shear forces, acknowledged to increase the operating force, but currently, outside of the scope of the measuring devices in use, result in under-estimation of forces in action. Methods of measuring shear forces, in addition to normal forces, are badly needed, as so many interface sites between horse (or equipment) and rider, including the thorax, the back, the different areas on the face and within the oral cavity, involve contact with areas of high levels of curvature. Through combining the use of advanced technology, and what is known from previous research about the effects of pressure on tissue and neurophysiology of pain, the potential exists to provide empirical evidence which will allow development of guidelines that could, if regulated, substantially improve the welfare of the competition horse.

The overall aims of the research described in this thesis are:

- to investigate the pressures, (nature, location, distribution) in use by riders
- To adapt technology available to allow measurement of pressures at the interface between equipment and tissue
- To identify methods by which riders could monitor pressures applied by their use of training and control devices.
Chapter 2

Exploring usage of equestrian equipment by Irish riders

Introduction
The variety of bits available for use in horse training and riding is substantial. For example, the product catalogue of one Irish saddlery wholesale store lists 102 different bits (Mackey Ireland, 2016). The wide range of bits available to control the motion of an animal is striking since there is limited variation in the anatomical features displayed among individuals (Engelke and Gasse 2003). It prompts the question of why such a variety is needed to elicit the limited number of responses required in the majority of equestrian disciplines. The variety of bits available also clarifies the challenge to researchers to quantify and accurately describe the nature, range and location of pressures exerted on equine oral structures during ridden activities. As equitation science develops, there is growing interest in the apparatus used at the human-horse interface. Rein tension studies are of particular importance (Warren-Smith et al., 2007, Heleski et al., 2009 Kuhnke et al., 2010, Randle et al., 2011) but the effects of rein tension depend on the bits being used. Research has shown that up to 91% of ridden horses showed some form of problem behaviours under saddle (Hockenhull and Creighton, 2012). The most frequent problem displayed was lack of slowing down or resistance in response to bit pressure. While incorrect training is likely to be an important causative factor in the findings of this study, one likely consequence in many such cases is that the rider resorts to using a different bit or other restrictive devices such as particular noseband types in an effort to increase the response to bit pressure (McGreevy and McLean, 2010). Lack of knowledge of learning theory was found among equestrian coaches (Warren-Smith and McGreevy, 2008) and may also be lacking among the equestrian population. The lack of understanding of learning theory may contribute to the reliance by riders on a range of additional artificial aids such as whips, spurs and martingales in order to elicit desired responses (McGreevy and McLean, 2010). Competition regulations specify permitted bit and noseband types and also influence the equipment purchased and used by riders. Show jumping regulations,
at all levels from international competition (under FEI governance) to association (such as Irish Pony Club, Association of Irish Riding Clubs) impose fewer restrictions on equipment allowed in competition than most other disciplines. Therefore a survey of what is in use by Irish and international show jumping riders, and, in addition, bit type sales figures, may provide an overview of the preferred equipment in use by the population of riders who are not restricted in their choice of equipment.

Materials and Methods

Bit sales
Information on the numbers and type of bits sold in Ireland was drawn from sales data supplied by two horse equipment retail stores: Horseware Ireland (a long-established (1985) horse equipment retail store) and Equipet (a more recently established (2006) chain, comprising three stores, selling pet and horse related equipment). Bit sales records from Horseware Ireland from 1st Jan 2011 to 20th Sept 2012 and bit sales records from Equipet throughout 2011 were analysed.

Equipment usage in competition
Data were collected by observing and recording the equipment used on 861 show-jumping horses as they competed in competitions at five locations in Ireland during 2012 and 2013. Four of the locations were equestrian centres which host regular show-jumping competitions and leagues which are run under the regulations of the Irish show jumping governing body, ShowjumpingIreland. One location was an international five day show run under FEI rules. For each competitor the following data were recorded:

i) Bit type
ii) Noseband type
iii) Martingale (present or absent)
iv) Spurs (present or absent)
v) Class
iv) Fence height (maximum)
ii) Age of horse (where possible)
While it was not possible to identify the characteristics of the bit concealed by the mouth (number of joints, shape, material), bits were grouped according to whether they appeared to be a direct action snaffle bit (snaffle) or had additions to the bit ring which enabled the bit to exert a lever action. Examples seen included the wilkie and butterfly snaffle and others which could not be identified and were classified as ‘Snaffles with additions’. In order to investigate whether there was any relationship between the level of severity of the bit in use, and other factors, bits were categorised into severity levels of either 1 or 2. Severity level 1 included direct action bits only, i.e., the snaffle bit. All bits that employed a lever action and are therefore more severe in action were classified as severity level 2. Horse age was recorded where available. This was possible where horses were competing in age specific classes (5, 6 and 7 year old classes) and where competitor lists were available giving details of the competing horses including age. Results were assembled and recorded on a spreadsheet (Microsoft Excel, 2010).

**Data analysis**

Using SPSS (IBM SPSS Statistics, Version 22, 2015) the Kolmogorov-Smirnov test was applied to test tack usage data for normality. The data were found to have non-parametric distribution. The Independent samples Kruskal-Wallis test and Mann-Whitney test were carried out to identify relationships between horse age and bit severity, the use of martingale, whip or spurs, and also between fence height and the level of bit severity. Cross tabulation was carried out and Pearson Chi-square values generated on categorical data including bit type, bit severity, martingale, spurs and whip usage to identify relationships between different equipment usage and to investigate whether usage was associated with horse age or level of competition.

**Results**

**Bits – Sales**

Table 2 shows a breakdown of the combined bit sales for two Irish outlets (n=404). The total numbers sold include bits used for double bridles, for breaking-in young horses and for driving horses as well as bits used for riding. The single jointed snaffle was the most frequently sold bit, making up 46% of overall bit sales, followed by the double jointed snaffle (13%) of sales.
Table 2: Breakdown of combined bit sales by Horseware and Equipet

<table>
<thead>
<tr>
<th>Combined Bit Sales from Horseware Ireland And Equipet</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Snaffle (SJ)</td>
<td>Snaffle (DJ)</td>
<td>Bar Snaffle</td>
<td>Gag</td>
<td>Pelham</td>
<td>Bradoon</td>
<td>Kimblewick</td>
<td>Weymouth</td>
<td>Mouthing Bits</td>
</tr>
<tr>
<td>176</td>
<td>49</td>
<td>39</td>
<td>29</td>
<td>17</td>
<td>24</td>
<td>12</td>
<td>1</td>
<td>15</td>
</tr>
</tbody>
</table>

Combined Bit Sales from Horseware Ireland And Equipet (Continued)

<table>
<thead>
<tr>
<th>Combined Bit Sales from Horseware Ireland And Equipet (Continued)</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Hackamor e</td>
<td>Tongue e bits</td>
<td>Foal Bits</td>
<td>Drivin g</td>
<td>Wilki e</td>
<td>Butterfl y</td>
<td>Miscellaneous</td>
<td>Total</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>9</td>
<td>0</td>
<td>19</td>
<td>1</td>
<td>11</td>
<td>384</td>
<td></td>
</tr>
</tbody>
</table>

Abbreviations: SJ = Single Jointed, DJ = Double Jointed
Miscellaneous included Dexter (racing) snaffles, Waterford bits (multi-jointed snaffle)

Figure 1 Breakdown of combined riding bit sales by retail companies Horseware Ireland and Equipet (n=322)

Figure 1 shows the breakdown of the types of riding bits bought. Several bits not normally used in riding horses included in Table 2 have been excluded from the breakdown in Figure 1. These include bits designed to prevent the horse putting its tongue over the bit and those used specifically for racehorses. Mouthing bits, tongue bit, foal bits and driving bits have also been excluded from Figure 1.
**Direct action versus lever action bits**

Bits can be divided into two major groups, according to their mode of action. Direct action bits, such as the snaffle bit act directly on the mouth, whereas lever action bits exert pressure through a lever action. The load (rein pressure) is exerted at a location removed from the point of pressure or fulcrum (in the case of the bit – the bars of the mouth, lips, tongue) by a distance, the length of which determines the pressure or load brought to bear on the part of the bit to which the headpiece is attached (Figure 2).

![Diagram of a first class lever](image)

**Figure 2** Illustration of a first class lever, as used in the design of many equestrian bits. Rein force applied causes the bit shank to move around the fulcrum (bit) causing weight to be exerted though the cheekpiece.

Examples of lever-action bits include the pelham (Figure 3), kimblewick or gag. This results in pressure being exerted through the cheek-pieces of the bridle to the poll, in addition to the pressure exerted through the bit (McGreevy and McLean 2010).
Figure 3 Pelham bit, with arrows identifying the points of lever action. The bit acts as a fulcrum around which the lever, (bit shank) rotates, when rein force is applied, causing weight to be exerted through the cheekpiece.
In order to identify the proportion of direct action bits as opposed to lever action bits sold by the two companies, bits were grouped according to the following categories:

1. Single jointed snaffle
2. Double jointed snaffle
3. Bar snaffle

Bits used in double bridles (Bradoon, Weymouth) and mouthing bits were not included. The double bridle is rarely used in show jumping and the mouthing bit is used primarily during the breaking-in process.

Direct action bits made up 82% of riding bit sales (n=264) and lever action bits made up 18% (n=58) (Figure 1). Combined sales figures for retailers Horseware and Equipet show that single jointed snaffles made up 55% of bit sales, with snaffle bits accounting for 82% of bit sales overall.

**Equipment usage in competition**

*Age of horses observed*

Data regarding horse age were available for 242 of horses observed. Data were collected from age-specific competitions for 5, 6 and 7 year old horses. Competitor lists giving horse details including age allowed age data to be collected from a small number of the other competitions (Figure 4).
Figure 4 Distribution of ages of horses for which age data were available (n = 242)

**Bits-Usage in competition**

Table 3 Percentages of different bit types in use

<table>
<thead>
<tr>
<th>Bit type</th>
<th>Frequency</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Snaffle</td>
<td>568</td>
<td>66.7</td>
</tr>
<tr>
<td>Gag</td>
<td>73</td>
<td>8.6</td>
</tr>
<tr>
<td>Pelham</td>
<td>133</td>
<td>15.6</td>
</tr>
<tr>
<td>Wilkie Snaffle</td>
<td>31</td>
<td>3.6</td>
</tr>
<tr>
<td>Butterfly Snaffle</td>
<td>7</td>
<td>.8</td>
</tr>
<tr>
<td>Hackamore</td>
<td>5</td>
<td>.6</td>
</tr>
<tr>
<td>Snaffle with additions</td>
<td>22</td>
<td>2.6</td>
</tr>
<tr>
<td>Other</td>
<td>13</td>
<td>1.5</td>
</tr>
<tr>
<td>Total</td>
<td>852</td>
<td>100.0</td>
</tr>
</tbody>
</table>
Sixty seven per cent of horses wore simple snaffle bits (n=568) (Table 3). The second most common bit was the pelham (n=133) which represented 16% of bits. Nine per cent of horses wore a gag bit (n= 73). The wilkie and butterfly snaffle were worn by 4% (n=31) and 1% (n= 7) of horses respectively and the hackamore bridle by 1% (n=5). Snaffles with additions were worn by 3% (n=22). A significant relationship was found between fence height in the competition and the type of bit used (H=72.48, df = 6, p < 0.001), with the snaffle bit more likely to be used in competitions of lower fence height (Table 4).

Table 4 Median, mean and standard deviation values of competition fence height found for different bit types

<table>
<thead>
<tr>
<th>Bit Type</th>
<th>Median</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Butterfly snaffle</td>
<td>1.40</td>
<td>1.34</td>
<td>0.09</td>
</tr>
<tr>
<td>Pelham</td>
<td>1.30</td>
<td>1.30</td>
<td>0.19</td>
</tr>
<tr>
<td>Snaffle with additions</td>
<td>1.30</td>
<td>1.24</td>
<td>0.28</td>
</tr>
<tr>
<td>Other</td>
<td>1.25</td>
<td>1.26</td>
<td>0.22</td>
</tr>
<tr>
<td>Gag</td>
<td>1.20</td>
<td>1.20</td>
<td>0.21</td>
</tr>
<tr>
<td>Wilkie snaffle</td>
<td>1.20</td>
<td>1.19</td>
<td>0.19</td>
</tr>
<tr>
<td>Hackamore</td>
<td>1.20</td>
<td>1.25</td>
<td>0.13</td>
</tr>
<tr>
<td>Snaffle</td>
<td>1.10</td>
<td>1.14</td>
<td>0.19</td>
</tr>
</tbody>
</table>

A significant relationship was found between the height of fences in the competition and the severity level of the bit (U=54399, p < 0.001). Lever action bits were more likely to be used in classes with higher fence height (Mdn 1.3m) compared to direct action bits (Mdn 1.1m) (Figure 5).
There was a significant relationship between horse age and severity level of the bit (U=4338.5, p < 0.001), with older horses more likely to wear more severe bits.
Nosebands in use by show jumping riders

Table 5 Percentages of different noseband types found

<table>
<thead>
<tr>
<th>Noseband Type</th>
<th>Frequency</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cavesson</td>
<td>165</td>
<td>19.9</td>
</tr>
<tr>
<td>Flash</td>
<td>467</td>
<td>56.3</td>
</tr>
<tr>
<td>Grackle</td>
<td>132</td>
<td>15.9</td>
</tr>
<tr>
<td>Micklem</td>
<td>27</td>
<td>3.3</td>
</tr>
<tr>
<td>Drop</td>
<td>12</td>
<td>1.4</td>
</tr>
<tr>
<td>Rope cavesson</td>
<td>4</td>
<td>0.5</td>
</tr>
<tr>
<td>Rope cavesson with flash</td>
<td>19</td>
<td>2.3</td>
</tr>
<tr>
<td>Other</td>
<td>3</td>
<td>0.4</td>
</tr>
<tr>
<td>Total</td>
<td>829</td>
<td>100.0</td>
</tr>
</tbody>
</table>

The flash noseband was the most frequently used noseband making up 56% (n=467) while the cavesson (n=165) was the second most common at 20%, and the grackle the third most common at 16% (n=132) (Table 5). There was a relationship between noseband type and bit type ($\chi^2(49) = 117.23$, p=<0.001). The most frequent combination found was the snaffle bit with the flash noseband, followed by the snaffle bit with the cavesson noseband (Figure 6). The second most frequently found bit, the pelham, was also most frequently paired with the flash noseband but also, less frequently, with the cavesson and the grackle nosebands.
Figure 6 Distribution of bit-noseband combinations. Types of bit, as listed on the right side of the Figure are displayed as colour coded bars coupled with the noseband types they are used with, along the X-axis.

*Frequency of martingale usage among show jumping riders*
Martingales were worn by 87.5% of horses (n=747). Older horses were significantly less likely to wear a martingale (H=17.68, p < 0.001) (Figure 7).
Figure 7 Boxplot showing distribution of ages of horses fitted or not fitted with a martingale.

There was no relationship between martingale use and either bit type ($\chi^2(7) = 5.94$, $p=0.55$) or bit severity level ($\chi^2(1) = 0.37$, $p=0.54$).
Whip and spurs usage among show jumping riders

Figure 8 Frequency of spur usage in competitions of different fence height. Numbers of riders not wearing spurs (No spurs) and wearing spurs (Spurs) are displayed by bars colour coded for increasing fence height. Colours specifying fence height are shown on right side of Figure.

Out of a total of 859 riders, sixty nine percent of riders wore spurs (n=596). Spur usage was found at all levels of competition (Figure 8). Fifty four per cent of riders carried a whip (n= 355) while 46% did not (n=299). There was a relationship between whip and spur use ($\chi^2(1) = 6.43, p=0.01$). Riders not carrying a whip were also less likely to wear spurs (Figure 9).
Figure 9 Frequency of carrying of whip and wearing of spurs among riders. The frequency of carrying a whip (Whip) or not carrying a whip (No whip) among riders not wearing spurs is displayed on the left side of the Figure, and a similar breakdown (of carrying or not carrying a whip) for riders wearing spurs can be seen on the right side of the Figure.

Riders of older horses were more likely to wear spurs ($U=2036.5$, $p < 0.001$) but there was no relationship between horse age and the likelihood of the rider carrying a whip ($U=2046$, $p=0.09$). There was no relationship between the wearing of spurs and either the severity level of the bit ($\chi^2(1) = 1.29$, $p=0.25$) or the type of bit ($\chi^2(7) = 7.20$, $p=0.41$). There was no relationship between the carrying of a whip and either bit type ($\chi^2(6) = 8.04$, $p=0.23$) or bit severity level ($\chi^2(1) = 0.26$, $p=0.61$).
Discussion

Concern has been expressed among equine and equitation scientists regarding the use of excessively tight nosebands possibly threatening the welfare of competition horses by preventing normal behaviours and expressions of discomfort and potentially causing pain and tissue damage (McGreevy et al., 2012). However, this study produces the first data which identify the importance to the rider of limiting mouth opening during competition. The flash noseband was the most frequently used noseband (56%, n= 467), and was most frequently worn with the snaffle bit. The flash noseband consists of a cavesson noseband with an additional strap which closes around the muzzle beneath the bit. The stated purpose of the flash noseband is to limit the ability of the horse to open its mouth (Kapitzke, 2004, Muir and Sly, 2012) and consequently to reduce the possibility of the horse putting the tongue over the bit (Micklem, 2003) or evading the pressure of the bit by moving the bit to another part of the mouth where pressure exerted by the bit may not be as aversive to the horse. The grackle noseband, also employing a strap which fastens beneath the bit is likely to be employed for the same reason and represented 16% of nosebands seen (n= 132). The combined totals of flash and grackle nosebands (72%) indicate that prevention of mouth opening is valued by a high percentage of riders.

The crank cavesson noseband is designed to facilitate ease of fastening of the noseband to a high level of tension. The current study does not differentiate between standard and crank cavaessons, and as the data was collected through observation, no measure of tightness could be recorded. However, the strap fastening beneath the bit in both the grackle and flash nosebands are unlikely to achieve the goal of keeping the mouth shut unless fastened to a considerable degree of tightness. It has been suggested that the use of nosebands which may be tightened to the extent that they exert significant pressure on the muzzle cause an increased sensitivity to bit pressure (McGreevy et al., 2012). The high frequency of flash and grackle noseband usage suggests that riders may rely on this increased sensitivity to bit pressure or to additional unspecified pressures exerted by the noseband to control the equine athlete.

Snaffle bits are the most frequently sold bits, representing 76% of bit sales by the retail stores referred to, with 55% and 15% of sales represented by single jointed snaffles, and double jointed snaffles respectively. This predominance of the snaffle bit was also found in competition, seen on 76% of horses observed, although the identification of
type of snaffle (single versus double jointed) was not possible on the ridden horses observed. During the early training of a horse, the snaffle bit is most frequently recommended (Klimke, 1994, Micklem, 2003). Greater usage of snaffle bits observed in the lower level (with lower fence height) classes may simply be a consequence of the horse having been started in the snaffle bit. Alternatively it may be the preferred option for use by amateur riders competing at lower levels of competition. The higher representation of lever action bits in higher level competition may be as a result of several factors. Precise control of the movement of the horse is of greater necessity when horses are being ridden in top level classes that demand greater precision in terms of pace, direction and location of take-off point before a fence. The horse reaching this level of competition may have been subjected to lengthy periods of training during which progressive desensitization to bit pressure may have occurred, resulting in the necessity for stronger pressures, through the use of more severe bits, being applied. Highly experienced riders, such as those competing in international classes are likely to be more capable of using equipment that may, in the hands of a less experienced rider, cause an undesired reaction due to high levels of pressure being applied. Further research is required to identify whether this is the case.

Eighty seven percent of horses observed wore martingales, with younger horses more likely to wear a martingale than older horses. The martingale is used to limit the ability of the horse to raise its head, acting by exerting downward pressure on the bit through the reins if the horse raises its head (Heleski et al., 2009). The high frequency of use of martingale might suggest that the device is used to pre-empt or prevent undesired behaviours rather than as a consequence of previous problematic behaviours. The degree to which the martingale restricts upward movement of the head is determined by the level to which the bifurcated strap attached to the girth and connecting to the reins is tightened.

Use of the martingale may alter the action of the bit in ways that are not yet understood (Heleski et al., 2009). Traditionally, such devices are added when the horse performs a behaviour which the rider finds problematic such as failing to respond to bit pressure or raising the head excessively. An elevated head frequently results in the horse becoming less responsive to bit pressure, and is also a characteristic of flight response, so is performed when the horse attempts to escape from a fear-inducing situation. As a result a raised head and neck often result in reduced control by the rider and a greater
likelihood of injury to the horse or rider. In show jumping horses, a horse that throws up its head on approach to an obstacle poses a threat to safety of both horse and rider. This behaviour is often accompanied by an increase in speed (rushing) which creates problems for the rider in controlling the pace and direction of the horse while approaching a fence. The higher frequency of lever action bits in older horses may have some bearing on the lower frequency of martingales. Different modes of action of non-snaffle bits may reduce the ability of the horse to raise the head and thus eliminate the need for a martingale.

In the equestrian world, emphasis throughout the training of horses is placed on the concept that the horse is ‘on the bit’. This is characterised by a head and neck carriage where the horse displays ventral flexion at the poll, is responsive to the rider’s cues and maintains the head and neck carriage without coercion by the rider (McGreevy et al., 2010). This is achieved through progressive training, but sustained bit pressure exerted by the rider can result in the horse adopting a similar posture as the horse learns to avoid greater bit pressures by holding the head and neck in this position (McLean and McGreevy, 2010b) Achieving this position in a shorter time span is made possible by the use of pressure exerted by the bit and ancillary devices. The prevalence of the use of martingales and low fitting nosebands among riders may be at least partially explained by these factors.

Spurs were worn by 69% of riders. Spurs are used by the rider to refine or strengthen the cue, delivered by the rider’s lower leg. If a horse is unresponsive to pressure applied by the lower leg, a spur reduces the area over which the pressure is distributed during delivery of the cue, significantly increasing the pressure, thereby increasing the likelihood of a response. Amateur riders, with less experience of developing an independent and secure ‘seat’ (the ability to maintain balance on the horse without relying on grip by the lower leg or hands) are likely to perform greater numbers of random movements of the lower leg as they rely more heavily on the lower leg to maintain their position on the horse. Use of spurs by an amateur rider is therefore likely to result in the horse being subjected to aversive and possibly painful pressures administered unwittingly by the rider. For this reason, spurs are recommended for use by advanced riders only (BHS, 1992, Muir and Sly, 2012). However, the use of spurs among riders observed during the current study was distributed throughout the classes, with 22 out of 34 (65%) of riders participating in the smallest class (80 cm) using spurs.
Whips were carried by 54% of riders (n=355). Thirty three percent of riders used both whip and spurs, while 20% of riders used neither. This is likely to represent the percentage of horses on which riders were confident of getting sufficient response to leg pressure alone. The low percentage of horses being ridden with neither whip nor spur to strengthen leg aids suggests that a significant percentage of horses may not be trained to respond to leg pressure or may have become desensitised to this pressure.

The use of equipment additional to the traditional snaffle bridle and cavesson noseband such as restrictive nosebands, martingales and the use of spurs suggest that the majority of riders are relying on potentially high levels of pressure application for their success and safety as riders. If most of the equipment in use on the observed horses is being used out of necessity rather than through following a fashion for the use of particular equipment, it would appear that the majority of riders experience difficulties in either controlling forward movement of their horses and / or eliciting forward movement when required in their horses. The former would reflect the findings of Hockenhull and Creighton (2012). Further research is required to identify whether current training methods are resulting in reduced responsiveness to bit pressure and increasing the requirements for training devices, which apply significantly higher levels of pressure in order to control flight responses and elicit required forward responses.

**Conclusion**

Snaffle bits are the most widely sold and also used in show jumping competition. However, most riders use other devices in combination with snaffle bits. Only occasional riders rely on the pressure of a snaffle bridle alone, without the additional use of martingales and low-fastening nosebands. Spurs are widely used at all levels of competition. All of the above suggest that horses are being subjected to significant levels of physical pressure exerted on various aspects of their anatomy. Concern for possible welfare implications indicate the necessity for research into pressure at specific locations on the horse’s anatomy exerted routinely in the course of equestrian sport.
Chapter 3

An analysis of visible patterns of bit wear

Introduction
Control of the ridden horse is carried out through application of physical pressures by various aids including bits, the legs, spurs, the seat and the whip. Release of pressure immediately after a desired response rewards the animal and is said to reinforce the response. Therefore, the release of pressure in equitation is an example of negative reinforcement. The bit has been in use on horses for approximately 6000 years (Budiansky, 1997). A wide range of bit designs are in use. While the selection of a given bit is usually based on its apparent effectiveness, very little is known about the exact mechanism of action of different types of bit. There are significant knowledge gaps relating to which oral structures receive the greatest bit contact and bit-applied pressure and also relating to the levels of pressure imposed on oral tissues (Engelke and Gasse, 2003).

Equestrian personnel and equestrian regulatory bodies are increasingly seeking scientific data related to the use of certain bits and other equitation – related equipment, to guide and support regulatory decisions relating to both traditional and novel bits (Mathieson, 2015, Casey et al., 2013). Fluoroscopic imaging of the position of the bit in the oral cavity (Clayton, 1985) has helped identify the relationship between bit position and intraoral osseous structures. Furthermore, the relationships between common bits and soft tissues in the mouth (including the tongue and mucous membranes covering osseous structures) were further clarified by Engelke and Gasse (2003). It is clear that the tongue is the structure that most consistently interacts with the bit and encounters bit pressure (Manfredi et al., 2005, Engelke and Gasse, 2003). The dimensions of the tongue at the position where the bit sits are such that the lateral margins of the tongue cover the bony ridges of the diastema (or bars of the mouth), thereby supporting most of the bit-induced pressure, unless the tongue has been retracted or is lying over the bit (Engelke and Gasse, 2003). The correctly fitted bit also makes near continuous contact with the lips and diastema, and intermittent contact with the hard palate and the premolar and canine teeth (Clayton and Lee, 1984, Engelke and Gasse, 2003). Later
work by Manfredi et al (2009) demonstrated the reactions of the horse to bit pressure. These included chewing, retraction of the tongue and, for some horses, bulging of the tongue over the bit as bit pressure increased (Manfredi et al., 2009). In addition, the position of the joint of single-jointed bits has been shown to travel dorsally and approach the hard palate when bit pressure is applied (Manfredi et al., 2009).

Bit-induced damage to oral structures and surfaces has been described by several veterinarians (Cook, 1999, Jansson et al., 1998, Lancker et al., 2007). For example, damage to the second premolars as a direct consequence of bit usage has been described (Cook, 2011, Johnson and Porter, 2006) and is believed to occur when the horse draws the bit caudally using the tongue, seizes it between the premolars (usually on one side) and bites down. Gentle chewing on, or ‘mouthing’ the bit is traditionally seen as a sign of so-called acceptance of the bit (Kapitzke, 2004) although there is no scientific evidence to support such an indicator. However, Manfredi et al. (2009) found an increasing likelihood of ‘mouthing’ on the bit as rein pressure increased. They suggest that many oral movements by the horse are carried out in an attempt to relieve bit pressure either on the tongue or hard palate.

The mode of action of the bit is influenced by a number of factors including the type or design of bit, the thickness of the bit, the material from which the bit is made and various types of additional equipment, such as nosebands and additional bits such as in the double bridle, in which two bits are used (McGreevy et al., 2012). Head position will influence the action of any bit by altering the tissue-bit contact surfaces and corresponding pressure distribution. Ridden horses carry the head with a greater degree of ventral flexion than is seen in unridden horses (McGreevy et al., 2010). It is likely that the presence of a bit, or other equipment that exerts pressure on the horse's head, influences this change in head position (McGreevy and McLean., 2010). Rein tension exerted when the horse is displaying ventral flexion will more readily transmit pressure onto the tongue and mandible (via the diastema) than when the neck is extended. Similarly, changes in the position of the rider’s hands will affect the direction of pressure from the bit within the horse's mouth, with raised hands pulling the bit in a more dorsal direction than when the hands are lowered.

The total length of the bit relative to the dimensions of the oral cavity will influence the aspect / area of the bit and the tissue it contacts. A bit is said to be properly fitted in the horse’s mouth when there is a distance of half a centimetre between the outer surface of
the horse's lips and the bit ring (Manfredi et al., 2005). This distance is recommended to prevent pinching of the skin by movements of the bit ring. However, evidence is lacking regarding the effect of a poorly fitted bit on the horse. Pressure (and hence wear) is likely to be closer to the centre of the bit or spread over a more diffuse area due to lateral movement of the bit in cases where the bit is longer than the recommended length.

Asymmetric rein tension may result in movement of the bit laterally through the horse's mouth before maximal pressure is exerted on the lips and bars of the mouth. The bit ring or cheek pieces help prevent the bit from being pulled fully through the horse’s mouth (Figure 10). However, where lateral movement of the bit is possible, physical signs of wear are likely to be distributed over a wider area of the bit surface.

Figure 10 The cheek pieces of a snaffle bit are intended to prevent the bit from being pulled laterally through the horse’s mouth.

The resistance of a metal to changes in its surface contour depends on the type of metal, with some, such as stainless steel, being much harder than others such as copper. The resistance of a solid material to pressure is measured in yield strength. Yield strength is measured in Pascals (Pa), where one pascal is equivalent to one Newton per meter squared (1 Pa ≡ 1 N/m²). The yield strength of stainless steel is typically 500MPa ($10^6$ Pa).
Pa) whereas that of copper is 70 MPa and brass is approximately 200 MPa (Avallone et al., 2006). This explains why, when compared with stainless steel bits, copper-coated bits show clearer signs of wear and more detectable changes in areas where the bit comes into contact with a sharp edge which, in the oral cavity, is likely to be the premolar teeth. While most contemporary bits are manufactured from stainless steel, copper is the most common alternative metal to steel used in bits. The use of copper is believed to increase the amount of saliva produced by the horse, which in turn is thought to improve the horse’s relaxation and sensitivity to the bit (Muir and Sly, 2012) although there is currently no empirical evidence to support this belief.

The aim of the current study was to identify the areas on the bit that come into most frequent and sustained contact with oral structures. The study focuses on snaffle bits (Figure 11) because they are the most commonly used bits across the equestrian disciplines (Hill et al., 2015).

![Figure 11 Double jointed snaffle bit with central lozenge, showing bit ring, bridle cheek-piece and rein.](image)

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Materials and Methods

Preliminary Study
A preliminary macroscopic inspection of various bits revealed areas of discoloration and changes in surface contour at specific locations, which appeared to follow a pattern. These changes in appearance were most evident in non-stainless steel bits. Among the bits observed, copper-coated bits showed most significant changes in appearance as a result of use.

The most notable changes in appearance observed within the range of bits examined were:

- changes in lustre (a polished appearance) suggestive of prolonged or frequent contact with or movement against other surfaces which we described as burnishing (Figure 12)
- indentations on the bit surface consistent with contact with hard objects (these were assumed to be indents due to teeth contact; Figure 13)
- deposits of food material on the bit surface
- saliva staining (with dried deposits of saliva or other fluid).

Hypotheses
Based on the preliminary study, the following hypotheses were formulated:

1. The extent and distribution of burnishing would be greatest on the ventral and caudal aspects of the bits, due to greater sustained pressure exerted on the bit by oral structures as a result of rein tension.

2. The distribution of bite marks would be mainly on the medial area of the bit.

3. Higher levels of food deposits and salivary staining would be found on the rostral and dorsal surfaces, away from the areas of greatest pressure on the bit.
Figure 12 Changes in lustre or burnishing (a) on the bit above is evident on both the centre ‘lozenge’ and arm of the bit in comparison with areas of lower reflectivity (b)

Figure 13 Damage to the bit surface due to contact with sharp edges within the oral cavity
Selection of bits for assessment

A visual examination of the entire collection of bits in three local private yards [a livery yard (n=26), a hunting yard (n=14) and a private training yard (n=20)] was carried out. It was not possible to identify the ages of the bits assessed. Snaffle bits were the most common bit encountered. From the pool of 60 bits, all the snaffle bits that had visible surface changes (including burnishing, changes in surface topography, staining and deposition of food matter) were selected (n = 27). They were laid out on a flat surface and photographed. Bits in the collections that did not show visible signs of wear were not investigated any further (n = 33).

For each bit, four photographic views were recorded using the camera function of an iPhone 5c (Apple, Model ME501B/A). The views were as follows:

1) Rostro-caudal view (front to back)
2) Caudo - rostral view (back to front)
3) Dorso-ventral (top to bottom)
4) Ventro-dorsal (bottom to top)

Photographs were taken in daylight to optimize the detection of surface changes. After subsequent inspection, the images of 6 bits were discarded due to poor photographic quality that made assessment of surface aspects difficult to carry out. Common flaws included blurring, incomplete picture or high reflectivity due to sunlight. Images of the remaining bits (n = 21) were numbered and an individual who was unaware of the purpose of the study was asked to select 15 of the numbers at random. The corresponding photographs for each of the 15 bits were then prepared for presentation to the selected observers (N = 5) for individual scoring. The observers included veterinarians (n=3) and animal scientists (n=2). The bits finally used for assessment purposes comprised single and double-jointed snaffle bits of varying composition and type of ring attachment, as detailed in Table 6.
Table 6 Description of a random sample of 15 snaffle bits assessed for signs of wear

<table>
<thead>
<tr>
<th>Material</th>
<th>Type of Joints</th>
<th>Type of Ring attachment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stainless Steel</td>
<td>Single Jointed</td>
<td>Loose Ring</td>
</tr>
<tr>
<td>Copper</td>
<td>Double Jointed</td>
<td>Eggbutt</td>
</tr>
<tr>
<td>Plastic</td>
<td></td>
<td>Baucher/ Cheekpiece</td>
</tr>
<tr>
<td>Metal Alloy</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>9</td>
<td>7</td>
</tr>
<tr>
<td>4</td>
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<td>1</td>
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<td>2</td>
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<tr>
<td>3</td>
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</tbody>
</table>

For the purposes of scoring separate areas on the bit for wear-related changes, the image of each bit was divided into four zones which were clearly identified by dividing lines as shown below (Figure 14). Where a bit with a central lozenge, such as the French link snaffle was included, the lozenge was numbered and assessed as a fifth zone.

![Figure 14](image_url)

Figure 14 Each photographic image of each bit was divided into separate numbered zones for assessment of wear
For each zone, the assessors were asked to assign a score of 1-5 (where 1 = None, 2 = Small amount, 3 = Moderate amounts, 4 = Quite a lot, 5 = Very high levels) for the following qualities:

1. Increased shininess of bit surface (burnishing)
2. Indentations on the bit (putative bite marks)
3. Deposition of food particles
4. Saliva staining
5. Other

Results were recorded by each assessor in a spreadsheet (Microsoft Excel, 2010) (Table 7)

Table 7 Grades allocated for Bit 12, Rostro-Caudal View by Assessor 1.

<table>
<thead>
<tr>
<th>Bit No</th>
<th>View</th>
<th>Zone</th>
<th>Burnish</th>
<th>Food Deposits</th>
<th>Bite Marks</th>
<th>Salivary Staining</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td></td>
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<td>4</td>
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<td>3</td>
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</tbody>
</table>

Data Analysis
The Cronbach’s alpha value was derived using SPSS (IBM SPSS Statistics, Version 22, 2015) to assess the level of agreement between the five assessors. The Kolmogorov-Smirnov test was applied to test for normality. The data were found to have non-parametric distribution. The independent samples Kruskal-Wallis test was carried out to identify differences in the levels of bite-mark damage on the centrally located areas compared to the lateral areas (areas nearest the bit ring). Differences in levels of burnishing, bite marks, food deposition and saliva staining on the different views and zones of the bit were also assessed using the independent samples Kruskal-Wallis test. The Mann-Whitney test was used to compare levels of burnishing, bite marks, food deposits and saliva staining on different zones and views of the bits.
Results

The Cronbach’s α value for overall inter-observer reliability was found to be high (0.94), indicating a high level of agreement between the five assessors.

Burnishing

Figure 15 Boxplots displaying median and interquartile ranges of scores for overall distribution of burnishing on the four views of the bits assessed. Burnishing was scored from 1-5 on 4 different views. (View 1 = Rostro-caudal, View 2 = Caudo-rostral, View 3 = Dorso-ventral, View 4 = Ventro-dorsal)

Burnishing was deemed to have arisen from repeated surface wear and was defined as increased shininess and was graded from 1 to 5. There was no significant difference in the amount of burnishing distributed along the entire bit surface (H= 2.68, df =3, p = 0.44). Significant differences in burnishing were found on different aspects of the bits, (H= 19.56, df =3, p < 0.001) Significantly more burnishing was found on the caudal
aspect (back of the bit) compared to the rostral aspect (front of the bit) (U=-78.59, p < 0.05) (Figure 15). Similarly, the scores for burnishing on the ventral aspect of the bit were significantly higher than for the dorsal aspect of the bit (U=-69.24, p < 0.05). Burnishing was significantly higher on the ventral view than the rostral view (U=-98.95, p < 0.001). There was no significant difference between caudal and ventral burnishing scores (U=-20.35, p = 1.00).

Bite marks

Figure 16  Boxplots displaying median and interquartile ranges of scores for bite marks on zones 1–4 of all bits assessed. Zones 1 and 4 are lateral zones, while zones 2 and 3 are medial zones, closest to the central joint of the bit.
Bite marks were defined as discrete indentations on the surface of the bit. The amount of bite indentation was scored from 1 to 5. Significant differences were found between bite marks on different zones of the bits ($H=23.51$, $df=3$, $p < 0.001$) (Figure 16). Significantly higher scores for bite marks were found on zone 3 than zone 4 ($U=27.32$, $p < 0.05$) (Figure 17). Zone 2 also had significantly higher bite marks than zone 4 ($U=28.35$, $p < 0.01$).

![Estimated marginal means of bite marks on the four zones of bits. Zones 1 and 4 are lateral zones, while zones 2 and 3 are medial zones, closest to the central joint of the bit.](image)

There were no significant differences found in levels of bite marks between each of the four aspects of the bits ($H=5.34$, $df = 3$, $p = 0.15$)
Figure 18 Mean scores of bite mark damage on 15 bits. Bits numbered 1,3,4,6 and 12 are copper coated bits. Copper has a lower yield strength than other materials used in bit manufacture and is more susceptible to damage from contact with hard structures such as teeth.

Significant differences were found between bite mark levels on individual bits (H=351.78, df=14, \( p < 0.001 \)). Copper coated bits showed higher levels of bite mark damage than the other bits included in the study (manufactured from stainless steel, metal alloys and plastic covered) with some differences being significant (Figure 18). Bits 1,3,4,6 and 12 are copper plated whereas bits 2,5,8,9,10 and 11 are stainless steel. Bit no 7 is a plastic coated bit and bits 13,14 and 15 are manufactured from metal alloys.
Food Deposits

Figure 19 Boxplots displaying median and interquartile ranges of scores for food deposit levels on four aspects of the bit. (View 1 = Rostro-caudal, View 2 = Caudo-rostral, View 3 = Dorso-ventral, View 4 = Ventro-dorsal)

Food deposition was defined as residual organic material on the intra oral surface of the bit (Figure 19) with the amount present scored from 1 to 5. There was a significant difference between levels of food deposits on the different aspects of the bit (H=36.46, df=3, p < 0.001). The caudal aspect (View 2) had significantly lower levels than the levels of food deposits found on each of the rostral (U=140.92, p < 0.001) and ventral aspects (U=-72.96, p < 0.05) (Figure 19).
Saliva Staining

Saliva staining was scored as discolouration without the presence of organic material, scored from 1 to 5. There was a significant difference in the levels of salivary staining (H=14.94, df=3, p < 0.001). The caudal levels (View 2) were significantly lower than the levels of salivary staining found on each of the rostral (View 1) (U=70.24, p < 0.05) and ventral aspects (U=-83.51, p < 0.005) (Figure 20).

Figure 20 Boxplots displaying median and interquartile ranges of scores for salivary staining on caudal, rostral, ventral and dorsal views of 15 bits. (View 1 = Rostro-caudal, View 2 = Caudo-rostral, View 3 = Dorso-ventral, View 4 = Ventro-dorsal)
Figure 21 Visible bit damage due to bite marks and also accumulation of food material in the damaged area in a plastic coated bit.

**Discussion**

While every effort was made to identify the ventral and dorsal aspect of each bit correctly, one third of bits (n = 5) were unattached to a bridle at the time that photographs were taken and so it was not possible to identify actual dorsal / ventral areas unambiguously. Two thirds of bits were either attached to a bridle or of a design whereby the bit could only be correctly fitted in one way, leaving no doubt regarding the dorsal or ventral surfaces.

The bit areas observed as showing greatest wear or burnishing as a result of contact with the oral structures were the ventral and caudal aspects. This finding reflects the expectation that rein tension generally pulls the bit in a caudal, ventral, or caudo-ventral direction, depending on the position of the horse’s head and the rider’s hands. Fluoroscopic studies in a standing horse identified movement of the bit in a ventral direction (embedding more deeply into lingual tissue) on application of increased bit pressure (Manfredi et al., 2009). The distribution of burnishing along the entire length
of the bit is unsurprising given the fleshy and relatively large structure of the tongue, shown previously to occupy most of the intra-oral space (Engelke and Gasse, 2003). Along with the adjacent diastema and lips, the entire length of the bit within the oral cavity is likely to lie in contact with physical structures for the duration during which the bridle is fitted. Manfredi et al (2009) showed a specific movement whereby the bit was lifted and moved caudally between the premolars by the tongue. This tongue action is also likely to contribute to the burnishing found on the ventral and caudal aspects of the bit. Due to the reversible nature of most of the bits used in this study, it was not possible to identify differences in levels of wear on left versus right sides of the bit, which may occur due to rider ‘handedness’ or laterality.

Damage to bits due to biting or chewing may be caused in a number of ways. Fluoroscopic studies of the position of different bits in horses’ mouths have shown that horses use the tongue to move the bit into different positions within the mouth (Clayton and Lee, 1984, Manfredi et al., 2009). It is likely that the centrally located bite marks (Figure 21) are as a consequence of the horse gripping or biting on the bit when the central area is pulled caudally by the tongue as described by Manfredi et al (2009). If the marks seen are as a result of biting, the distribution of bite marks should be similar on opposite aspects (caudal versus rostral, dorsal versus ventral). This was found to be the case. The higher level of bite damage on the caudo-rostral view compared to the ventro-dorsal view suggests that some rotation of the bit may occur as the tongue lifts and pushes the bit caudally towards the premolar teeth. It is possible that this behaviour momentarily reduces bit pressure on oral structures and surfaces sufficiently to reinforce and increase further performance of the behaviour.

It is safe to assume that one possible motivation for a horse to move the bit in the mouth is to reduce discomfort resulting from the presence of the metal object in its mouth. The higher frequency of chewing behaviours and tongue movements found during application of higher levels of rein tension support this suggestion (Manfredi et al., 2009). That is, the motivation to resolve discomfort increases as the bit becomes more intrusive (McGreevy, 2015). Manfredi et al (2009) found a reduced frequency of use of the tongue to elevate the bit and move it caudally when higher levels of rein tension were applied. Rein tension may, by pulling the bit more firmly against oral structures, make it more difficult for the horse to lift and move the bit caudally.
Horses are highly motivated to perform oral behaviours, and will spend between 50 and 80% of their daily time budget grazing (McGreevy, 2004). While grazing, they readily expel foreign bodies and continue to chew and collect further roughage. Fine-tuned responses to the presence of inappropriate particulate matter are needed to minimise damage to internal mucosal surfaces. It is possible that a certain amount of chewing or biting on the bit can be explained by a reflex reaction to any foreign body in the mouth. Licking and chewing behaviours have also been attributed to activation of the sympathetic nervous system as a response to a stressful event, with the licking and chewing occurring after the event (Henshall and McGreevy, 2014). Conflict behaviours in horses, carried out in response to confusion (McGreevy and McLean, 2010) include oral movements such as mouth opening, tongue protrusion and chewing movements. All of the above may contribute to the deposition of bite marks on bits.

Fewer food deposits were found on the caudal aspect of bits. Given the higher levels of wear found on the caudal and ventral aspects, and the caudo-ventral direction of bit movement as a result of rein pressure (Manfredi et al., 2005), it is likely that food deposits on the aspect of the bit exposed to greatest contact with oral surfaces are removed due to movement between oral and bit surfaces.

Less saliva staining was found on the caudal aspect of bits. The salivary duct carrying saliva from the largest salivary gland, the parotid gland, opens into the oral cavity opposite the second premolar and first molar teeth, caudal to where the bit lies. Salivary ducts from the smaller sublingual and mandibular salivary glands open into the oral cavity ventral and rostral to the position of the bit in the mouth (Budras et al., 2003). Distribution of saliva staining did not reflect locations of saliva duct openings into the oral cavity. As with food particles, it is likely that any excess fluid such as saliva is removed from the caudal aspect of the bit due simply to the close contact that the bit will have taken up with oral structures due to rein tension.

The nature of the physical contact between the bit and oral structures, resulting in bit wear, is likely to be influenced by many factors including individual equine responses to bit pressure (Manfredi et al., 2009), anatomy and dimensions of morphological features relative to bit dimensions (Engelke and Gasse, 2003) and the duration of use of the bit. Information regarding the above criteria was not available for the current study. Therefore interpretation of these data is limited to comparison of specific areas for the various changes seen, and the scoring of levels of specific wear-related changes.
This study has provided new information on the interaction between horses and the bits used to control them. The study should inform the placement of biomedical interface pressure transducers or pressure sensors into bits to measure the pressures they exert on oral structures in the ridden horse. One possible method is to embed pressure sensors at locations on the bit that make contact with areas in the oral cavity. Riders apply pressure to these anatomical locations to strengthen desirable responses from the horse through negative reinforcement. We know that rein tension measurements are of importance in equitation science (Pierard et al., 2015) but these metrics do not allow for variability in oral morphology from one horse to the next. Placement of pressure sensors directly onto the bit at locations (identified here) where rein tension is likely to translate to concentrated bit-applied tissue pressures within the mouth, could provide, in a very direct way, useful insights in relation to the action and mechanisms of the operation of bit control on the horse. Such sensors (preferably in the form of a closely spaced array) should not alter the shape or function of the bit, i.e. should be minimally intrusive, and should provide reliable dynamic quantitative data in real time. Embedded, low profile microelectromechanical system (MEMS) pressure sensors have the potential to meet these and other applications in a range of environmentally challenging environments (O’Muiris et al, In press). Placement of pressure sensors at the critical locations on the bit that receive pressure will allow the measurement of forces that most accurately reflect salient cues to the horse. Sensors embedded into the bit allow pressure measurements without altering the surface contour or action of the bit.

Conclusions

1. The higher levels of evidence of wear on the caudal and ventral surfaces of the arms of both single- and double-jointed bits suggest that these surfaces encounter more rider-induced intra-oral pressure and friction than others in the buccal cavity. The low frequency of bite marks on the lateral half of the arms of the bits assessed implies limited grasping of this area of the bit between the premolar teeth. This may reflect either negligible reinforcement from such manoeuvres or the inability of the horses to move the lateral areas of the bit towards the teeth. This finding suggests minimal likelihood of embedded pressure sensors placed in this area being damaged by the horse biting down on them during data collection.
2. The areas of wear recorded on bit surfaces as described above are diffuse, and do not identify exact locations of greatest pressure. Rein tension translates to bit-applied tissue pressure within the oral cavity. From the bit wear data presented, it is clear that this tension does not convert to a uniform pressure distribution between the bit and the tissue it contacts within the mouth. One would expect soft tissue to deform in order to distribute the rein tension (force) over a larger area thereby reducing the actual local bit-tissue interface pressure. On the other hand, tissue that does not have this degree of freedom will, if contacted by the bit, experience intense localized pressure. It is likely that when the horse experiences such localized high pressures, it will adjust its mouth/tongue, in order to redistribute and relieve the pressure (Manfredi et al., 2009). Under normal use conditions the bit is likely to move laterally within the mouth. Therefore, sensors with fixed locations on the bit may ‘sample’ pressures across a range of tissue locations and tissue types particularly if located on the ventral and caudal aspects of the bit.
Chapter 4

Noseband use in equestrian sports – an international study

Introduction

By nature, the horse is a so-called flight animal, responding to frightening situations by fleeing. Many equestrian sports routinely demand fast locomotory responses, which are akin to the flight response and, whether caused by a fear reaction or performed in response to a conditioned cue from the rider, are generally accompanied by high levels of arousal. In equestrian sport, fast locomotory responses in a highly aroused horse can be difficult to control. Injury rates in equestrian sports are high in comparison with other sports (Hawson et al., 2010a), so control of the horse is of paramount importance for the safety of horse and rider. Humans control horses through a combination of restraint and training. Training occurs through the use of negative reinforcement, which relies on the removal of aversive pressure immediately the desired response has been performed (McGreevy and McLean, 2010).

The bridle is the main instrument for controlling horses throughout the world and is used in all equestrian disciplines. Its use dates back approximately 6000 years and relies on application of pressure to sensitive areas of the horse’s head and oral cavity. Historically, bridle designs have varied not least in their inclusion of nosebands that apply pressure at different locations on the horse’s head (Budiansky, 1997). Contemporary nosebands vary in width, design and mechanisms of tightening to offer a range of potential pressures. Many bridles designed for the Olympic disciplines (eventing, dressage and show-jumping) now incorporate a Swedish cavesson noseband, more commonly known as the crank noseband. This type of cavesson has a leveraged buckle design that allows the noseband to be tightened to a much greater tension with less force than is possible with the French cavesson, more commonly called the plain cavesson (McGreevy et al., 2012, Casey et al., 2013).

Traditional recommendations about bridle fitting suggest that after the noseband has been fastened, two fingers should fit comfortably beneath the noseband. The origin of
this guideline is unknown but it has been appearing in equestrian texts since 1956 (Anon, 1956) up until the present (Stecken, 1977, Klimke, 1994, Huntington et al., 2004, Kapitzke, 2004, Muir and Sly, 2012). However, the variation in the assessors’ finger size and varying opinions on where the fingers should be placed to assess noseband tightness have been cited as shortcomings of this guideline. Consequently, few, if any, governing bodies or organizers of equestrian events have a process in place to assess and regulate noseband tightness. The Federation Equestre Internationale (FEI) Code of Conduct for the Welfare of the Horse states that ‘Any practices which could cause physical or mental suffering, in or out of competition, will not be tolerated” (FEI, 2013). However, there is a lack of scientific data on the sensitivity of equine tissues to pressure, the levels of pressure required to activate nociceptors (pain receptors in the skin and soft tissues) and cause pain perception and, ultimately, the levels of pressure likely to cause tissue damage. These knowledge gaps make it difficult for the FEI to ensure that it has eliminated noseband use that could cause physical or mental suffering.

Apart from noseband tightening, the width and positioning of nosebands may influence their impact on the horse (Casey et al., 2013). For a given tightness, narrow nosebands will generate higher pressures on supporting tissues than wide ones. The nasal bones are progressively less broad rostrally than caudally, so the position of the noseband on the horse’s head may influence the extent to which sub-noseband pressure is exerted against bony structures rather than soft tissue (Goody, 2004). The traditional recommendation regarding proper position of the noseband is that 1.5-2 fingers should fit between the upper margin of the noseband and the distal margin of the facial crest (Kapitzke, 2004). This guideline suffers from the same lack of precision as discussed earlier (in reference to tightness) and is not enforced, nor have the possible consequences for the horse of variation in noseband position and width been investigated.

Equestrian texts acknowledge the need to use pressure on the head in training and controlling horses (Micklem, 2003, Kapitzke, 2004). The commonly targeted locations for pressure application via bridles include the diastema, tongue, lips, chin groove and poll. The authors are unaware of any reference in authoritative equestrian texts or literature to the use of noseband pressure as an adjunct to the acknowledged sites of pressure control. The magnitude and range of both static and dynamic pressures under nosebands and the distribution of such pressures relative to distinct anatomical features are critical to understanding the control function of such pressures as well as their impact on animal well-being. Some preliminary work has been reported that, as
nosebands are tightened, there is evidence of increased sensitivity to the bit (Randle and McGreevy, 2013) and an increase in eye temperature, suggestive of stress (McGreevy et al., 2012).

A growing awareness of horse welfare has been accompanied by concerns regarding some common traditional practices in equitation (McLean and McGreevy, 2010a). The practice of over-tightening nosebands is of concern to equitation scientists and some veterinarians (McLean and McGreevy, 2010b, McGreevy 2015). In dressage, riders are penalised if their horses open their mouths, so there may be an incentive for riders to prevent mouth opening. If this practice increases the riders’ control of their horses, an additional incentive arises. Tight nosebands may have an appeal to riders but may mask undesirable oral activity and increase sensitivity to the bit(s) at the expense of horse welfare. It is possible that tight nosebands cause pain and possible tissue damage as the horse fights against the noseband in attempts to seek comfort through various oral activities.

Preliminary research suggests the possibility that vascular perfusion to the muzzle may be compromised by tight nosebands (McGreevy et al., 2012). As a response to growing concern about the practice of over-tightening nosebands, the International Society of Equitation Science (ISES) designed a simple device (the ISES Taper Gauge) with geometric features analogous to one finger and two fingers (ISES, 2012). The gauge was designed to allow riders and competition organizers to assess and regulate noseband tightness. The society also issued a position statement advising regulatory authorities and riders to check noseband tightness levels to ensure that the horse is not subjected to excessive pressure (ISES, 2012). However, over the past four years, the uptake of the taper gauge by equestrian governing bodies has been negligible. This may reflect the lack of available data on the prevalence and possible consequences of excessively tight nosebands. The aim of the current study was to provide data on current noseband design, position and tightness in equestrian competition.

**Materials and Methods**

**Taper gauge**

The ISES Taper Gauge (Figure 22) was designed to allow riders, coaches and tack inspectors at competitions to measure and regulate noseband tightness levels. It tapers
smoothly from one finger diameter to that of two fingers, as determined from a sample of ten adult males and ten adult females, (circumference 102 mm) (McGreevy et al, 2012). The Taper Gauge was used to estimate the tightness of the nosebands reported in the current study.

Figure 22 Taper Gauge designed by the International Society for Equitation Science to allow measurement of approximate noseband tightness. At standard recommended noseband tightness, the taper gauge can be easily inserted beneath the noseband as far as the 2 Finger notch.

**Callipers**

Tuberculosis skin thickness callipers (Duggan Veterinary Supplies Ltd, Tipperary, Ireland), were used to measure noseband width and position. These callipers were designed specifically for use on skin and, as such, have blunt, rounded arms that can grasp a fold of skin without causing skin damage and therefore do not pose a risk to the horse in this context.
Animals
Approval from the University of Limerick Animal Ethics Committee was granted to assess the type and method of usage of nosebands in competition in the disciplines of eventing, show jumping and dressage (Number 2013_6_1_ULAEC). Competitions were selected where the horses were required to undergo a formal tack inspection immediately prior to, or following, their participation in the competition.

Venues
Data were collected at the following locations:

1. Young Horse Eventing League, Ireland

Data were collected from horses (n=139) competing in an annual eventing league for young (4 and 5 year old) horses run one day per week over five weeks at various locations in Ireland. This league is conducted under the regulations of the Future Event Horse League (FEHL). All horses were required to undergo a tack inspection prior to completing the cross-country phase.


Data were collected from horses and ponies (n=143) competing at the Dressage Ireland National Dressage Championships run over three days. Permission was sought from riders as they left the arena after completing their dressage test.

3. International CCI* and CCI** event, UK.

This FEI event was conducted under FEI and British Eventing regulations and run over three days. All horses were subjected to a tack inspection, carried out by FEI tack stewards immediately following the dressage phase of the event. Data were collected from horses and ponies (n=213) immediately following the official tack inspection during two days of the competition.

4. National Dressage Championships, Belgium

This event was run and organised by the FEI, under FEI regulations over three days. All horses were subjected to a tack inspection carried out by FEI tack stewards immediately following the dressage test. Data were collected from horses and ponies (n=126) immediately following the official tack inspection during two days of the competition.
5. Performance Hunter Classes, Ireland

Data were collected during performance hunter classes for both Connemara ponies and Irish Draft horses (n=62). This competition was organized and regulated by the FEHL. Data were collected during a tack inspection carried out immediately prior to competing during one day.

6. International Dressage CDI 3* show, Belgium

This event was conducted under FEI regulations and run over a six day period. All horses were subjected to a tack inspection, carried out by FEI tack stewards immediately following the dressage test. Data were collected from horses (n=54) immediately before the official tack inspection during one day of the competition.

All noseband measurements and tightness level assessments were carried out by the author. An assistant recorded data including noseband type during competitions listed 1 – 3 above. All data were recorded by the author during competitions 4 – 6. The competition venues were chosen on the basis of permission being given by the organizers, officiating FEI stewards or governing bodies. A written outline of the purpose of the data collection was placed immediately adjacent to the location of data collection at each location. Verbal queries were addressed as they arose. Riders were not obliged to permit data collection if they did not wish to participate in the study. A small number of riders (n=13) were unwilling to participate in this study. A check-sheet and clip-board were used on each occasion to record data on noseband tightness, width, position and noseband type. Data were collected between June 2013 and March 2016 and stored in a spreadsheet (Microsoft Excel, 2010).

The following data were collected and recorded:

1) Date and competition (or class in which the horse was competing) were recorded as well as location of competition.

2) Age of horse – where available. Recording of horse age was not possible for all classes but age data were recorded for the young event horse classes and the international event.

3) Horse and rider details were recorded to allow identification of horses that had been presented at previous competitions. Repeat measurements were not taken on individual horses.
4) Type of noseband. This study did not differentiate between different types of cavesson noseband and therefore crank nosebands were assigned to the same group as the standard cavesson.

5) Width of the noseband in mm: This was measured by placing the arms of the callipers on the caudal and rostral margins of the noseband lateral to the nasal bone, approximately level with the ventral edge of the facial crest (Figure 23).

6) Distance between the ventral edge of the facial crest on the right hand side of the face and the upper (caudal) margin of the noseband immediately distal to the facial crest was measured using the callipers (Figure 24). The measurement was not recorded for either grackle nosebands (n = 49) or Micklem bridles (n = 26) as the position of the noseband in both of these was above the ventral edge of the facial crest.

7) Tightness of the noseband. The tightness of the noseband was assessed in the midline of the nasal planum, by sliding the ISES Taper Gauge under the noseband, in a rostro-caudal direction as far as it would progress without causing dorsal displacement of the noseband on the nose, or elevation of the horse’s head. Dorsal displacement of the noseband on the nose or elevation of the horse’s head were regarded as evidence of excessive force.

Figure 23 Use of TB callipers to measure the width of the noseband (mm)
Figure 24 Use of TB callipers to measure distance (mm) between rostral margin of facial crest and caudal margin of noseband

Noseband tightness was categorised as follows:

- Zero fingers (0 F): the noseband was too tight to allow the tip of the taper gauge to be inserted beneath the noseband.
- 0.5 fingers (0.5 F) = the tip of the taper gauge could be introduced beneath the noseband but the gauge could not be moved upward under the noseband to the 1 finger notch without excessive force.
- 1 finger (1.0 F) the taper gauge could be moved comfortably to the 1 finger notch, but no further without excessive force.
- 1.5 fingers (1.5 F) the taper gauge could be moved easily beyond the 1 finger notch but not as far as the 2 finger ridge without excessive force.
- 2.0 fingers (2.0 F) the taper gauge could be easily moved to the 2 finger ridge with minimal force.
- Nosebands fastened so loosely as to permit the taper gauge to move easily beyond the 2 finger ridge were recorded as greater than 2.0 fingers.
Data Analysis

Analysis was carried out using SPSS (IBM SPSS Statistics, Version 22, 2015). Kolmogorov-Smirnov values were generated to test the data for normality. The Kruskall-Wallis test was used to compare noseband tensions in each of the three disciplines of eventing, dressage and performance hunter. Mann-Whitney tests were used to compare noseband tightness levels between disciplines, competition type and age of horse. Mean ± standard error of the mean, and also median and interquartile ranges for noseband width and distance between rostral margin of the facial crest and dorsal margin of the noseband were calculated.

Results

Data were collected from 750 horses and ponies, of which 47% (n=354) were competing in eventing, 45% (n=334) were competing in dressage and 8% (n=62) were competing in performance hunter classes. Noseband width values (Figure 25) had a non-parametric distribution (D(663)=0.07, p < 0.001). Measurements of distance between the facial crest and the proximal (upper) margin of the noseband were not normally distributed (D(619)=0.08, p < 0.001. Noseband tensions were not normally distributed (D(737)=0.281, p < 0.001).

Noseband Type

The flash was the most common noseband (n=326) and the drop noseband the least common (n=17) (Figure 25).
Figure 25 Frequency of usage of five different noseband types on 750 horses competing in eventing, dressage and performance hunter classes

**Noseband Width**

![Graph showing distribution of noseband widths](image)

Figure 26 Distribution of noseband widths (mm) found on 750 horses competing in eventing, dressage and performance hunter classes

Noseband width ranged from 10-50 mm (median = 30 mm, IQR = 22, 35) (Figure 26) and was greatest in dressage competitions (Figure 27).
Figure 27 Boxplots displaying median and interquartile range of measurements for noseband widths (mm) distributed over six competition types. Widths differ significantly except where they share a superscript.

Noseband position

Figure 28 Noseband position histogram for distance (mm) between the rostral margin of the facial crest and the caudal margin of the noseband (n=619).
The median noseband position was 17mm from the facial crest and measurements ranged from 0 mm to 70 mm (Figure 28). There was no significant difference in this measure between noseband types (H=3.65, p=0.45). There was a significant difference in the distance of the noseband to the facial crest within competition type (Figure 29). The noseband–to-crest distance was significantly less for the dressage phase of the international event than it was for both the dressage championships, Ireland (U = -107.03, p < 0.001) and the international (CDI) dressage competition in Belgium (U = -109.04, p < 0.005). No other significant differences were found between competition types.

Figure 29 Boxplot showing median and interquartile range of measurements of distance from the rostral margin of the facial crest to the dorsal margin of the noseband (mm) for six competition types. Values with different superscripts differ significantly.
Dressage Championships, Ireland had the highest mean noseband-to-crest distance (21 ± 1 mm) with a median of 20 mm and an interquartile range of 13 – 28 mm, followed by the international (CDI) dressage competitions, Belgium (20 ± 1 mm) with a median of 20 mm and an interquartile range of 16 – 24 mm. Young Event Horse Classes had a mean noseband-to-crest distance of 18 ± 1 mm, with a median of 18 mm and an interquartile range of 12 – 23 mm, while Performance Hunter Classes had a mean noseband-to-crest distance of 19 ± 2 mm with a median of 17 mm and an interquartile range of 11 – 23 mm. The lowest mean noseband-to-crest distances were in the dressage phase of the international event (16 ± 1 mm) with a median of 15 mm, an interquartile range 10 – 21 mm and in the dressage championships in Belgium with a mean of 18 ± 1 mm, a median of 16 mm and an interquartile range of 13 – 21 mm (Figure 29).

**Noseband tightness**

Figure 30 Distribution of noseband tightness measurements found in horses (n = 750) competing in the disciplines of dressage, eventing and performance hunter. Tightness (Fingers) is measured as the number of fingers that fit flat under the noseband at the frontal nasal plane.
The median noseband tightness in all horses measured (n=737) was found to be 0.5 fingers. Forty four per cent of nosebands were tightened to zero fingers tightness, 7% to 0.5 fingers, 23% to 1 finger, 19% to 1.5 fingers and 7% to 2 fingers tightness (Figure 30).

Noseband tightness measurements for individual disciplines were not normally distributed (eventing: D(352) =0.328, p < 0.001, dressage: D(323) =0.241, p < 0.001, performance hunter: D(62) = 0.224, p < 0.001). There were significant differences in noseband tightness levels among the three disciplines (eventing, dressage and performance hunter) (H(2) =27.99, p < 0.001). Tightness levels of nosebands were highest in eventing competitions (Mdn = 0.0) (n=352), then in dressage competitions (n=323) (Mdn = 1.0, p < 0.001) and were lowest in performance hunter classes (n=62) (Mdn = 1.0, p < 0.001).

There were significant differences in noseband tightness levels between different competition types (H=47.34, df=5, p < 0.001) (Figure 31).

Figure 31 Boxplots showing median and inter-quartile range of measures of noseband tightness level (Fingers) in 6 different competition types. Tightness levels differ significantly except where they share the same superscript.
Adjusted significance p values for multiple comparisons of noseband tension between competition types are shown in Table 8.

Table 8 Results of pairwise comparisons (Mann-Whitney U and Adjusted Significance p values) of noseband tension levels between different competitions

<table>
<thead>
<tr>
<th>Competition</th>
<th>Mann-Whitney U</th>
<th>Adjusted significance p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dressage phase of international event – Dressage Championships Ireland</td>
<td>-104.39</td>
<td>0.001</td>
</tr>
<tr>
<td>Dressage phase of international event – Performance Hunter</td>
<td>124.18</td>
<td>0.001</td>
</tr>
<tr>
<td>Young event horse class - Dressage Championships Ireland</td>
<td>-95.04</td>
<td>0.001</td>
</tr>
<tr>
<td>Young event horse class - Performance Hunter</td>
<td>-114.83</td>
<td>0.01</td>
</tr>
<tr>
<td>Dressage Championships Belgium - Performance Hunter</td>
<td>98.95</td>
<td>0.006</td>
</tr>
<tr>
<td>Dressage Championships Belgium - Dressage Championships Ireland</td>
<td>79.17</td>
<td>0.005</td>
</tr>
<tr>
<td>International Dressage (CDI) Belgium – Dressage Championships Ireland</td>
<td>119.59</td>
<td>0.003</td>
</tr>
<tr>
<td>International Dressage (CDI) Belgium - Performance Hunter</td>
<td>140.34</td>
<td>0.003</td>
</tr>
</tbody>
</table>

Within eventing competitions, no significant difference was found in noseband tightness level between horses competing in the dressage phase (n=213) and at the cross-country phase (n=139) (U=9.35, p>0.05). The horses sampled and competing in the cross-country phase of the event were all competing in a league run for young event horses only, so data were collected from either four or five year old horses. These had
noseband tightness levels which were not significantly different to those at the dressage phase (age range 6-19 years). Similarly, comparison of noseband tightness between four year old horses (n=80) and five year old horses (n=59) found non-significant differences although the tightness levels in the older horses were higher (U=2064, p>0.05).

Figure 32 Boxplots displaying median and interquartile ranges of scores for noseband tightness measured for five different noseband types. Tightness levels differ significantly except where they share the same superscript.

Significant differences in noseband tightness were found between the five different types of noseband used by competitors (H=74.89, p < 0.001). The flash noseband was found to be significantly tighter than the drop noseband (U=239.28, p < 0.001) and also the cavesson (U=117.99, p < 0.001) and Micklem (U=164.23, p < 0.005) (Figure 32). Differentiation was not made between different cavesson noseband types. Therefore, the cavesson results included both plain and crank cavesson nosebands. Median, interquartile range, mean and standard error values of noseband tightness for five different noseband types are shown in Table 9.
Table 9 Median, interquartile range, mean and standard error values of noseband tightness levels found for five different noseband types

<table>
<thead>
<tr>
<th>Noseband Type</th>
<th>Median</th>
<th>Interquartile range</th>
<th>Mean</th>
<th>SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cavesson</td>
<td>1.0</td>
<td>(0.0, 1.5)</td>
<td>0.9</td>
<td>0.04</td>
</tr>
<tr>
<td>Flash</td>
<td>0.0</td>
<td>(0.0, 1.0)</td>
<td>0.5</td>
<td>0.03</td>
</tr>
<tr>
<td>Grackle</td>
<td>0.5</td>
<td>(0.0, 1.0)</td>
<td>0.7</td>
<td>0.09</td>
</tr>
<tr>
<td>Micklem</td>
<td>1.5</td>
<td>0.0, 1.5)</td>
<td>1.0</td>
<td>0.14</td>
</tr>
<tr>
<td>Drop</td>
<td>1.5</td>
<td>(1.0, 2.0)</td>
<td>1.3</td>
<td>0.17</td>
</tr>
</tbody>
</table>

Discussion

The study described shows that 44% of competition horses in dressage and eventing competitions at national and international level, under the regulations of the FEI, British Eventing, Dressage Ireland and the Future Event Horse League had nosebands tightened to such an extent that it was not possible to insert the ISES taper gauge under the noseband (classified as zero fingers’ tightness). This indicates a widespread tendency to tighten the noseband to a substantially higher level of tightness than that suggested in equestrian texts (Anon, 1956, Stecken, 1977, Klimke, 1994, Huntington et al, 2004, Kapitzke, 2004, Muir and Sly, 2012). Over half of all nosebands tested were tightened to 0.5 fingers or tighter. Only 7% of nosebands were fitted at the tightness level of 2.0 fingers, and only one noseband (0.1%) was at greater than 2.0 fingers tightness level. The authors acknowledge that the methodology did not allow for more exact measurements than those possible using the ISES taper gauge. The use of the taper gauge was intended to ensure that the results of the current study are relevant to those considering the ISES position statement and historic advice. However, the findings, grouped into six tightness levels, give an indication of current noseband usage trends. They highlight the need for further research into riders’ motivations to tighten nosebands excessively.

Regulations within some equestrian disciplines prohibit certain noseband types while others, such as elite dressage competitions mandate double bridles with cavesson noseband (of which the crank type is the most common). Crank nosebands allow a doubling of the tightness achievable for a given amount of handler effort.
The tightest nosebands were found among eventing horses. This is not entirely surprising since the control of a horse is inherently more challenging as the horse is ridden at speed towards, and over, obstacles and over uneven terrain (Ekberg et al., 2011). However, any use of relentless pressure defies the principles of learning theory since it does not provide an opportunity to release the pressure and condition the horse through negative reinforcement (McLean and McGreevy, 2010b). Thus, riders who come to rely on tight nosebands are effectively training their horses to work only with such devices.

For performance hunter classes, horses are ridden over a variety of obstacles that can include show-jumping and cross-country type fences. Competitors are also required to execute basic ridden movements similar to a simple dressage routine which are often performed immediately after completion of the show-jumping phase. Horses are frequently ridden in a show-type bridle which typically includes a plain cavesson noseband, without the crank functionality. The absence of the crank function may, in part, explain the lower noseband tightness found in the performance hunter class in this study.

The current study reveals the prevalence of restrictive noseband usage on competition horses of all ages. Noseband tightness levels does not appear to be influenced by the stage of training or the particular traits of the horse being ridden since tightness did not differ significantly between young and older event horses in the study. The widespread usage of tightness levels of less than two fingers may be indicative of habitual or routine over-tightening of nosebands as a pre-emptive response rather than as a consequence of previous training or control problems.

The findings of this study indicate that most competition riders, in the disciplines of dressage and eventing, in at least three European countries use tight nosebands. However, some equestrian sports such as reining show no reliance on nosebands. In the absence of regulations or guidelines outlining recommended or permitted noseband tension in competition, competitors are free to adjust the noseband to the tightness level that they deem necessary or appropriate. The widespread use of tight, i.e. less than 2.0 fingers, nosebands in the current study in three European countries and across the disciplines of eventing and dressage under FEI and national federation regulations points to the need for similar, more extensive studies to establish the prevalence of this practice worldwide. The lack of regulation of noseband tightness in competition may
reflect the lack of available data on noseband usage and on the possible consequences of excessively tight nosebands.

Several reasons for using a tight noseband have been suggested. A tight noseband may reduce the likelihood of horses opening their mouths (Micklem, 2003). Mouth-opening is penalised if it occurs during dressage competition, as it is interpreted as a resistance or evasion (McGreevy, 2015, FEI, 2016). Oral movements, such as putting the tongue over the bit or moving the position of the bit in the oral cavity, are likely to be inhibited by restrictive nosebands (Kapitzke, 2004, Heuschmann, 2006, McGreevy and McLean, 2010). Such movements, often called evasions, may reduce the impact of bit pressure and thus compromise rider control. Preliminary research on the relationship between noseband tightness and response to bit pressure indicates that tight nosebands result in increased sensitivity to bit pressure (Randle and McGreevy, 2013, Pospisil, 2015). This effect may be as a consequence of compression of the oral structures including the lips and tongue. In a UK survey, 84% of riders (n= 790) reported lack of responsiveness to bit pressure, including not slowing down when asked to, and jogging when asked to walk (Hockenhull and Creighton, 2012). The current findings may reflect riders’ efforts to address such problems, at least partly, by tightening nosebands, rather than putting the required time into training horses to slow, stop or stand still from a rein cue (Ladewig, 2011).

Mouth-opening is thought to be a manifestation of oral discomfort (Christensen et al., 2011) and can be a response to increased rein tension (Manfredi et al., 2009). Possible adverse consequences of excessive tightening of the noseband include restriction of mouth-opening and other normal behaviours (McGreevy et al., 2012), pain, tissue damage, buccal ulceration/laceration as a consequence of buccal mucosa being pressed against the sharp edges of premolar teeth (Tell et al, 2008) and some restriction on breathing (Kapitzke, 2004).

Few data are yet available on the physiological effects of noseband pressure on the sub-noseband tissues of horses. Some information on the effects of compressive devices such as tourniquets and ligatures on human tissue is available (Shaw and Murray, 1982, Noordin et al., 2009) and this may provide some guidance for future equine studies. Improper tourniquet use can result, for instance, in neuron (nerve cell) damage after compression at 50 mmHg over two hours, with more damage at higher pressures (Rydevik and Lundborg, 1977). Following the use of a tourniquet, electromyographic
and functional evidence of damage to nerve conduction and muscle function has been reported in 71% of patients (Dobner and Nitz, 1982). Similarly, some degree of impaired sciatic function in dogs is associated with every tourniquet application (Rorabeck and Kennedy, 1980). Pain caused by pressures of 300-400 mmHg resulted in half of the human participants being withdrawn from a tourniquet study (Hagenouw et al., 1986). A tight noseband exerts pressure directly on superficial anatomical structures of the horse’s head. These include several muscle groups, the lateral nasal artery and vein and the facial and infraorbital nerves. If the pressures exerted by a noseband result in neural damage, possible cumulative effects include denervation (and subsequent desensitization of an area) or trigeminal neuritis, a condition thought to be associated with head-shaking in horses (Newton et al., 2000, Madigan and Bell, 2001, Roberts et al., 2013). While desensitisation through anaesthesia of local nerve supply is useful in medical practice, the consequence in equitation may be a reduced sensitivity to facial and oral pressures exerted by riders.

**Conclusion**

Tight nosebands are a common feature of equestrian competition, with almost half of eventing and dressage competitors assessed in Ireland, England and Belgium tightening the noseband to the maximum possible tightness level. Seven per cent of nosebands assessed allowed two fingers to be placed beneath the noseband at the nasal planum, with the remainder of nosebands being fitted tighter. This practice was not influenced by the age of the horse. The current study highlights the need for quantification of pressures exerted by tight nosebands.
Chapter 5

Estimating the pressures caused by a crank noseband from noseband force and facial curvature measurements.

Introduction

In equestrian sport, nosebands appear to be of value to riders in improving the horse’s response to rein pressure (ISES, 2012). It is thought that the tightened noseband sensitises the horse’s mouth, making the horse appear to be more ‘submissive’ (Randle and McGreevy, 2013). The rules of dressage create an incentive for the use of restrictive nosebands to improve ‘submission’, as penalties and lower marks apply if the horse is judged to be resisting the bit by opening its mouth or lolling its tongue out (FEI, 2016). This is unfortunate because the ‘submission’ marks are meant to reward lightness as evidence of excellent training. However, lightness is the quality on which judges are least likely to agree (Hawson et. al., 2010b).

The rules of dressage state that the use of certain nosebands is prohibited in competitions that mandate the use of a double bridle (McGreevy et. al., 2012). The use of a cavesson, or plain, noseband is permitted so long as it is “never as tightly fixed so as to harm the horse” (FEI, 2016). However, the rules fail to stipulate exactly how to measure the tightness of the cavesson. Therefore, because of the aforementioned (inadvertent) incentives, there is increasing use of nosebands that can be tightly levered or cranked so as to prevent any mouth opening (McGreevy et. al., 2012). There is anecdotal evidence of horses having bony changes including new bone formation consistent with chronic trauma at the site of nosebands, although no radiographic evidence has yet been published.

It has been shown that movement of the tongue is a mechanism by which horses attempt to dissipate pressure from the bit throughout the oral cavity (Manfredi et. al., 2009). It is suggested that the use of a tight noseband may limit the horse’s ability to move its tongue, thus resulting in the inability to relieve pressure on sensitive oral tissues.
including the bars of the mouth, the tongue and the hard palate (McGreevy et. al., 2012). Excessively tight nosebands, by definition, violate the so-called Five Freedoms (a list of criteria drawn up by the Brambell Committee in 1965) which are deemed necessary to ensure the welfare of animals under human management, in that they prevent the expression of normal behaviour but the transience of their use may mitigate the overall impact (Jones and McGreevy, 2010).

The aim of this pilot study was to establish a method for investigating the pressures applied across the nasal planes of riding horses at the level of the usual site of nosebands. This approach is likely to be of use in describing mechanisms that underpin the apparent lesions seen in horses that have been exposed to excessive pressure and should help inform the welfare concerns associated with excessively tight nosebands.

Materials and Methods

A ten year old cob gelding was fitted with a snaffle bridle (Elevator Bridle, XBSELS-F16BK, Full Size, E. Jeffries & Sons Ltd, England) with a single-jointed snaffle bit (with a 12.5 cm long mouth-piece) and a crank cavesson noseband (Figure 33). The noseband comprised two leather straps, a dorsal strap and a ventral strap normally linked using ‘D-rings’. The ventral strap supported a rectangular leather pad (125 mm long by 45 mm wide) of relatively uniform cross-section. The dorsal strap was non-uniform in section (see insert to Figure 33). A basic single strain gauge loadcell, designed to work over a force range of 0 to 100 N and calibrated over this range using masses in the range 0 to 10 kg, was fixed to the D-ring of the crank noseband while the other end was connected to the leather strap using a ‘T’ type link through a punched hole (Figure 33 and insert).
Figure 33 Single strain gauge on aluminium support linking the ventral strap to a D-ring of the noseband dorsal strap. The left insert shows the cross-sectional dimensions of the dorsal strap. The right insert shows a close-up of the loadcell.

The loadcell was wired to an Emant 300 USB DAQ system (Emant Pte Ltd., Singapore) which in turn was connected to a laptop running the Labview (National Instruments Ltd., UK) data acquisition and control package. A custom Labview Virtual Instrument (VI), developed to display and record the loadcell output at a sampling rate of 10 Hz was used. Foam padding was wrapped around the USB DAQ which was supported on a strap (a stirrup leather) on the horse’s neck (Figure 34). The loadcell was also wrapped in foam to provide a degree of shock protection and temperature stability.
Figure 34 Bridle fitted with Emant DAQ covered in protective foam (A) and attached to a stirrup leather placed round the neck. The loadcell (B) was also covered in foam for comfort and to improve temperature stability.

Three test exercises were carried out with the noseband fitted to a normal tightness level, whereby 2 fingers could easily fit under the noseband at the nasal plane (McGreevy et. al., 2012). Data were collected while the horse chewed hay, a concentrate feed mix (Horse and Pony Cooked Mix, Gowla, Tipperary, Ireland) offered in a bucket at waist height, and while the horse was given simultaneous voice and rein cues to step back. The feed-related treatments were chosen to allow identification of the range of forces exerted by chewing and mouth opening movements, as are frequently seen in the ridden horse. The step back test was selected because it is a simple, restricted linear motion exercise, elicited through rein pressures. Tests feasible while the horse was stationary were necessary as the load-cell was wired to the laptop data logger. Recording of data was continued both during the presentation of food and following the withdrawal of food when mastication continued for between 2 and 3 minutes. The
sequence was repeated three times. The microvolt output of the system was converted
directly to force using the calibration factor (5.86 \( \mu \)V/N). Tests were simultaneously
recorded using two digital camcorders, a Toshiba Camileo x400 placed approximately 4
m in front of the subject and a Supacam X5M placed 2 m to the right of the subject,
each mounted on tripods.

Following a procedure similar to that outlined in Casey et al (2010) based on principles of
compression therapy (Thomas, 2002), the pressure applied by the noseband to the
underlying tissue at any point along the internal surface of the noseband may be
estimated using LaPlace’s Law which, from the perspective of noseband studies, may
be expressed as \( P = \alpha \kappa F/W \), where \( \alpha \) is a unit conversion factor having a value of one
for Pascals (Pa, or N/m\(^2\)), \( \kappa \) is the curvature which to a first order approximation is the
reciprocal of the local radius of curvature, \( R \) (m), of the noseband (in the plane of the
noseband), \( \kappa = 1/R \) (m\(^{-1}\)). \( F \) (N) is the longitudinal force in the noseband obtained
experimentally using the loadcell. The force is assumed to be uniform around the
noseband. This is a reasonable assumption since the noseband is free to slide over the
supporting tissue. \( W \) (m) is the width of the noseband. It is more convenient to use units
of cm for \( W \), cm\(^{-1}\) for \( \kappa \), and mmHg for pressure (rather than Pa) in which case \( \alpha \) has
the value 75 (Eqn. 1).

\[
\text{Eqn. 1}
\]

\[
P = \frac{75 \kappa (cm^{-1}) F (N)}{W (cm)} \text{ mmHg}
\]

A flexible curve ruler (Premier, http://www.silkes.ie/store/product/20556/FLEXIBLE-
CURVE-60CM/) was used to obtain profiles of the dorsal and ventral portions of the
animal’s nose at a position corresponding to that of the noseband (Figure 34). The curve
ruler was pressed against the surface of the face, in the position of the noseband, to
achieve the correct contour. The ruler was then used to transfer the partial nose profile
onto graph paper to facilitate digitization, (Figure 34). The software package FindGraph
(© UniPhiz Lab), was used to digitize the profile from a scanned image (1 to 1 aspect
ratio). This generated an x-y data set for each profile based on calibration points marked
on the profile. The use of pre-marked calibration points (only two required per profile)
allowed verification of accurate profile transfer (Figure 34).
Figure 35 Capture of ventral and dorsal head profile at noseband level using flexible curve ruler

The Maple computer algebra package (© Maplesoft, Canada) was used to develop a Maple worksheet to calculate the first and second order derivatives of the analytical polynomial expression for the profile and through substitution into the above expressions for radius-of-curvature, (Eqn. 2), to provide a curvature data set, $\kappa(x)$.

**Eqn. 2**

$$ R = \frac{1 + \left( \frac{dy}{dx} \right)^2}{\frac{d^2y}{dx^2}}^{\frac{3}{2}} $$
Results

Figure 36: Extracts of force (N) versus time (s) data for horse eating hay. Mean estimated peak height (50 N) is identified (dotted line).

Figure 37: Extracts of force (N) versus time (s) for horse eating concentrate feed from a bucket. Mean estimated peak height of 40 N recorded during prehension of concentrate feed from a bucket (dotted line) dropped to 20 N during steady chewing.
Representative data segments for the three test conditions are shown in Figures 36, 37 and 38. The peak forces were caused by opening of the mouth against the closed noseband, thereby increasing the tension (longitudinal force per unit width) in the noseband. Closing the jaw reduced the tension. An average peak force value of 50 N was measured during the chewing of hay, (Figure 36). The value for eating concentrate feed was closer to 40 N while the horse was picking up feed with the lips but dropped to 20 N or lower for chewing (Figure 37). Higher than average peaks for both hay (at approximately 62 and 72 seconds, Figure 36) and concentrate feed (at approximately 65 and 80 seconds, Figure 37) appeared, from video footage, to correspond to movement of the food bolus within the mouth. Extremely high peaks occurred when feed was first offered (45 s) and later during feeding (78 s, approximately, Figure 37), corresponding to the horse biting at the grain in the bucket. The results for the step back exercise depended strongly on the horse’s level of compliance with the cues given (simultaneous use of voice and rein tension). The data plotted in Figure 38 shows peaks corresponding to head tossing at 509 and 511 seconds approximately; where head tossing occurred in advance of being given the cues to step back. Large peaks (in excess of 200 N) are seen where the horse resisted the cue (at 512 and 513 seconds approximately, Figure 38).
However, average peak values for compliance with the step back cue were closer to 25 N or less and were indistinguishable from normal mouth action. Once step back commenced, noseband force dropped close to zero. Large forces similar to those shown in Figure 37, i.e. values in excess of 250 N, were generated when the horse lowered his head towards the ground while opening his mouth. Since these forces were outside the calibration range (100 N) the data indicates only the presence of very large forces but the absolute values could not be measured.

The results for average peak force values found for eating agree with previous studies which found that the amplitude of mouth opening movement is influenced by feed type, with hay resulting in greater excursions of the mandible than concentrate feeds (Bonin et al, 2007). In addition, chewing of concentrate feed was found, in the current study, to follow a regular, constant amplitude pattern, whereas chewing of hay was punctuated by pauses and irregular peak sequences.

The digitized data points representing the dorsal and ventral profiles of Figure 39 are plotted in Figure 40 and Figure 41 respectively, along with the best fit polynomial curves for each data set. A seventh order polynomial was found to give a very good fit to both profiles (Correlation coefficient, $R^2 > 0.99$). The corresponding curvatures, calculated as outlined above from the polynomial curves, are also plotted in Figures 40 and 41. The curvature for the dorsal profile is entirely positive indicating that the slight profile depression either side of the sagittal plane has been smoothed out by the profile transfer and curve fitting process. In contrast, the pronounced profile depression around the sagittal plane for the ventral profile is clearly resolved and produces a corresponding negative curvature, Figure 41.

By substitution of the curvature data into Eqn. 1 and using the average of the peak force values measured directly for each test condition used in the study, e.g. 50 N (eating hay), 40 N (eating feed concentrate), 25 N (step back), as $F$, it is possible to infer a sub-noseband peak pressure profile for each test. These are plotted, for the dorsal profile case, in Figure 42. While the peak curvature in the region of the mandibular rami ($\kappa \approx 0.62$) is almost double the value at the lateral nasal margins ($\kappa \approx 0.34$), the wide rectangular pad that contacts the mandible ($W = 4.5$ cm) reduces the overall effect of this increased curvature and so peak pressure values at the mandibular rami are likely to be only larger by a third than the peak values at the lateral nasal margins, i.e. $(0.62 / 0.34) \times (33 / 45) = 1.33$. 
Figure 39 Schematic representation of profiles obtained from dorsal (upper trace) and ventral (lower trace) nose locations corresponding to noseband position with (x, y) digitization calibration points superimposed.

Figure 40 Plot of 7th order polynomial representing the partial equine nose profile (y) and corresponding curvature (Kappa) at the dorsal noseband location.
Figure 41 Plot of 7th order polynomial representing the partial equine nose profile (y) and corresponding curvature (Kappa) at the ventral noseband location.

Figure 42 Predicted pressure values based on measured noseband force and noseband curvature for the dorsal profile of Figure 26: ○ - hay; □ - feed concentrate; ◊ - step back (little resistance).
Discussion

While noseband force and tension measurements may provide useful animal behaviour insights, the utility of such measurements would be extended considerably if the data could be transformed into localised pressure values occurring at interfaces between the noseband and key anatomical sites such as the mandibular rami, lateral margins of the nasal bone and soft tissue covering the vestibular surface of the molar teeth. Following an approach used previously to infer pressure variations under a nominally constant tension bandage based on limb profiles extracted from MRI scan sections of a human leg (Casey et al., 2010), profile curvature and force data were combined in order to provide a lower estimate of the in vivo pressures likely to occur at some of these sites under a noseband at normal tightness level.

The use of a load cell as described demonstrates the feasibility of using such a device to establish in vivo bridle noseband forces. The configuration reported allows noseband tightness to be adjusted. Extra holes were punched in the noseband strap to allow shortening of the strap to compensate for the inclusion of the linked loadcell. However, the leather strap was not looped through the D-ring so the tightening functionality of the crank noseband was moderated. This could be overcome by replacing the chrome/steel D-ring with an aluminium D-ring with integrated strain gauges. The noseband was tightened only to the recommended level of tension (two fingers could fit comfortably beneath the noseband). Therefore, it seems likely that, although tight, this noseband would have to be substantially tighter to adequately replicate competition conditions.

The flexible curve ruler method of profile extraction is simple and reasonably effective but is limited to partial nose profiles. The recorded profile shows both positive (convex) and negative (concave) curvature. Positive curvature arises where the centre of curvature is inside the tissue or support body. The noseband will rest on the tissue in such regions. Negative curvature arises where the centre of curvature is outside the tissue. In such regions, the noseband will ‘hammock’ between prominences on either side (O’Brien and Casey, 2002), i.e. it will not be in contact with the tissue underneath and so cannot apply any pressure. In this situation the load is redistributed or concentrated at the prominences. The curvature plots identify very clearly where such critical load bearing regions are likely to occur. For instance, the curvature peaks at the lateral edges of the nasal plane identify these locations as likely to be subject to concentrated forces and pressures. This finding echoes that of Murray et al (2015) who measured forces of $64 \pm 19\text{N}$ at this location in 10 horses wearing crank nosebands,
measured at trot. No details are given regarding tightness level of the nosebands in that study.

A slight depression between the nasal bones at the location of the usual noseband position was found to have a depth of approximately 2.5 mm below the edges of the nasal bones. A Vernier callipers depth gauge was used to measure this indentation. However, the curve ruler method of profile extraction tends to smooth out such small undulations (see dorsal profile, Figure 26). The polynomial fit algorithm introduces further smoothing unless higher order terms are used, i.e. greater than 4th order. Increasing the order can, however, amplify digitization artefacts associated with the profile transfer process.

The noseband applied pressure is expected to be highest at regions of high curvature (Eqn. 1). The pressure values predicted here are most likely conservative estimates of the actual pressures under the noseband. In the current analysis, we assumed that the noseband has a flat transverse inner profile. However the inner transverse profile of the noseband is more complex (see insert to Figure 21), with a central convex prominence where the leather bulges between two lines of stitching, with a radius of curvature of about 2 cm corresponding to a transverse localised curvature of 0.5 cm⁻¹. This is similar in value to the peak curvatures in the longitudinal direction. A compound curvature may be calculated if necessary. However, in simple terms, the transverse curvature of the noseband will add to the longitudinal curvature of the anatomical structures producing pressures significantly in excess of what has been calculated here. Thus the transverse convex profile reduces the effective width of the noseband making it more severe than would be expected from simple width measurements. Combined with this, the hammocking effect will tend to further increase pressures at anatomical prominences such as the mandibular rami.

The predicted peak pressures ranged from 200 to 400 mmHg but, as is clear from the head tossing data, considerably larger pressures are likely to arise. Acute pressure gradients can produce tissue damage including nerve damage (McEwen and Casey, 2009). The preliminary data described in this study strongly suggest the need for further research in this domain. A possible future approach may be to use a combination of force/tension measurement with an integrated noseband loadcell and pressure sensor deployment at a site such as the wide/flat mandible pad which offers the best prospects for reliable pressure measurement. One could use the single pressure measurement as a
datum level from which pressures at other sub-noseband anatomical sites could be ‘indexed’ based on actual force measurements and known or measured anatomical profiles. These developments would permit the capture of combined pressure and force noseband data for simple stationary activities such as chewing hay and concentrate feeds, licking and crib-biting, most of which behaviours can be easily elicited (McGreevy, 2004). Similarly this approach could be used to gauge the pressure level that deters a horse from attempting to yawn or chew. A wireless version of the load cell similar to wireless pressure measurement systems already developed (Casey, 2012) would allow measurements to be carried out while the animal is being exercised, schooled or competing in an arena.

While a load-cell with a range of 100 N may be adequate for ‘gentle’ test conditions such as those used here, it is likely that devices with considerably expanded range will be required to reliably quantify the noseband forces arising during routine exercise and competition conditions. The use of a 0-100 N load-cell force range was made based largely on the materials available rather than advanced knowledge of the forces expected. While this range was adequate for eating exercises combined with a ‘standard’ tightness noseband, load-cells with considerably higher range are probably required for exercise related tests.

**Conclusion**

Preliminary data from this approach to measuring pressures under a noseband identify areas on the face (left and right nasal bones on the dorsal profile, ventral aspect of the mandibular rami on the ventral profile) subjected to peak pressures, and the behavioural events which correspond with those pressure peaks. The approach described could be of use in studies of general oral behaviours around foraging, as well as crib-biting and wind-sucking. Further development is required before the approach described could be applied to the ridden horse, but the peaks in pressure corresponding to particular behaviours extrapolate well to behaviours frequently displayed by the ridden horse, such as chewing, head tossing and resisting pressure cues, and suggest that pressures as high as, or in excess of those calculated, may come into play against facial anatomical structures on a regular, if not frequent basis.
Chapter 6

Exploratory studies on measuring sub-noseband pressures and bit pressures on the ridden horse

Introduction
Measurement of pressures exerted by the bit and noseband in the course of ridden activities is becoming more feasible through advances in technology (McGreevy et al., 2014) but still poses challenges at several levels. Previously developed technology such as the rein tension gauge provides insights relating to rein pressures delivered through different bits (Potz et al., 2014), the level of pressure horses are prepared to endure to access a food reward (Christensen et al., 2011) or the likely oral responses to increased rein tension (Manfredi et al., 2009). Nevertheless, it remains an indirect measure of the dynamic interaction between equine tissues and the interfacing equipment (bits, bridles). Measurement of pressures at interesting tissue-device interfaces generally will require placement of discrete pressure-sensing devices at the specific site which brings with it a range of challenges (Casey et al., 2011). Temperature (Zammit et al., 2010), moisture (Jansson et al., 2013) and the presence of shear forces (Greve and Dyson, 2013) influence pressure sensor output and can produce measurement artefacts. Bit-tissue and nose-noseband interfaces are particularly challenging. Sensing devices will need to be minimally intrusive, i.e. not change significantly the nature of the interface. They will also need to operate accurately and reproducibly, i.e. hold calibration, during physically demanding and fluctuating conditions and so must be robust yet sensitive.

The aims of the studies described in this chapter were to:

- Further explore methods of measuring sub-noseband pressures with a view to extending such measurements to the ridden horse;
- Identify anatomical locations where sub noseband pressures might be usefully measured;
- Establish the feasibility or otherwise of measuring intra-oral bit pressures;
- Check the feasibility of simultaneously measuring both bit and noseband pressures in a small group of ridden horses.
Materials and Methods

Four exploratory studies were devised and carried out in order to check the feasibility of measuring bit pressures and sub-noseband pressures in the ridden horse. These were:

- Study 1: Measurement of sub-noseband pressures in the ridden horse, with sensors placed in two locations
- Study 2: Measurement of left and right bit pressures during delivery of rein cues for turns and step back
- Study 3: Simultaneous measurement of left and right bit pressures and sub-noseband pressures in the ridden horse
- Study 4: Simultaneous measurement of left and right bit pressures and sub-noseband pressures in a group of ridden horses

A system capable of wireless transmission between ridden horse and data logger (laptop/PC) is essential for such work. Two different wireless platforms and systems were used. A Zigbee wireless system with digital biomedical interface pressure transducers (pressure sensors), custom developed at UL was used for studies 1 to 3. A Bluetooth system (Emant 380 Bluetooth data acquisition module) with analogue BIPT sensors was used for study 4. Biomedical interface pressure transducers (BIPTs) (Patent Ref: US 20120330192 A1) developed for use with human tourniquets were adapted for use in these explorations. An Asus notebook (Model EeePC) running a pressure plotting application (OroPress) was used to receive, plot and store the data for off-line processing and analysis. Temperature was also measured and used to compensate the pressure signals for temperature-induced changes.

In studies 1-3, a 12 year old 153 cm gelding cob was used. During ridden trials, the cob was ridden by his owner. Habituation to both the environment and the equipment fitted on the horse was carried out prior to data collection on each occasion. A cavesson bridle (Elevator Bridle, Full size, E. Jeffries & Sons, Ltd, England) was used in all trials. Six adult amateur riders participated in study 4. All six riders stabled their horses at a private livery yard and rode their own horse in the study. The horses, four geldings and two mares, were aged from 8 to 18 years and were all receiving regular (four times weekly minimum) exercise. All had extensive experience of being ridden and had been previously ridden using snaffle bits. The saddle normally used on the horse was fitted, with a saddle blanket beneath, in the ridden trials.
Voice recordings were taken using the voice recording function on an iPhone (iPhone 5 Model MD128B/A) during which events and responses were described. Video recordings were taken during studies 1 and 3 (Supacam X5M, Supacam, Santa Monica, California, USA) and 4 (Sony Handycam HDR-XR260 8.9 (HD AVCHD Progressive)). The data measurement frequency during each trial was 100 Hz. The ISES taper gauge was used during each trial to aid noseband tightening to the desired tightness levels. In each case the bit was fitted so that one clear wrinkle of lip tissue was visible around the bit. Data were downloaded onto an Excel Spreadsheet (Microsoft Excel, 2010).

**Data analysis**

The spreadsheet pressure data was in mBar. This was converted to mmHg through the use of a conversion factor of 0.75. ($1\text{ mbar} = 0.75\text{ mmHg}$). Data were plotted as scatter plots, and the voice recordings were used to identify behavioural events corresponding to variations in output.

**Study 1: Measurement of sub-noseband pressures in the ridden horse, with sensors placed in two locations**

**Sensor Placement on Noseband**

Following calibration at 0 mmHg and 200 mmHg two analogue pressure sensors were surface-mounted on the inner aspect of a cavesson noseband at the following locations:

a. Lateral vestibular – where the noseband passes over the premolar teeth

b. Sub-mandibular - at the midline between the mandibular rami (Figure 43)
Pressure sensors were surface mounted onto the inward-facing surface of a noseband at the locations shown by arrows (A: lateral vestibular and B: sub-mandibular)

Each sensor was approximately 3 mm in height and was embedded in a flexible polymer mould which was 18 mm in diameter. The sensor was held in place using electrical insulating tape which had an 8 mm diameter punch hole to allow the sensor sensing port to protrude and thereby make direct contact with tissue.

**Data Collection**

Three ridden trials, each lasting approximately 6 minutes were carried out on a grass arena. During each trial the rider was instructed verbally to carry out a series of exercises incorporating walk, trot and canter, transitions between gaits, halt and rein back. On the same day, a further trial (duration of approximately 2 minutes 40 seconds)
was conducted on a sand arena, where the horse was ridden through the gaits of walk, trot and canter and jumped over a solid obstacle (approximately 80 cm height and width). Data were collected while the noseband was tightened to both one finger and two fingers tightness levels.

Results

Sub-noseband pressures: sub-mandibular and lateral vestibular sensor placement

Very low pressures (typically less than 100 mmHg) were recorded by the sensor placed between the mandibular rami with occasional peaks of up to 210 mmHg. Substantially higher pressures were recorded at the lateral vestibular site where the noseband passes over the cheek covering the vestibular surface of the premolar teeth. As the output from this sensor was deemed to be of greater value to the current research because it was placed on a convex surface, subjected to greater pressures, subsequent analysis focuses on data from this site.

During the ridden flatwork trial, with the noseband at one finger tightness, pressures recorded by the laterally placed sensor reached saturation level peaks, i.e. 1400 mmHg and so were above the range measurable. The corresponding events have been identified in Figure 44. The highest peaks in pressure coincided with the following events:

- step back
- halt
- downward transitions (trot to walk, canter to trot)
- left and right turns
- one possible stumbling event

Pressure peaks for which a corresponding behavioural incident is not evident may be due to oral movements which were difficult to identify on video footage. In addition, occasional events occurred off screen and so could not be identified. With the exception of the peaks described above, pressure tended to span the 100 to 300 mmHg (2 – 6 psi) range.
Figure 44 Ridden flatwork trial with pressure sensor positioned laterally at the lateral vestibular location at one finger noseband tightness. Pressure peaks correspond with transitions, turns, step back, head tossing and chewing.

During the ridden trial over jumps, fewer peaks in pressure were recorded, and the peaks were mainly associated with jumping efforts (Figure 45). Lower peaks were recorded, occurring mainly during head tossing incidents, and also during upward transitions to canter. During the first and second jumping efforts, pressure peaks of 1407 mmHg (saturation point for the sensor), were recorded. The pressure peaks recorded during the third and fourth jumping effort were substantially lower, and coincided with smaller jumping efforts, and less head and neck extension. Other events resulting in a peak in pressure were a head toss and upward transition from trot to canter.
Figure 45 Jumping trial with pressure sensor positioned laterally (2 fingers tightness). Pressure peaks are associated with jumping efforts, head tossing and upward transition from trot to canter.

Study 2 Measurement of left and right bit pressures during delivery of rein cues for turns and step back

Sensor Positions: Bit: Caudal aspect, left and right cannons
Following calibration at 0 mmHg and 200 mmHg, two analogue pressure sensors were surface-mounted onto the caudal aspects of the arms of a stainless steel, single jointed snaffle bit, at a distance of 2.5cm from the medial edge of the bit ring, (Figure 46). Each sensor was fitted as described above. The bit was fitted to a standard cavesson bridle with the noseband fastened at two fingers tightness. A small deposit of aqueous gel (Aquagel Lubricating Gel, Parker Laboratories, NJ, USA) was applied to the surface of the sensor to reduce the possible effect of shear forces. A 6 x 7 cm Tegaderm patch (3M™ Tegaderm™ Transparent Film Dressing, St. Paul, USA) was then applied and secured to seal in the sensor and aquagel (Figure 46).
Data collection
The bridle was fitted with the noseband fastened at 2 fingers tightness. After an initial equilibration period, necessary to allow the sensor reach body temperature, the equipment was zeroed while the horse was calm and not showing any head or oral movements. Data collection was carried out for 3 separate recording periods of approximately 2.5 minutes each. A handler stood by the horse’s left shoulder and held left and right reins in approximately the same position as they would be if held by a mounted rider. Data were collected while the horse was subjected to alternating pressure on left and right reins. The pressure was released when the horse turned his head to the corresponding side. In addition, simultaneous pressure was applied to both left and right reins until the horse took a step backward, whereupon pressure was released. Rein contact was maintained during random head tossing and voluntary head and neck movements by the horse.
Results

Rein pressure eliciting turns of the head and neck applied by a handler standing adjacent to the horse’s left shoulder resulted in measurement of pressures of up to 309 mmHg (Figure 47). Recorded pressure levels showed greatest variation during application of rein pressure and also when vigorous head tossing was performed by the horse. Pressures required to elicit responses (left and right turn, step back) did not result in high pressure output values as the horse was sensitive and responsive to low levels of bit pressure. Occasional negative pressures were recorded. These may have arisen due to shear forces, i.e. the bit pulling sideways through the mouth, or as a result of changing lip-sensor contact area or a combination of both.

Figure 47 Pressure output from left and right surface-mounted bit sensors during application of left and right rein cues to an unmounted horse. Pressure peaks occur during rein cues and also during head tossing.
Study 3: Simultaneous measurement of left and right bit pressures and sub-noseband pressures in the ridden horse


One of two methods was used to embed digital pressure sensors in the left and right arms of a rubber-coated full cheek snaffle bit. On the left-hand shank of the bit, a shallow channel was pared from the rubber, to sufficient depth that the sensor would not protrude beyond the surface of the bit. The sensor and a protective silicon mould were secured to the underlying rubber using double-sided sticky tape (Scotch® ATG Adhesive Transfer tape 976). On the right shank of the bit, a segment of rubber was cut using a scalpel blade. A circular punch was then used to extrude a cylinder of rubber equal in depth and diameter to the sensor. The sensor was placed into the evacuated channel and the rubber segment was replaced into the original location, using double-sided sticky tape to secure it to the underlying surface. Both sensors were placed on the caudal aspect of the bit, 2.5cm from the medial edge of the bit ring (Figure 48).

Insulating tape, with an 8 mm diameter hole punched out, was wrapped around each shank of the bit, securing the sensor and surrounding material in place. The punched hole was placed over the sensor, thereby leaving the sensitive sensor surface unaffected. A small quantity of aqua gel was applied to the surface of each sensor. Finally, a Tegaderm patch (6cm by 7cm) was wrapped around the areas of left and right bit shanks demarcated by the insulating tape to provide further protection from possible salivary damage.

A pressure sensor was embedded in a cavesson noseband by excising a section of leather and synthetic material providing padding to the noseband using a scalpel and pinchers, to a width of approximately 18 mm. This created a depression on the inward-facing surface of the noseband. The sensor was attached to the noseband in a manner similar to that used to secure the bit sensors.
Figure 48 Biomedical interface pressure transducer (pressure sensor) embedded in the left and right arms of a rubber coated snaffle bit. A Tegaderm patch wrapped around the left and right bit arms reduces sensor exposure to saliva.

**Data collection.**

Following calibration at 0mmHg and 200mmHg, data were collected during a ridden trial lasting eight minutes, on an arena demarcated in a field. The noseband was adjusted to an approximate two fingers tightness. Placement of the holes on the noseband did not allow precision in this measure and the final tightness level was between 1.5 and 2.0 fingers (<2.0). Data collection was commenced with the bridle in hand, i.e. before it was fitted to the horse and continued during fitting and afterwards, to allow measurement of pressures exerted by the oral and nasal tissues on sensors throughout the fitting process. This was followed by data collection during a series of ridden exercises. These involved the horse being ridden by an experienced amateur rider in a series of circles and straight lines, incorporating left and right turns and halts, and with the rider changing between the three gaits of walk, trot and canter, in both left and right directions. The rider was instructed verbally regarding the desired exercises during the trial.
Results Study 3
Simultaneous measurement of noseband and bit sensor pressures in the ridden horse at less than 2.0 fingers noseband tightness resulted in substantial pressure peaks from all three sensors (Figure 49, Figure 50). Pressure levels recorded frequently exceeded 700 mmHg. Bit pressures on the right bit were found to be consistently lower than pressures on the left bit, even at rest (Figure 49). Accuracy of the sensors deteriorated beyond the calibrated range of pressures, approximately 300 mmHg, and saturation appeared to occur at 1120 mmHg.

Figure 49 Output from left and right bit sensors during ridden trial at walk trot and canter. Transitions between gaits are identified by arrows at 657 seconds (walk to trot) and 668 seconds (trot to canter).
Figure 50 Output from embedded noseband sensor during ridden trial during walk trot and canter. Transitions between gaits are identified by arrows at 657 seconds (walk to trot) and 668 seconds (trot to canter). The noseband sensor is placed at the frontal nasal plane, and the noseband tightened to slightly tighter than 2.0 Fingers.

**Study 4: Simultaneous measurement of left and right bit pressures and sub-noseband pressures in a group of ridden horses**

**Sensor position:** Noseband: frontal plane, Bit: Left and right cannons – caudal aspect.

**Data collection:**
The snaffle bridle (as described in Study 3) fitted with left and right bit sensors and one centrally placed noseband sensor was used on each horse to collect data. A ridden habituation trial with each of the six horses was carried out on the day prior to data collection during which horses wore a replica of the bridle and data acquisition unit with connecting circuitry. The following day data collection was carried out during a 6 minute ridden trial during which four riders, each riding their own horse, were asked to ride through a series of upward and downward transitions between walk, trot and canter, left and right turns and halts. Data were downloaded to an Excel spreadsheet (Microsoft Excel, 2010). During data collection from the fourth rider, the left bit sensor ceased to function. Data from this trial were discarded and data were not collected from riders 5 and 6.
In studies 1-4, the flexible circuitry extending from the sensors was secured at the cheek-piece of the bridle by insulating tape from where it passed beneath the throatlash of the bridle along the neck (Figure 51) to an Emant 380 USB Data Acquisition unit, suspended at the base of the neck by a stirrup leather.

![Flexible circuitry from bit and noseband sensors secured at the cheekpiece and throatlash of the bridle](image)

**Figure 51** Flexible circuitry from bit and noseband sensors secured at the cheekpiece and throatlash of the bridle

**Data analysis**

For comparative purposes, data collected during study 3 using the same bridle but carried out in a different location were also analysed (Rider 1). Data from each of the ridden trials in study 4 and also study 3 were plotted out in 10 second sections from the beginning of recording to the finish. Using synchronised video and voice recordings, data points corresponding with specific events that occurred during each 10 second section were labelled with details of the relevant event (Figure 52). The ranges of pressure values and the changes in output coinciding with specific behavioural events or
horse-rider interactions were identified for closer examination. The low sample numbers used in these studies are useful for scoping and exploratory studies designed to check the feasibility of measuring pressure data directly on ridden horses but cannot be used as a basis for statistical analysis.

Figure 52 Example of 10 second plot of data collected from Rider 2 with timing of events. The horse is walking between 498 – 506 seconds, with a transition to trot at 506 seconds. LB=Left Bit, Nb= Noseband, RB= Right Bit

The following events were selected for analysis:

- Halt, Walk, Trot and Canter: A four second sequence of each of the gaits and a halt. Calm responses, uninterrupted by head tossing or other events were chosen.
- Transitions: Four upward (2 walk-trot, 2 trot-canter) and four downward (2 canter-trot and 2 trot-walk) transitions were identified for each rider. A four second sequence of data including the two seconds immediately before and immediately after the transition were analysed
- The remainder of the upward and downward transitions were also analysed (total n = 72).
- Four seconds of data immediately preceding the change in gait, and immediately following the change in gait were plotted in order to identify changes in bit and noseband pressure during preparation for and immediately following transitions.
For all data sequences chosen the following values were also calculated

- Variance
- Maximum
- Minimum
- Absolute pressure-time product (PtAbs)

The absolute pressure-time product (PtAbs) parameter effectively integrates the area between the time axis and the pressure trace. It is representative of the total overall pressure recorded over a period of time. PtAbs values for left and right rein for each rider during all upward and downward transitions were summed to allow comparison for each rider between upward and downward transitions. For each of the selected transitions (8 for each rider), analysis of the maximum pressures and the PtAbs values for four seconds preceding the transition, and four seconds immediately following the transition was carried out.

For each transition, the maximum left or right bit pressure during the four seconds immediately following the transition was compared to the maximum pressure during the 4 seconds preceding the transition, and the change recorded as an increase or a decrease. Where bit pressure remained the same (within 5 mmHg of the previous value) this was classified as equal and added to the figures for decrease. In order to identify whether maximum bit pressures are greater during upward or downward transitions, the maximum pressures recorded for left and right bit for each of the 8 selected transitions for each rider were added, and the resulting sums compared with the equivalent for downward transitions.

**Results Study 4**

**Gaits:**
Higher maximum bit pressures were consistently seen at canter than at walk or trot. Noseband pressures also increased at canter on all horses except that of Rider 3. Similar increases with gait were found in PtAbs area values for both bit and noseband sensors (Table 10).
Table 10 Maximum left and right bit and noseband pressure values (mmHg) for four riders during walk, trot and canter. LB=Left bit, RB = Right Bit, NB = Noseband

<table>
<thead>
<tr>
<th></th>
<th>Rider 1</th>
<th>Rider 2</th>
<th>Rider 3</th>
<th>Rider 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max (mmHg)</td>
<td>LB</td>
<td>RB</td>
<td>NB</td>
<td>LB</td>
</tr>
<tr>
<td>Walk</td>
<td>313</td>
<td>101</td>
<td>714</td>
<td>157</td>
</tr>
<tr>
<td>Trot</td>
<td>227</td>
<td>156</td>
<td>677</td>
<td>114</td>
</tr>
<tr>
<td>Canter</td>
<td>1137</td>
<td>1031</td>
<td>1145</td>
<td>285</td>
</tr>
</tbody>
</table>

Table 11 Absolute Pressure-Time product (PtAbs) values from left and right bit and noseband pressure sensors for four riders during walk, trot and canter. LB=Left bit, RB = Right Bit, NB = Noseband

<table>
<thead>
<tr>
<th></th>
<th>Rider 1</th>
<th>Rider 2</th>
<th>Rider 3</th>
<th>Rider 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>PtAbs (mmHg s)</td>
<td>LB</td>
<td>RB</td>
<td>NB</td>
<td>LB</td>
</tr>
<tr>
<td>Walk</td>
<td>606</td>
<td>121</td>
<td>551</td>
<td>243</td>
</tr>
<tr>
<td>Trot</td>
<td>525</td>
<td>116</td>
<td>229</td>
<td>170</td>
</tr>
<tr>
<td>Canter</td>
<td>7474</td>
<td>3211</td>
<td>15072</td>
<td>219</td>
</tr>
</tbody>
</table>

Transitions

In upwards transitions, the maximum bit pressure recorded was greater in the trot-canter transition than the walk-trot transition in 3 out of 4 riders – with only Rider 4 showing lower maximum bit pressure during the walk-trot transition (Table 12). In downward transitions, higher maximum bit pressures were recorded in the canter – trot transitions than trot-walk transitions in all 4 riders. The sum of maximum pressures recorded for left and right bit for each of the 8 selected transitions for each rider indicated that none of the 4 riders showed consistently higher bit pressures during downward transitions than upward transitions, with two riders (R1, R4) showing higher maximum bit pressures during upward transitions, and no clear pattern evident in R2 and R3 (Table 12). PtAbs values for transitions also reflected this trend.
Table 12 Sum of maximum pressures (mmHg) recorded for left and right bit sensors during upward and downward transitions

<table>
<thead>
<tr>
<th>Rider</th>
<th>Upward Transitions</th>
<th>Sum of Max P (mmHg)</th>
<th>Downward Transitions</th>
<th>Sum of Max P (mmHg)</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Walk-Trot(*2)</td>
<td>1064</td>
<td>Trot-Walk(*2)</td>
<td>969</td>
<td>↓</td>
</tr>
<tr>
<td></td>
<td>Trot-Canter(*2)</td>
<td>2362</td>
<td>Canter-Trot(*2)</td>
<td>1674</td>
<td>↓</td>
</tr>
<tr>
<td>2</td>
<td>Walk-Trot (*2)</td>
<td>458</td>
<td>Trot-Walk(*2)</td>
<td>605</td>
<td>↑</td>
</tr>
<tr>
<td></td>
<td>Trot-Canter (<em>1)</em></td>
<td>759</td>
<td>Canter-Trot(*1)</td>
<td>357</td>
<td>↓</td>
</tr>
<tr>
<td>3</td>
<td>Walk-Trot(*2)</td>
<td>508</td>
<td>Trot-Walk(*2)</td>
<td>628</td>
<td>↑</td>
</tr>
<tr>
<td></td>
<td>Trot-Canter(*2)</td>
<td>1156</td>
<td>Canter-Trot(*2)</td>
<td>853</td>
<td>↓</td>
</tr>
<tr>
<td>4</td>
<td>Walk-Trot(*2)</td>
<td>2046</td>
<td>Trot-Walk(*2)</td>
<td>942</td>
<td>↓</td>
</tr>
<tr>
<td></td>
<td>Trot-Canter(*2)</td>
<td>1918</td>
<td>Canter-Trot(*2)</td>
<td>1888</td>
<td>↓</td>
</tr>
</tbody>
</table>

*Data for only one canter to trot transition was collected for rider 2.

The PtAbs average value for 36 upward transitions was 713 mmHg s compared to the average value for 36 downward transitions of 566 mmHg s. While there were too few transitions for each rider to detect any trends within individual riders, a visual inspection of the left and right bit pressure values (both max and PtAbs) showed no pattern in terms of changes in maximum bit pressure during upward and downward transitions.
**Comparison of Left and Right Bit sensors**

Maximum pressures were greater on the left bit than on the right bit during the majority of gaits and transitions for all 4 riders. Variance on the left bit sensor was greater for all riders than the right bit sensor at canter. At halt, maximum values and variance are also greater for left bit than right for all 4 riders. The left bit sensor also recorded higher pressures through the majority of transitions (Table 13).

Table 13 Frequency of higher pressure recorded by individual (left versus right) bit sensors during eight transitions, four upward and four downward, for four horses. The first and second of each upward and downward transition is indicated by A and B respectively.

<table>
<thead>
<tr>
<th>Transition</th>
<th>Left Bit</th>
<th>Right Bit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walk-Trot A</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Walk-Trot B</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>Trot-Canter A</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Trot-Canter B*</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Canter-Trot A</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Canter-Trot B*</td>
<td>3</td>
<td>-</td>
</tr>
<tr>
<td>Trot-Walk A</td>
<td>2</td>
<td>1 (and one level)</td>
</tr>
<tr>
<td>Trot-Walk B</td>
<td>3</td>
<td>1</td>
</tr>
</tbody>
</table>

*Data for only one canter to trot transition was collected for rider 2.

During gaits and transitions, maximum noseband sensor pressures were uniformly higher in R1 than in the other horses throughout (Table 14). PtAbs values were also highest during transitions for R1.
Table 14 Maximum noseband pressures recorded during two upward (A and B) and two downward (A and B) transitions by four horses (R1 – R4). R1 = Rider 1, R2 = Rider 2, R3 = Rider 3, R4 = Rider 4.

<table>
<thead>
<tr>
<th>Transition</th>
<th>R1</th>
<th>R2</th>
<th>R3</th>
<th>R4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walk-Trot A</td>
<td>10.6</td>
<td>3.4</td>
<td>-0.2</td>
<td>429.8</td>
</tr>
<tr>
<td>Walk-Trot B</td>
<td>1125.4</td>
<td>8.5</td>
<td>-0.6</td>
<td>268.4</td>
</tr>
<tr>
<td>Trot-Canter A</td>
<td>1141.3</td>
<td>337.9</td>
<td>-0.4</td>
<td>29.1</td>
</tr>
<tr>
<td>Trot-Canter B</td>
<td>1115.5</td>
<td>185.5</td>
<td>-0.6</td>
<td>400.9</td>
</tr>
<tr>
<td>Canter-Trot A</td>
<td>1118.8</td>
<td>341.4</td>
<td>-0.5</td>
<td>526</td>
</tr>
<tr>
<td>Canter-Trot B</td>
<td>866.8</td>
<td>No data*</td>
<td>-0.7</td>
<td>393</td>
</tr>
<tr>
<td>Trot-Walk A</td>
<td>677.7</td>
<td>9.7</td>
<td>-0.5</td>
<td>25.9</td>
</tr>
<tr>
<td>Trot-Walk B</td>
<td>1117.4</td>
<td>484.8</td>
<td>-0.5</td>
<td>483.3</td>
</tr>
</tbody>
</table>

*Data for only one canter to trot transition was collected for rider 2.

Discussion

Oral movements such as chewing or yawning, head and neck movements related to transitions, stumbling, and extending while jumping, resulted in substantial peaks in pressure recorded by noseband pressure sensors, and to a lesser extent, bit sensors. Transitions between gaits and resistances, shown as head raising and mouth opening, also resulted in extreme peaks. The findings suggest that throughout ridden exercises, the noseband, whether tightened to recommended tightness level of two fingers or tighter, is being continually pressed against sub-noseband tissue in a pulsatile fashion with maximum pressure peaks occurring at levels of pressure far in excess of 300 mmHg and possibly even higher than 1400 mmHg. Sensor calibration in each study was over a smaller range than the levels of pressure recorded. Pressures recorded outside of the range of calibration may not be accurate but are suggestive of high, intermittent pressure exerted against sub-noseband tissues.

Measured bit pressures coincided with pressure applied directly via the reins as expected. However, a turn response elicited by rein pressure resulted in increased pressure recorded by the contralateral sensor on occasions. This is likely to be as a result of lack of release of the opposite rein as the horse turns away from that side. Similarly, random head turns, raised head or head tossing resulted in increased pressure being exerted against bit sensors. Substantially higher bit sensor pressures were recorded on
the ridden horse (Study 3) in comparison with the stationary horse in Study 2. Head movements during locomotion and rider hand movements are likely to have been contributory factors (Eisersiö et al., 2015). Maximum pressures were highest at canter, with lowest bit pressures recorded in some instances at trot. This may be explained by the fact that head movements during trot are less than at walk and canter. The highest pressure readings at canter compared to walk or trot found here correspond with the findings of several rein tension studies (Clayton et al., 2005, Eisersiö et al., 2015). These findings may be due to increased head and neck movements during canter but may also be partially explained by the likelihood of riders maintaining a stronger rein contact during higher or faster gaits.

The higher maximum bit pressures and average PtAbs values recorded during upward transitions would suggest that in general oral bit pressures are greater during upward transitions than downward transitions. If this is the case, previous training of horses to respond to a bit cue to signal a request for deceleration by the rider may be progressively weakened by the delivery (whether intentional or not) by riders of greater bit pressures during other events such as when the horse is being asked to accelerate (during upward transitions). If the preliminary findings of this study reflect the experience of horses ridden by amateur riders in general, bit pressure, used as a cue to ask for desired responses such as deceleration or turns may not be regular, consistent and discernible to the horse among other bit pressure changes. Lack of any consistent pattern of changes in bit pressure during transitions and at different gaits indicate a complexity of horse – bit – rider interactions that has also been found in other studies (Egenvall et al., 2015, Eisersiö et al., 2015). This has implications for both welfare and safety. Lack of predictability and controllability is a recognized stressor for animals. Lack of predictability of salient and potentially painful pressures such as intraoral pressures caused by the bit, and lack of controllability of outcome, e.g., by offering the correct response such as the requested transition, may contribute to the deterioration of trained responses to bit pressures which would result in reduced safety of the rider.

Baseline and peak pressures recorded by the left bit sensor in Studies 3 and 4 were consistently higher than for the right bit pressure sensor. This may have been as a consequence of an unintended greater depth of placement of the sensor on the right shank than on the left, with the left sensor protruding to a greater extent from the bit and being exposed to higher pressure levels. The consistently higher left bit pressures found in the current study are in agreement with the findings of previous rein tension gauge
and rider symmetry studies (Symes and Ellis, 2009, Hawson et al., 2014a) and contradictory to others (Eisersiö et al., 2013, Egenvall et al., 2015, Eisersiö et al., 2015). All four riders taking part were right handed. Rider handedness is thought to influence the amount of variance and rein tension applied although laterality of the horse also plays a role. Kuhnke et al., (2010) found that, in a study of 11 riders, horses with left laterality were ridden with significantly stronger mean tension in the left rein than in the right rein (1.5 vs. 1.4 kg; $P = 0.04$). In addition, greater maximum tension was applied via the left rein on right-lateralised horses, and vice versa on left lateralised horses. The laterality of the horses used in the study described was not recorded.

A number of factors can be identified which may contribute to the higher noseband pressures measured for Rider 1 (R1). Data from R1 were collected during a ridden trial carried out on in a field normally used for grazing. The size of the demarcated arena was also smaller (15 m² compared to 20 m²) necessitating greater frequency of rein cues to elicit turns. The noseband tightness, due to the placement of holes on the strap was marginally tighter than the intended 2 Fingers level of tightness, and therefore, likely to have been slightly tighter than the nosebands on the other 3 horses.

The loss of function of a bit sensor during data collection indicate that further development of the current methodology is required before it can be used in research or by riders to assess applied pressure levels by bits and nosebands. Investigation into the malfunction revealed corrosion damage caused by saliva to copper components of the flexible circuitry adjacent to the sensor. Improved waterproofing may help to address this issue. Other potential problems with the current methodology include the possibility of bit rotation in the mouth resulting in the sensor position being changed rotationally (Figure 1). Lateral movement of the bit through the mouth due to rein pressure or head turning may also displace the sensors from a position of contact with oral tissues. Irrespective of these issues, which may result in loss of, or under – measurement of true pressures, the pressures measured are true, and cannot have been produced by anything other than pressure exerted by tissues. The levels of pressure recorded are such as to indicate the need for more precise and reliable methods of measuring pressures which are likely to be of significance both to tissue health and horse welfare.
Different types of sensor, with different ranges and saturations points were used during the studies described, in order to identify the sensor type most suited for use in the environment being studied (Casey et al., 2011, Casey et al., 2013). Saliva, biting actions and tongue movements of the horse have the potential to damage or destroy sensors placed in the mouth. However, use of a sensor with insufficient range results in saturation of the sensor, and limits the possibilities for measuring true peak pressure values. This was found to be the case in Studies 1 and 3. However, the peak pressures measured indicate that sub-noseband tissues, and to a lesser extent, oral tissues, were being exposed to pulsatile pressure peaks of significant levels.

Sub-noseband sensors were placed in three locations. The contours of the tissue at the location of sensor placement are likely to influence output (Casey et al., 2013, Doherty et al., 2013). The concavity between the mandibular rami resulted in low pressure output from the sensor placed at that location, compared with pressure output of up to 1400 mmHg at the lateral vestibular position and 1118 mmHg (saturation point) at the frontal nasal plane. Placement of the sensor on a convex surface such as on the convexity of the dental arcade poses challenges as shear forces are likely to distort values. Placement of the sensor at the frontal nasal plane in Study 3 was deemed to be the most appropriate for future research as shear forces at a point midway between the nasal rami are unlikely to be significant.

Use of pressure sensors and wireless transmission systems opens up options which may, with further investigation, allow horses in competition scenarios provide valuable
information on the horse-rider interactions operating through the use of pressure. The ranges of pressures measured both on intra-oral surfaces and at locations compressed by the noseband clearly highlight the need for further investigation. Measuring pressures exerted on vital tissues will help predict the possibility of pain or damage being inflicted by routine practices in equitation.

**Conclusion**

These studies have shown that it is possible to acquire dynamic pressure data relating to the pressures arising at nose-noseband interfaces and at oral tissue-bit interfaces while the horse is being ridden and performing activities such as walking, trotting, cantering and jumping. Pressure peak events can largely be correlated with horse/rider activities including upward and downward transitions, turns, resistance to cues (head raising) but also stumbling, chewing, head tossing and head and neck lowering. Outside of pressure peak events, the baseline pressure pattern of both bit and noseband sensors is pulsatile, corresponding to head movements during each stride. It is clear from the data obtained that pressure peak values routinely exceed 300 mmHg and may possibly reach values considerably in excess of this value. Therefore if a dedicated pressure sensing technology is to be developed for further studies in this area, it should have a dynamic range reaching up to 1500 – 2000 mmHg in order to be robust enough to withstand the challenges of the measurement environment.

The trials described the measurement of noseband pressure at three locations, of which two were of value. However, other areas covered by the noseband may also offer valid locations from which to measure pressures. Similarly, the areas on the bit against which pressure is exerted by oral structures are several, and the methods described recorded pressure at one discrete location on each arm of the bit. The methodology described yielded more consistent and logical findings when employed to measure sub-noseband pressures in comparison to bit pressures. The nature of pressure exerted by the noseband, i.e., pulsatile but at extremely high levels, suggests that variation in tightness levels may have a major impact on the pressure levels exerted by the noseband. Investigations were limited to one type of noseband, but raise the question of whether other commonly used noseband types exert pressure in similar locations and at similar levels. The findings described in this chapter highlight the possibilities with regard to use of pressure sensors to measure both noseband and bit related pressures. This
development may help in guiding recommendations to owners of appropriate levels of noseband tension through future research.
Chapter 7

Investigation into the effect of three noseband tightness settings on noseband tension and skin and eye temperatures

Introduction
In the history of equestrian literature, mention of appropriate noseband tightness was first included in equestrian texts in the 1950s (Anon, 1956). The guideline of fitting the noseband sufficiently loose so that two fingers could fit under the noseband, has been cited in many other textbooks since that time (Stecken, 1977, Klimke, 1994, Micklem, 2003, Muir and Sly, 2012), although the position of insertion or whether the fingers should lie flat against the skin is not always specified. However, without regulation and with an apparent benefit to riders of increased sensitivity to bit pressure (Randle and McGreevy, 2013, Pospisil et al., 2014) when the noseband is tight, riders have no reason to follow this guideline. Welfare concerns have been raised by equitation scientists, and evidence is beginning to appear of the possible adverse effects of excessively tight nosebands (Fenner et al., 2016, McGreevy et al., 2012).

The development of the ISES taper gauge as a direct consequence of concern among the equitation scientists regarding the welfare implications of tight nosebands has allowed some standardised measurement to be carried out (ISES, 2012). However, despite this advance, variation in opinion exists regarding where the two fingers should be placed to check noseband tightness. A variety of appropriate locations have been suggested including on the cheek, lateral to the mandibular rami and beneath the mandibular rami. The topography or profile of the horse head at the location of the noseband has been shown to comprise several areas of marked convexity, particularly at the locations of the nasal bones, mandibular rami and lateral vestibular area (Casey at al., 2013). In areas where there is concavity, noseband pressure is minimal or absent. Stretching or so called hammocking of the noseband between adjacent bony prominences will result in lifting of the noseband away from the tissue between these points (O’ Brien and Casey,
(2002) thereby resulting in zero or minimal noseband applied pressure on the intervening tissue. Instead the tensional force of the noseband will be transferred to the adjacent prominences and will be concentrated there. This must be borne in mind when selecting noseband tightness measurement sites. For instance, when a site lateral to the mandibular rami was used to guide tightness setting of a noseband with the ISES taper gauge, the actual tightness was significantly increased compared to the tightness which resulted when the gauge was used to set the same tightness but using the frontal plane site instead (McGreevy at al., 2012).

Pressures exerted against sub-noseband tissues are also influenced by the width of the noseband. Currently there would appear to be a trend towards the use of wider nosebands in dressage (Chapter 4). Estebe at al., (2000) showed that, on humans, wider tourniquets could occlude blood vessels at lower pressures than was needed with narrow tourniquets. In the same study, patients reported higher pain levels with the wide tourniquet cuff (140 mm) than a narrow cuff (70 mm) for similar inflation pressures. Therefore, increasing the width of nosebands may increase the risk of blood vessel occlusion under the noseband. Forces of 64 ± 19N were measured beneath crank nosebands worn by five horses during trot (Murray at al., 2015). No indication was given of noseband tightness in this study, and measurements were limited to the dorsal aspect of the face. Studies designed to evaluate the effects of tight nosebands should therefore not only measure tightness but should also record noseband widths to allow more comprehensive evaluation.

Body heat is released through the skin by several different methods including radiation, convection, conduction and evaporation (Yanmaz et al., 2007). Infrared thermography (IRT) is the measurement of radiated heat from the body. Body heat production depends on tissue metabolism and local circulation, which in turn are influenced by nutritional status, health, activity and fitness levels. Stress has been shown to increase heat production, possibly as a result of catecholamines, or through activation of the hypothalamic pituitary adrenal axis and the consequent changes in tissue metabolism caused by cortisol (Stewart et al., 2005). Changes in eye temperature, in particular, have been found, in some studies to correlate positively with salivary cortisol (Stewart et al., 2005). Increase in eye temperature was found by Yarnell et al (2013) to correlate with salivary cortisol during clipping, thought to be an aversive procedure. This change in eye temperature has been suggested as a diagnostic indicator of stress related to experimental treatments, such as the use of a particular training device (Hall et al.,
or to investigate stress levels associated with competition (Valera et al., 2012, Sánchez et al., 2016). Thermography has been used in a pilot study to identify possible effects on vascular perfusion caused by tight nosebands. Preliminary results from 5 horses show a significant reduction in skin temperature following 10 minutes of wearing a tightly fastened crank noseband (McGreevy et al., 2012). No significant change in eye temperature related to noseband tightness was found during the study.

Increases in skin temperature have been shown, in many cases, to be related to pathology. Temperature changes as a result of clinical pathology can be localised to the affected area, such as in the case of localised inflammation, or generalised, due to changes in systemic metabolism. Inflammation results in localised changes in blood flow, usually in the form of increased blood flow to the area. This phenomenon is used by veterinarians to detect muscle, ligament and tendon lesions (Marr, 1992, Turner, 2001), joint inflammation and vertebral column injuries in horses (Turner, 1991) through the use of IRT. Swelling caused by tissue damage may however, reduce blood flow to that particular location due to increased pressure caused by localised oedema (Turner 2001). Where blood supply is reduced due to swelling or infarction of tissues, the cooler area detected by thermography is usually surrounded by an area of increased temperature, caused by shunting of the blood into local vascular networks (Turner 2001).

Skin temperatures are influenced by both tissue metabolism and blood flow. The pattern of emitted radiation is determined by local circulation and the relative blood flow, with venous return, carrying blood away from metabolically active tissues, resulting in higher levels of emitted radiation than arterial supply (Yanmaz et al., 2007). Increased blood supply to the hoof, found in cases of laminitis, can be detected by IRT and occurs in advance of clinical signs, assisting in early diagnosis (Turner, 1991). Navicular syndrome is characterised by reduced blood flow to the caudal aspect of the navicular bone. Exercise normally increases blood flow and pre- and post-exercise thermographic images are used as diagnostic tools for detection of the condition (Turner, 2001). With navicular syndrome, the reduced vascular perfusion does not respond to exercise.
The aims of the study reported here were to:

- Measure noseband force at three different noseband tightness levels;
- Trial and further develop an instrument designed to measure noseband tension (N/cm) based on noseband tightness and the widths of the noseband.
- Investigate the effects of three different noseband tightness levels on eye temperature
- Investigate the effects of three different noseband tightness levels on skin temperature above and below the noseband

**Materials and methods**

**SafeBand Probe**

The SafeBand Probe is an electronic gauge currently being developed by Aaron PCB Ltd., Shannon (Mr Gerard Murray, Director) and the University of Limerick (Dr Vincent Casey) under a ‘Mid-West Competitive Feasibility Fund 2013’ funded project. The gauge is a hand-held instrument which comprises a ‘single finger probe’ which was 15mm wide and 14mm high (V3) and 15 wide by 15 mm high (V4). The probe is contoured in order to facilitate easy insertion under a noseband without risk to horse or operator and is pre-calibrated using dead-weights spanning 0 – 20kg. Embedded firmware algorithms allow the combination of noseband width metrics and noseband lift-off force metrics to provide an objective digital indication of the noseband tension. A ‘hold’ function allows the operator select a reading which satisfies measurement protocol conditions. The reading may be read while the instrument is on the animal or retained for reading once removed from the animal.
Noseband tension data collection was carried out during 2 stages. During Part 1, the SafeBand V3 version was trialled to test it for ease and safety of use (Figure 54 A and B). Following Part 1, modifications were made to the SafeBand V3 to improve certain aspects. The resulting amended version, SafeBandV4, was used during Part 2 of the study (Figure 54 C and D). Calibration of the SafeBand probe was checked by dead weight testing the devices prior to, and following data collection during both Part 1 and Part 2 of the study, (Figure 55). Post field trial calibration checking indicated that the device retained calibration yielding near identical slopes (sensitivities) to the pre-trial tests.
Figure 55 Dead weight test on SafeBand (SB) V4 prior to field trial demonstrating excellent linearity and no appreciable hysteresis between loading and unloading. The equations above and below the plotted data describe the line generated from data collected during loading (A) and unloading (B).

**Thermography**

The FLIR i7 Thermography camera (FLIR Systems AB, SE-182 11 Danderyd, Sweden) was used to collect thermography data. The FLIRi7 camera captures 140 × 140 pixel thermographs with a thermal sensitivity of 0.1°C, simultaneously with a visible image. Calibration of the camera was carried out one month prior to data collection. Temperatures were recorded from a distance of approximately 1 metre from the horse’s head and at a 90° angle to the horse. All measurements were taken from the right side of the horse. A document specifying a random order of fitting nosebands at three different tensions on 12 individual horses was produced (www.randomizer.org) and followed. Noseband tensions of 2.0, 1.0 and 0.5 fingers tension were applied.
Study 1 Use of the SafeBand V3 to measure noseband force at three noseband tightness levels

Animals
Fifteen horses ranging in age from four to twelve years, all with experience of wearing bridles were used. During data collection all were fitted with their usual bridle (or a replacement bridle in the case of brood / retired mares). All bridles included a cavesson noseband. Nosebands were fitted with two fingers spacing (approximately) between the rostral margin of the facial crest and the caudal margin of the noseband. The ISES taper gauge was used to assist in assessing and adjusting the noseband to the required tension specified by the random order.

Data Collection
Following the random order indicated, each bridle was fitted and the noseband tightened to the allocated tension. Using the SafeBand V3 probe, resting noseband tension at the midline rostral position was assessed and recorded at the frontal nasal plane. Where mouth movements were displayed, measurement was recorded only after 3 consecutive seconds of mouth immobility. Following data collection the bridle was left in place but the noseband loosened to greater than 2 fingers (very loose). After a minimum half hour rest period on each occasion, the procedure was repeated twice, at the randomised noseband tightness level. Data were collected from one group of seven horses, followed by a second group of eight horses. All horses were stabled individually. All data were collected on the same day, during a four hour period (9.30 am – 1.30 pm).

Data Analysis
The range of noseband loads (forces) recorded (max, min, mean) at each different noseband tightness level was calculated. Data were tested for normality using the Kilmogorov-Smirnov test. ANOVA was carried out to investigate the effect of noseband tightness on noseband force. Paired samples T-tests were carried out to compare noseband force at each noseband tightness setting. ANOVA was carried out to compare noseband force measurements from Study 1 and Study 2.
Results - Noseband Loading Forces

Table 15 Noseband forces (N) at the frontal nasal plane measured by the SafeBand V3 probe at three different noseband tightness settings. (2.0 F = 2 fingers, 1.0 F = 1 fingers, 0.5 F = 0.5 fingers)

<table>
<thead>
<tr>
<th>Horse</th>
<th>Noseband tightness 2.0 F</th>
<th>Noseband tightness 1.0 F</th>
<th>Noseband tightness 0.5 F</th>
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<tr>
<td>Mean</td>
<td>20</td>
<td>36</td>
<td>52</td>
</tr>
</tbody>
</table>

* Could not tighten further - closer to 1F than 0.5 F
** Loose
*** Could not fit probe
**** Marked depression between L and R Nasal bones
***** Very tight
Noseband force data were found to be normally distributed. At 2.0 fingers setting pressures recorded ranged from 8N to 36 N (mean $19.8 \pm 2.10$ N SEM). Forces recorded at 1.0 Fingers ranged from 23 to 63 N (mean $= 35.8 \pm 3.87$ N SEM). At the 0.5 Fingers setting, three of the fifteen nosebands were too tight to allow the tip of the SafeBand probe to be passed beneath the noseband (Horses 9, 11 and 15). Of the remaining 12, forces at 0.5 F ranged from 35 to 83 N (mean $= 52.4 \pm 4.70$ N SEM, Table 15). Irregularities regarding accuracy of noseband tightness and an anatomical variation (a deep concavity between left and right nasal bones on one horse) were identified (Table 15). When these data were removed, the mean values recorded were:

- 0.5 Fingers: 53 N/cm
- 1.0 Fingers: 34 N/cm
- 2.0 Fingers: 20 N/cm

There was a significant effect of noseband tightness on noseband force ($F = 19.82$, $p < 0.001$). There were significant differences in noseband force between 2.0 and 1.0 fingers noseband tightness ($t(14) = -4.29$, $p < 0.05$) and also between 1.0 and 0.5 fingers noseband tightness ($t(11) = -7.45$, $p < 0.001$).

**Study 2 Use of the SafeBand V4 and of thermography to measure noseband eye and skin temperature at loose and three different noseband tightness fittings**

The aim of this study was twofold; to measure noseband force at loose and three different noseband tightness levels, and secondly, to investigate whether noseband tightness level is associated with a change in eye temperature, and temperature of the skin at the location of a major blood supply to the muzzle. Twelve horses ranging in age from four to twelve years (four of which had also participated in Study 1), all with experience of wearing bridles were fitted with a snaffle bridle with cavesson nosebands (using the bridle normally worn by the horse where possible). Noseband types and fitting were as for Study 1.
Data collection for both Study 1 and Study 2 took place at Rincoola Stud, Abbeylara, Co. Longford. All horses were currently in training or had been previously used for riding and were retired for breeding purposes. Bridles were fitted and horses restrained by familiar handlers throughout. All bridles were fitted with either a single-jointed full cheek snaffle bit or a single-jointed Baucher snaffle bit.

**Data collection**

Data were collected from one group of four horses, followed by two groups of eight horses, separated into two groups of four. During data collection from the first group, two stables were used, on either side of a corridor, with data collected from one pair of horses while the other pair were on a half hour rest period, during which they were returned to their own stables. Data from the first group (n=4) were collected from each horse at approximate 1 minute intervals, with data collection at each noseband tightness collected during a 10 minute period. During data collection from the second group (n=8), four stables were used, and measurements were recorded at approximate 2 minute intervals, over a 20 minute period for each noseband tightness level. Only thermography data from the second group of eight horses were used in analysis as the time period over which data were collected was different (20 minutes) from the first group (10 minutes).

The noseband was initially left unfastened. Using the SafeBand V4 probe the noseband pressure at the frontal nasal plane and at the approximate point where the lateral nasal artery and vein pass under the noseband (Figure 56) was measured and recorded. Eye temperature, and skin temperatures approximately 1 cm above and below the noseband at the approximate point where the lateral nasal artery and vein pass under the noseband were recorded for 10 consecutive measurements using the FLIR camera (Figure 57: a, b and c). An estimate of ambient temperature on the day was recorded at three hour intervals from a car thermometer.
A habituation period was allowed before the introduction of either the ISES taper gauge or the SafeBand probe beneath the noseband, by holding the gauge or probe on the surface of the noseband, at the frontal nasal plane for a minimum of 3 seconds (or a longer duration if deemed necessary based on the behaviour of the horse). The width (mm) of each noseband was measured using TB callipers at the beginning of data collection. All food was withheld from horses for a minimum of ten minutes prior to each bridle fitting to minimize chewing movements during data collection.

Figure 56 Lateral nasal artery and vein passing beneath the noseband lateral to the nasal bone.

Figure 57 Thermographic images of a) The approximate location of the lateral nasal artery and vein above the noseband. b) The approximate location of the lateral nasal artery and vein below the noseband. c) The eye.
Following a random order, each noseband was then tightened to one of three randomly allocated noseband tensions (2.0, 1.0 and 0.5 Fingers tightness level). The ISES Taper Gauge was used to aid adjustment of the noseband to as close as possible to the required tightness.

![Image](image.png)

**Figure 58** Use of SafeBand V4 to measure noseband tension at the frontal nasal plane (A) and at the approximate location of the lateral nasal artery and vein (B).

Using the SafeBand probe, the noseband pressure at the frontal nasal plane and at the approximate point where the lateral nasal artery and vein pass under the noseband, was measured and recorded at the beginning of each data collection period (Figure 58). Each horse was allowed a minimum of one half hour rest period between each data collection period with the bridles removed. The above steps were repeated for the two further noseband settings. During data collection, horses were housed in four adjacent stables, two on either side of a central corridor, in a covered, American barn-style building. Thermography data were collected from four horses consecutively. All data were collected on the same day, during a nine hour period (9.30 am – 6.30 pm).

**Data analysis**

The range of noseband forces recorded (max, min, mean) at each different noseband tightness level was calculated. ANOVA was carried out to investigate the effect of noseband tightness on noseband force. Paired samples T-tests were carried out to
compare noseband force at each noseband tightness setting. ANOVA was carried out to compare noseband force measurements from Study 1 and Study 2.

Kolmogorov-Smirnov tests were carried out to test for normality of thermography data. Using SPSS (IBM SPSS Statistics, Version 22, 2015), the mean values of skin and eye temperatures for each horse during each reading were combined and the overall mean for each reading was used in analysis. This was done to eliminate the effect of dependency between measures, and was deemed appropriate due to low levels of variation between individuals’ measurements (both mean and median values). ANOVA and pairwise comparisons with Bonferroni adjustments for multiple comparisons were carried out to analyse temperature differences between treatments. Noseband force measurements were normally distributed. Eye and skin temperatures were not normally distributed. However, when assessed individually, eye temperature measures for the majority (8 out of 12) horses showed normal distribution. Mean ± SEM values are stated in all cases.
Results

Noseband Force

Table 16 Noseband forces (N) at the frontal nasal plane measured by the SafeBand V4 probe at loose and three different noseband tightness settings (2.0 F = 2 fingers, 1.0 F = 1 fingers, 0.5 F = 0.5 fingers)

<table>
<thead>
<tr>
<th>Horse</th>
<th>Loose Noseband</th>
<th>Noseband tightness 2.0 F</th>
<th>Noseband tightness 1.0 F</th>
<th>Noseband tightness 0.5 F</th>
<th>Noseband width (mm)</th>
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<td>Mean</td>
<td>0.4</td>
<td>14.2</td>
<td>39.0</td>
<td>63.2</td>
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</tbody>
</table>

*** Could not fit probe

At loose noseband tightness setting, noseband forces measured at the frontal nasal plane ranged from 0-1 N. At 2.0 Fingers setting forces recorded ranged from 7 to 22 N (mean = 14.2 ± 1.18 N).

Table 15). Forces recorded at 1.0 Fingers ranged from 20 to 50 N (mean = 39.0 ± 2.67 N). At 0.5 Fingers setting, two of the twelve nosebands were too tight to allow the tip of the SafeBand pass beneath the noseband and six allowed only partial insertion. These measures have been discounted in calculating the mean (Table 16). Noseband tensions at 0.5 Fingers measures ranged from 53 to 69 N (mean = 63.2 ± 3.66 N). At loose noseband setting, the measured force ranged from 0 to 1 N (mean 0.5 ± 0.2 N). There was a significant effect of noseband tightness on noseband force (F = 112.77, p <
There were significant differences in noseband force between 2.0 and 1.0 fingers noseband tightness \((t(11) = -8.82, p < 0.001)\) and also between 1.0 and 0.5 fingers noseband tightness \((t(3) = -3.64, p < 0.05)\).

Figure 59. Bar chart showing noseband force measurements (N) at three different noseband settings during Study 1 and Study 2. (2 F = 2.0 fingers noseband setting, 2 F = 2.0 fingers noseband setting, 1 F = 1.0 fingers noseband setting)

Noseband force measurements between Study 1 and Study 2 at each of the noseband tightness settings 0.5 and 1.0 fingers did not differ significantly between the two studies. At 2.0 fingers, there was a significant difference in noseband force measurement \((F = 4.76, p < 0.05)\) between Study 1 and Study 2 (Figure 59).
Noseband forces at the approximate location of the lateral nasal artery and vein ranged from 1 to 7 N at 2.0 Fingers (mean = 3.2 ± 0.55 N), from 2 to 17 N at 1.0 Fingers (mean = 8.7 ± 1.36 N) and from 3 to 28 at 0.5 Fingers (18.5 ± 1.90 N). At loose noseband settings, tension ranged from 0 to 2 N (mean 0.6 ± 0.19 N, Table 17). There was a significant effect of noseband tightness on noseband force (F = 43.51, p < 0.001). There were significant differences in noseband force between 2.0 and 1.0 fingers noseband tightness (t(11) = -3.58, p < 0.005) and also between 1.0 and 0.5 fingers noseband tightness (t(11) = -3.71, p < 0.005).

Table 17 Noseband forces (N) at the approximate location of the lateral nasal artery and vein measured by the SafeBand V4 probe at loose and three noseband tightness settings.

<table>
<thead>
<tr>
<th>Horse</th>
<th>Loose Noseband</th>
<th>Noseband tightness 2.0 F</th>
<th>Noseband tightness 1.0 F</th>
<th>Noseband tightness 0.5 F</th>
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<td>3</td>
<td>9</td>
<td>28</td>
</tr>
<tr>
<td>12</td>
<td>1</td>
<td>4</td>
<td>12</td>
<td>25</td>
</tr>
<tr>
<td>Mean</td>
<td>0.6</td>
<td>3.2</td>
<td>8.7</td>
<td>18.5</td>
</tr>
</tbody>
</table>
Eye temperature

The estimated marginal mean eye temperature was $32.58 \pm 0.09$ °C. There was a significant effect of noseband tightness on eye temperature ($F(3, 320) = 3.03, p < 0.05$). Eye temperature at the tightest noseband setting (0.5 Fingers) was significantly higher than eye temperature at the loose noseband setting ($p < 0.05$) (Figure 60). No other significant differences in eye temperature were found.

Figure 60 Estimated marginal means of eye temperatures in 8 horses at four different noseband tightness settings. Temperatures differ significantly except where they share the same superscript.

Estimated marginal means of eye temperature increased significantly from the first temperature measurement to the third ($p < 0.05$), and remained significantly higher than the first measurement throughout the remainder of measurements in each treatment with the exception of the fourth (Figure 61), with the eye temperature rising significantly from the first reading (mean 31.3°C) to the final reading (mean 32.7°C).
Figure 61 Estimated marginal means of eye temperatures during ten thermography readings taken during a 20 minute period in 8 horses at four different noseband tightness settings. Temperatures differ significantly except where they share the same superscript.

There was a significant effect of treatment on eye temperature, F(3, 440) = 4.32, p < 0.01. Within individual treatments, there was a trend for an increase in eye temperature as each horse progressed through the 10 measurements (Figure 62) but the increase was only significant during loose noseband treatment and 2.0 Fingers treatment and occurred during the first 3 measurements. Eye temperatures increased from 30.2 to 32.0 °C in the loose noseband treatment and from 29.6 to 32.9 °C in the 2.0 fingers treatment (between measurements 1 and 3 in each case, Figure 62).
Figure 62 Estimated marginal means of eye temperatures at four different noseband tightness settings during 10 thermography readings
**Skin temperature above noseband**

Figure 63 Estimated marginal means of skin temperature above the noseband on 8 horses at four noseband tightness settings. Temperatures differ significantly except where they share the same superscript.

The estimated marginal mean temperature of skin above the noseband was 28.42 ± 0.11. There was no significant change in skin temperature above the noseband over four noseband tightness settings (F(3, 280) = 1.92, p = 0.13, Figure 63).
Figure 64 Estimated marginal means of skin temperature above the noseband on 8 horses during ten thermography readings taken over a 20 minute period (at 2 minute intervals). Temperatures differ significantly except where they share the same superscript.

There was a significant increase in temperature of skin above the noseband which occurred during the first 3 measurements ($p < 0.01$), but no other significant change occurred (Figure 64). There was no significant effect of treatment (noseband tightness) by time on skin temperature above the noseband ($p = 0.98$, Figure 65).
Figure 65 Effect of noseband tightness and time on estimated marginal means of skin temperature above the noseband at 4 noseband settings during ten thermography readings taken over a 20 minute period.
Skin temperature below the noseband

The estimated marginal mean temperature of skin below the noseband was 28.7 ± 0.14 °C. There was no significant effect of noseband tightness (F (3, 280) = 2.13, p = 0.1) on skin temperature below the noseband (Figure 66).

![Graph showing estimated marginal means of skin temperature below the noseband at four noseband tightness settings on 8 horses. Temperatures differ significantly except where they share the same superscript.](image)

Figure 66 Estimated marginal means of skin temperature below the noseband at four noseband tightness settings on 8 horses. Temperatures differ significantly except where they share the same superscript.

There was a significant effect of reading number (F (9, 280) = 2.68, p < 0.01) on skin temperature below the noseband (Figure 67).
Figure 67 Estimated marginal means of skin temperature below the noseband during ten thermography readings. Temperatures differ significantly except where they share the same superscript.

There was no significant effect of treatment (noseband tightness) and time on skin temperature below the noseband ($p = 1.0$, Figure 68).
Figure 68 Effect of treatment (noseband tightness setting) and time on estimated marginal means of skin temperature below the noseband at 4 noseband settings during ten thermography readings.
At all 4 noseband tightness levels, skin temperatures above the noseband remained lower than below the noseband (Table 18).

Table 18 Mean skin temperatures above and below the noseband at 4 different noseband tightness fittings

<table>
<thead>
<tr>
<th>Noseband Tightness (Fingers)</th>
<th>Above noseband</th>
<th>Below noseband</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loose</td>
<td>27.8 0.23</td>
<td>28.2 0.28</td>
</tr>
<tr>
<td>2.0 Fingers</td>
<td>28.5 0.23</td>
<td>28.8 0.28</td>
</tr>
<tr>
<td>1.0 Fingers</td>
<td>28.1 0.23</td>
<td>28.5 0.28</td>
</tr>
<tr>
<td>0.5 Fingers</td>
<td>28.5 0.23</td>
<td>29.1 0.28</td>
</tr>
</tbody>
</table>

**Discussion**

The noseband force measurements recorded by the first and second version of the SafeBand probe (V3 and V4) were similar, with significantly higher difference found only at 2.0 fingers noseband tightness. This is likely to have been due to the slightly greater size of the probe tip on Safeband V4 (15 mm in height and width) compared to V3 (14 mm in height, 15 mm in width). Based on forces measured by both, it is clear that noseband force increases by between 14 and 24 N when noseband tightness levels increase from 2.0 to 1.0 F, and a further 19 to 24 N when tightened from 1.0 F to 0.5 F. If a similar increase in force occurs when tightening from 0.5 to 0 F, then the range of noseband force experienced at the frontal nasal plane could be in the region of 73 to 89 N or greater. Pain in horses is difficult to measure, but persistent noseband forces of 53-69 N (equivalent to dead weights of 5-7 kg) against skin is likely to be of significance. These forces are marginally higher than the mean strike force exerted by jockeys (46.90 ± 5.39 N SEM) during an investigation into whip impact in horses (McGreevy et al., 2013). While direct comparison cannot be drawn, as whip impacts are delivered at speed, the effects of sustained pressures of the magnitude found in this study warrant further investigation. A range of studies into levels of force required to stimulate nociceptors in humans, farm and laboratory animals describe a wide range of forces,
with the highest found among cattle and sheep (Greenspan and McGillis, 1991). The mean mechanical threshold for stimulation of nociceptors on a hind limb in cattle was shown by Ley et al (1996) to be 6.9 N. This study, comparing healthy cattle (n=62) with lame cattle, used application of gradually increasing pressure, with the pressure required to elicit a response (raising or shaking the leg) measured by a strain gauge pressure transducer. The device used to apply pressure was programmed to cut out at a force of 20 N to prevent tissue damage. Mean forces required to stimulate nociceptors in sheep were 4.9 N (Welsh and Nolan, 1995). The forces exerted by nosebands in the current study are an order of magnitude greater than the forces used to stimulate nociceptor activity in both cattle and sheep.

The large noseband forces arising at 0.5 Fingers may explain the reduced frequency of chewing, swallowing and yawning in horses with extremely tight nosebands (Fenner et al., 2016). Previous findings with regard to noseband tightness levels in international competition (Chapter 4) found that 51% of nosebands are tightened to the level of 0.5 Fingers, or tighter (close to or at 0 Fingers). Force measurement as high as 95 N was found beneath one noseband under which the probe could not be fully inserted. This and other similar measures have not been included in the analysis, but suggest the possible force levels that can exist as a consequence of nosebands tightened to levels in excess of 0.5 Fingers.

While every effort was made to tighten the noseband to the desired 2.0, 1.0 or zero Fingers tightness levels, precision in this regard was not possible due to the placement of holes on the noseband, and variation in the diameter of each horse head, at the location of noseband position. Therefore, while the digital gauge offers a precise force measurement, the range of the variations in noseband and horse head dimensions limit the findings to a predicted range of measures (min, max, mean) rather than exact tension measurements associated with specific noseband tightness levels. Tension can be defined as force per unit width. As tension measurement can be calculated by dividing force by noseband width, noseband width data were collected alongside force measurements. However, the usefulness of tension as a measure needs further investigation, as arterial occlusion has been found to be possible at lower pressures with wider tourniquet (Estebe et al., 2000). Therefore, tension measurements utilizing noseband width were not deemed to be of value to the current study.
In addition, the probe necessarily lifts the noseband to a height of approximately 15 mm at the measurement site and this is likely to increase the noseband applied force/tension over what would exist in the absence of the probe. However, this increase will be uniform across all nosebands assessed, and the tension measurement should be sufficient to allow the development of guidelines regarding permitted or acceptable levels of noseband tension.

One horse, on which measurements were taken during Part 1, had a deeper than normal concave indent between left and right nasal bones. This allowed easy insertion of the probe beneath the noseband, and resulted in low tension measurements at each of the three noseband settings. Such anatomical variation will not reduce the hammocking effect and may concentrate the load on the nearest convex structures (left and right nasal bone), so the registered measures will be misleading (Casey et al., 2013). However this anatomical variation was found only in one of 23 horses and is likely to represent a small fraction of the equine population.

While previous research (Chapter 4) found that 44% of nosebands in competition were tightened to 0 F level of tightness, it was not possible to include this setting during the current study. Given the dimensions of the probe, elevating the noseband sufficiently to insert the probe was not possible. However, this is an important, at present missing, piece of data which should be measured in order to identify the pressures experienced by almost half of the equine athletes in competition.

Following Study 1, a number of recommendations were made with regard to the design and function of the SafeBand V3 probe. These included reduced size of casing for greater ease of holding, a backlit display for greater visibility in areas of poor lighting and a tapered point on the probe to allow greater ease of introduction under tight nosebands. In addition, lateral orientation of the display to allow measurements to be read without the handler having to put his/her head in front of the horse was recommended, to reduce risk of handler injury. An inbuilt facility to lock the display after 3 seconds so that the probe could be removed before the display is read by the handler would also reduce injury risk during use. These suggestions were addressed and the SafeBand V4 with modifications as recommended, allowed greater ease of use and recording, and was well tolerated by the horses. The latest version incorporated a backlit display, which was activated simultaneously with the tension measurement mechanism. This caused an occasional low-level startle response, and as this occurred when the
device was already inserted beneath the noseband, could pose a threat to a handler if the horse reacted with a greater level of startle response. Therefore, it would be advisable for this back-lighting to be active during the habituation phase, so that the illumination does not undergo any further change once the probe is fully inserted.

The findings of previous research regarding a drop in skin temperature at the point of the facial crest, in association with very tight nosebands (McGreevy et al., 2012) suggested possible reduction in vascular perfusion as a result of the noseband tightness level. The current study investigated whether noseband tightness levels reduced blood flow through the lateral nasal artery and vein. Such a reduction might be expected to lead to a subsequent reduction in skin temperature, related both to noseband tightness and the duration of the restriction in blood flow. Skin temperature below the noseband was found to be higher than that above the noseband in all treatments. This may be due to less dense hair cover below the noseband resulting in greater levels of radiated heat, i.e. hair/fur will tend to attenuate radiation. This gradient can be seen clearly in the thermography pictures (Figure 57), where areas radiating more heat appear as more brightly coloured. No reduction in temperature below baseline levels (loose noseband) occurred in the skin either above or below the noseband at any stage, suggesting that vascular perfusion of the areas measured was not compromised by the noseband. This was contrary to the findings of McGreevy et al (2012). However, a padded crank noseband was used during that study, which may be more effective in occluding blood vessels than the traditional unpadded noseband at comparable tightness levels.

It is also possible that during the current study, measurements may have been taken from locations close to but not precisely at the location of the blood vessels of interest. While the blood vessels were visible on some horses (Figure 56), in the majority of cases they were not, and therefore there is likely to have been significant error in terms of accuracy in pinpointing the exact location of the blood vessels. In addition, the blood vessels lie superficial to a group of muscles (levator nasolabialis, levator labii superioris, buccinator muscle, levator labii ferioris, zygomaticus and caninus), which are likely to deform if placed under pressure, and the functionality of the blood vessel may not be compromised to the same extent as blood vessels close to a solid structure such as bone.

The increase in eye temperature found during each treatment may indicate some stress associated with the treatment itself, or with the general handling during each data
collection phase. This increase in eye temperature was found across all treatments, including the loose noseband treatment, and therefore, cannot be explained by treatment. However, the significant effect of noseband tightness level found on eye temperatures at 0.5 fingers compared to when nosebands were at the loose setting may indicate presence of a stress response. Based on previous research suggesting a correlation between salivary cortisol and eye temperature (Stewart et al., 2005) this finding may indicate higher levels of stress associated with the tightest noseband fitting, and reflect the findings of Fenner et al (2016). While all of the horses used in the current study had worn nosebands, none of the horses would have experienced the tighter noseband fittings investigated (1.0 and 0.5 Fingers). On removal of the nosebands, marked behavioural changes were displayed by some horses (including persistent licking and chewing). These behaviours reflect similar findings by Fenner et al (2016) of an increase in yawning, licking and swallowing after removal of the noseband at zero fingers fitting, thought to be post-inhibitory rebound. Increased eye temperature in relation to tight nosebands was also found by McGreevy et al., (2012) but this increase above baseline eye temperatures was found across four noseband tightness levels including loose noseband. A double bridle was used during that study, as opposed to the single bit used in the current study.

The profile of the horse face, described in Chapter 4, identifies a marked concavity lateral to the nasal bones. Hammocking of the noseband between convex areas, in this case the nasal bones and the lateral vestibular area will effectively reduce the lift-off height of the probe, and so may explain the apparent lack of impact of a tight noseband at this particular location. Ambient temperature is another variable which may have influenced thermographic findings, although airflow rather than ambient temperature is thought to have a greater impact on reliability of results, with temperatures in the region of 17°C described as ideal (Yanmaz et al., 2007). Ambient temperatures collected during the current study ranged from 4°C to 15°C, although the method of measurement was not validated (a car thermometer). These temperatures were not incorporated into the data, nor were any adjustments made to compensate for variations in ambient temperature, as described by McGreevy et al (2012). However the findings throughout the treatments were consistent, and as treatments took place throughout a nine hour period, with randomized order of treatment, ambient temperature did not appear to influence outcome.
High levels of reproducibility of IRT measurements have been found. Subject distance (usually in the region of 1 m), and camera angle, do not appear to reduce reliability of measurements (Westermann et al., 2013). Wind or air movements however, significantly reduce reliability of results, by cooling the skin and reducing radiated heat (Westermann et al., 2013). Other factors that influence measurements include direct sunlight, ambient temperature, debris or foreign bodies obstructing direct imaging of skin (Stewart et al., 2005) and also the presence of hair or fur. Hair cover reduces radiation of heat, with the impact of hair presence determined by hair length, type and density (Krogbeumker et al., 2009, Turner, 1991). While temperature readings taken from an individual animal are influenced by many factors, comparison of temperatures taken from symmetrical anatomical locations on the same animal or over a period of time can be used comparatively, to identify changes from baseline measures. Caution has been advised with assuming equivalence over symmetrical anatomical areas however by Westermann et al, (2013) who found mean differences of 0.33 °C between left and right forelimbs in healthy sound horses.

During future research, Doppler ultrasonography, used in human and veterinary medicine to measure blood flow rate (Williamson and Harris, 1996) could provide a more accurate and effective means of assessing the impact of different noseband tensions on blood flow. Thermographic imaging could also, possibly provide more informative measurements if used at locations shown to be exposed to highest pressure levels (Casey et al., 2013, Murray et al., 2015).

**Conclusion**

In this chapter, the results of two studies (n = 15 and n = 12 horses) which field tested a noseband tightness gauge developed specifically for the purpose of providing quantitative measures of noseband tightness have been presented. The gauge was developed further following feedback derived from ease of use during Study 1. With the modifications incorporated into the later version (SafeBand V4), noseband force measurements could be recorded with ease and minimal risk to the handler during usage. The tapered tip of the probe allowed ease of insertion beneath the noseband at an area of maximum force, while the backlit digital display facilitated ease of reading and recording force measurements.
The absence of regulations in equestrian sport regarding permitted noseband tightness levels poses a threat to equine welfare, but has been a challenge for regulatory authorities to address, given the lack of an available scientific methodology to provide an objective and unequivocal measurement. The development of the SafeBand probe could facilitate the development of regulations which would be based on an objective universal tightness index guided and supported by appropriate studies designed to provide an evidence base for the actual welfare implications of over-tight nosebands on horses.

The noseband measurements recorded in the current study indicate levels of force exerted by the noseband which are likely to be of significance in terms of nociceptor stimulation, restriction of oral movements and possibly tissue damage. These force measurements may explain the significant increase in eye temperatures found at the highest level of noseband tightness.
Chapter 8

Discussion

Pressures and control of the horse
Control of the horse is done through the use of natural and artificial aids. The natural aids are classified as the hands, voice, seat and legs, whereas bits, spurs and whips represent the artificial aids. These aids work through negative reinforcement, more commonly known as pressure-release. This involves the release of pressure once the desired response has been performed. In addition to the aids listed however, additional pressures are used by riders. Bridles exert pressure on several locations of the head, including through the noseband and headpiece. Lever action bits distribute pressure to other locations on the face in addition to the pressure exerted directly on oral tissues.

Pressure levels – a cause for concern?
Concerns have been raised by equine and equitation scientists regarding the levels and sustained nature of pressures exerted by some commonly used devices (McGreevy, 2011). Certain bits and crank nosebands use a lever action to achieve maximum force, and the absence of regulations or assessment of noseband tightness levels in competition have raised queries in relation to possible welfare problems. Lack of regulation, in the absence of any scientific measurement of routinely exerted pressures poses a potential threat to equine welfare.

Preliminary studies carried out into the effects of tight nosebands have reported increased sensitivity to bit pressure (Randle and McGreevy, 2013), increased eye temperature, suggestive of elevated salivary cortisol levels and reduced skin temperature in the region of tight nosebands (McGreevy et al., 2012). Fluoroscopic and radiographic investigation into the position of a variety of bits in the oral cavity, and the equine oral response to bit pressure, identified tongue movements and chewing as a response to increasing bit pressure (Clayton, 1985, Manfredi et al., 2005). Reluctance by naive horses to take up bit pressure, after first exposure to bit pressure, was found by Christensen et al (2011). Comparison of two different bit types by Potz et al (2014)
showed that use of one bit (the mullen-mouth snaffle) resulted in lower rein tension required to elicit a particular head position (nasal plane vertical to the ground) while walking and trotting on a treadmill. However, direct measurement of pressure levels exerted by either bits or nosebands on the tissues contacted under use conditions in the horse have not been carried out, to the author’s knowledge. Neither have pressure changes during movements, i.e. the dynamic effects of activities on noseband pressures, been examined.

Queries have been raised regarding the possible effects of bit and noseband pressures on a range of tissues. Suggested possible consequences of tight nosebands for the horse include damage to the oral mucosa, bone, skin, compromised vascular perfusion of tissues (McGreevy et al., 2012), compression of oral structures and prevention of a range of behaviours (Fenner et al., 2016). The actual pressure levels arising at tissue or locations most affected by the bit remain largely unexplored.

It is unknown whether habituation occurs with regard to both bit and noseband pressures. Apparent behavioural habituation takes place but there is little evidence to indicate whether or not nociception as a result of pressures or forces exerted by bits and nosebands persist during use. However, the paradigm of learning is well established, i.e., pressure trains through release. The sequence of stimulus-response-reward, i.e., operant reinforcement, constitutes the most common type of training used in horses (McLean, 2005). Immediate release of pressure is required for this training to be successful in teaching a response (McLean and McLean, 2008). Against this background, the sustained pressure of noseband, and also that of bits, where strong rein contact is maintained, does not incorporate a release, and therefore constitutes control through maintained pressure rather than through training (McLean and McGreevy, 2010).

The goal of the research reported here was to identify and test potential methods of measuring noseband and bit pressures and forces directly and under common use conditions with a view to understanding the nature (transient or sustained) and range of these parameters as experienced by horses when ridden. It was not feasible with available measurement technology to simultaneously measure distributed forces and pressures across the entire interface regions between, for instance, the bit and oral tissues. Therefore, in order to achieve the project goal specific sites which could yield useful insights had to be identified for localised, discrete measurement.
The main findings of this thesis were:

1. **Pressures and usage**

A broad scope survey of the aids commonly in use by Irish show jumping riders revealed a high prevalence of usage of spurs (69%), whips (54%) and martingales (87.5%). Of particular significance was the finding that 76% of riders used nosebands which fastened below the bit (flash, grackle and drop nosebands). The pressures exerted by the use of spurs, whips and martingales are expected to be transient, i.e. of short duration, unlike that of nosebands which may be both transient and sustained. Avoidance or reduction of forces exerted by nosebands or, in many cases, bits, is not possible. The existence of lever-action crank nosebands suggests that pressures exerted by some nosebands may be so high as to prevent mouth opening. Therefore, as a first step in understanding the implications of such forces and pressures on animal welfare, it is important to measure them.

An in-depth investigation, of 750 horses, in three countries, into noseband usage-including level of tightness confirmed that riders rely on very tight nosebands in competition. For instance 51% of nosebands were too tight to allow anything greater than the circumference of half a finger under the noseband at the nasal plane. This identified a clear need to investigate the levels of pressure beneath nosebands.

2. **Identification of methods suitable for measuring noseband and bit pressures**

Direct measurement of sub-noseband or bit pressures required the development of an appropriate measurement technology, as there was no precedent for measuring pressure in either area. Placing pressure-sensing technology into the mouth is challenging. In order to elicit reliable measurements, it is important not to alter oral behaviour or change the contour of the bit within the oral cavity. In addition, the environment is hostile, with salt, moisture, heat and strong forces (teeth, tongue movements) actively challenging the effectiveness and stability of any device placed within that environment. In order to place sensors into the mouth, a study of the wear on a range of bits identified the location on the bit least subject to bite damage and most likely to generate pressure measurements from lip contact. Progress was made in a series of studies undertaken. The feasibility of obtaining pressure data from pressure sensors placed on the left and
right arms of a snaffle bit and at three key locations under the noseband was demonstrated. Salivary damage to a bit sensor precluded continuation of the final bit pressure measurements planned, but sufficient data were generated to identify the range of pressures to be expected and the nature and form of the pressure signals arising at the selected locations during routine ridden exercise.

The key findings indicated baseline noseband peak pressure measurements of between 200 and 300 mmHg. Such pressures, if sustained, can prevent venous return in humans but could also lead to artery occlusion in shallow arteries over bone. Transient substantial pressure peaks in excess of 1400 mmHg coincided with routine events such as upward and downward transitions, turns and normal head movements. The effects of such large transients and the accompanying pressure gradients induced on tissue are unknown in this context. However, large pressure gradients associated with tourniquet cuffs are believed to contribute to nerve damage in human limbs.

Baseline bit peak pressures ranged from 0 to 200 mmHg but there were peaks of up to 1100 mmHg. Additional findings of interest were increased bit pressures during upward compared to downward transitions and less than half of downward transitions resulting in reduced bit pressure for the horse. However for further research at this location, an array of sensors is likely to yield more reliable measurements. Due to bit movement (bit has both rotational and lateral degrees of freedom in the mouth) single sensors cannot be guaranteed to always track the actual localised tissue-bit contact region. It is clear, though, that substantial pressure peaks arise. Evidence is lacking regarding what the exact implications of such high pressure transients are for horses in terms of tissue damage and pain stimulation.

3. Noseband force and tension measurement – development of a system of measurement

The feasibility of bit-tissue and noseband-nose contact pressure measurement was demonstrated. The noseband-nose environment is less challenging from a measurement perspective than the bit-mouth environment. Because of this and because of the prevalence of what might be classed as overly tight nosebands in competition horses, further work was focused on nosebands.
Pressure (force per unit area) and tension (force per unit length) are two measurable force related parameters in relation to the noseband environment. The complex shape of the nose and the further complexity of the constituent tissues, while not as complex as the oral environment, still presents significant measurement and interpretation challenges. A simple model of the nose specifically relating to the noseband region demonstrates the importance of local curvature in determining regions which are likely to experience concentrated forces and pressures. Using the model, it is possible to predict order of magnitude figures of pressure at these sites from measured noseband tensions. The model and related measurements showed that noseband pressures depend on noseband tightness, the radius of curvature of underlying tissues and the width of the noseband.

While the above approach generated empirical data, the need for a method of measuring noseband pressures in the field led to the development of a digital probe (the SafeBand gauge), which was tested over several stages in a lab environment to assess suitability for measuring noseband tension.

When the SafeBand gauge was deemed suitable for use in the field, a trial was undertaken involving 15 horses. Three ISES taper gauge set noseband tightness settings were used with each horse and the SafeBand gauge was used to measure the forces required to lift the noseband to a height of approximately 14 mm. These were found to range from 20 N (mean) at 2.0 F, to 53 N at 0.5 V, levels of force substantially greater than those likely to elicit activation of nociceptors. However, further modifications were needed to render the device safer and easier to use in a field situation, such as in a competition scenario, for use by officiating stewards. The suggested modifications were implemented, and the final field trial, with the revised version (SafeBand 4) was carried out to generate a further set of noseband force/tension data. During the same study, a thermographic investigation of skin and eye temperatures at loose and 3 noseband tightness levels was also carried out.
4. Noseband tension data – what forces are involved in tight nosebands, and are they associated with a possible stress response?

The key outcomes from the second SafeBand study were that nosebands fastened at 0.5 fingers, (a noseband tightness level which represents over half of the nosebands in competition today) resulted in mean force measurements of 63 N. This level of noseband tightness was associated with a significant increase in eye temperature, suggestive of a stress response. In addition, each increase of noseband tightness, from 2.0 fingers, to 1.0 fingers, and to 0.5 fingers increased noseband force by in excess of 20 N.

The road ahead

Based on the research described in this thesis, recommendations for further progress must include a development of the noseband force measurement gauge to include a method of measuring sub-noseband pressures at zero fingers tightness level. The SafeBand probe described is not equipped to fit beneath the nosebands of that level of tightness, but given the frequency of this noseband tightness level (44%) development of methods capable of measuring the pressures applied, in particular to areas subjected to the highest pressures, is to important next step. The popularity of low-fastening nosebands, used at extremely high levels of noseband tightness raises the question of distribution and levels of pressure beneath that group of nosebands.

Pain detection in horses is difficult, but progress in the development of methods of pain detection in horses (Dalla Costa et al., 2014) offers an exciting possibility of studying facial expression in horses wearing nosebands at the levels of tightness found during the research described, for evidence of pain. On the longer term, a longitudinal study of horse health, specifically horses exposed to tight nosebands could allow scientific investigation into the actual effects and consequences of tight nosebands. Radiography, neurology, measurement of cortisol levels in the living horse, and post-mortem examination for evidence of tissue damage are all potential avenues to be explored to help answer the many questions raised by the research described in this thesis. In the meantime, on the basis of the force and pressure measurements described, development of a safety scale, based on the objective measurements of noseband force/tension is now feasible, and with the expert opinion of veterinarians and welfare specialists, could allow the development of guidelines which could help protect the welfare of the equine
athlete until more conclusive evidence with regard to the impact of tight nosebands on the horse’s physical and mental well-being is available.
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Appendices

Appendix A: A preliminary report on force and facial curvature measurements for studies of equestrian apparatus
A preliminary report on force and facial curvature measurements for studies of equestrian apparatus

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Abstract

The pressures applied to horses via restrictive nosebands are of growing concern to equitation scientists and horsesport administrators. They prevent the expression of normal behaviour, may compromise blood flow and even damage bone. This report describes an approach to estimate in vivo pressures applied to the dorsal and ventral aspects of a horse’s nose via a so-called crank noseband. A load-cell calibrated over a load range of 0 to 100 N was integrated into a commercially available crank noseband. These force values were combined with anatomical curvature data to estimate the pressure applied by the noseband to the underlying tissue at any point along the internal surface of the noseband using Laplace’s Law. Partial profiles of both dorsal and ventral aspects of the horse’s nose, at a position corresponding to that of the noseband, were taken by contouring a flexible curve ruler to the nose. The ruler was stiff enough to retain the profile when removed from the nose thereby allowing faithful transfer of the profile to paper for digitization. Once digitized, straightforward mathematical algorithms were used to provide an analytical expression describing each profile, to calculate profile curvature point by point, and, using measured noseband force values, to transform the curvature into a corresponding sub-noseband pressure profile. This process was used to study pressures applied when the horse chewed hay, chewed concentrate mix and when it was cued to step backwards. The calculated pressures ranged from 200 mmHg to 400 mmHg; pressures that, in humans, are associated with nerve damage and other complications. As such, these preliminary data strongly suggest the need for more research in this domain. The current approach should inform some of the welfare concerns in ridden horses but should also be of use in studies of oral behaviours around foraging as well as crib-biting and wind-sucking.

Keywords: horse; welfare; nosebands; restrictive; pressure
Introduction

In equestrian sport, nosebands are frequently used to improve the horse’s response to rein pressure (ISES 2012). It is thought that the tightened noseband sensitises the horse’s mouth, making the horse appear to be more ‘submissive’ (Randle & McGreevy 2011). The rules of dressage create an incentive for the use of restrictive nosebands to improve ‘submission’, as penalties and lowered marks apply if the horse is judged to be resisting the bit by opening its mouth or lolling its tongue out (FEI 2009). This is unfortunate because the ‘submission’ marks are meant to reward lightness as evidence of excellent training. That said, lightness is the quality on which judges are least likely to agree (Hawson et. al. 2010).

The rules of dressage state that the use of certain restrictive nosebands is prohibited in competitions that mandate the use of a double bridle (McGreevy et. al. 2012). The use of a cavesson, or plain, noseband is permitted so long as it is “never as tightly fixed so as to harm the horse” (FEI 2009). However, the rules fail to stipulate exactly how to measure the tightness of the cavesson, and as such, and because of the aforementioned (inadvertent) incentives, there is increasing use of nosebands that can be tightly levered or cranked so as to clamp the jaws shut (McGreevy et. al. 2012). There is anecdotal evidence of horses having bony changes including new bone formation consistent with chronic trauma at the site of nosebands.

It has been shown that movement of the tongue is a mechanism by which horses attempt to dissipate pressure from the bit throughout the oral cavity (Manfredi et. al. 2010). It is suggested that the use of a tight noseband may limit the horse’s ability to move its tongue, thus resulting in the inability to relieve pressure on sensitive oral tissues including the bars of the mouth, the tongue and the hard palate. Restrictive nosebands, by definition, violate the so-called Five Freedoms in that they intentionally prevent the expression of normal behaviour but the transience of their use may mitigate the overall impact (Jones and McGreevy, 2010).

The aim of this pilot study was to establish a method for investigating the pressures applied across the nasal planes of riding horses at the level of the usual site of nosebands. This innovative approach is likely to be of use in describing mechanisms that underpin the apparent lesions seen in horses that have been exposed to excessive pressure and should inform the welfare concerns associated with restrictive nosebands.
Materials and Methods

A single subject (a cob gelding approximately 10 years old) was used in this pilot study. He was bridled (Elevator Bridle, XBSELS-F16BK, Full Size, E. Jeffries & Sons Ltd, England) with a single-jointed snaffle bit (with a 12.5 cm long mouth-piece) and a cavesson noseband with a crank tightening mechanism, Figure 1. The noseband comprised two leather straps, a dorsal strap and a ventral strap normally linked using ‘D-rings’. The ventral strap supported a rectangular leather pad (125 mm long by 45 mm wide) of relatively uniform cross-section. The dorsal strap was non-uniform in section (see insert to Figure 1).

A basic single strain gauge loadcell was assembled by bonding a 120 ohm gauge (RS632-180, Radionics Irl. Ltd.,) to an aluminium support bar (30 mm long, 10 mm wide and 2 mm thick). The load-cell was designed to work over a force range of 0 to 100 N and was calibrated over this range. Higher range devices could be used but there is generally a trade-off between expanded range and reduced sensitivity. One end of the aluminium support bar was fixed to the D-ring of the crank noseband while the other end was connected to the leather strap using a ‘T’ type link through a punched hole (see Figure 1 and insert).

Insert Figure 1

The loadcell was wired to an Emant 300 USB DAQ system (Emant Pte Ltd., Singapore) which in turn was connected to a laptop running the Labview (National Instruments Ltd., UK) data acquisition and control package. A custom Labview Virtual Instrument (VI) was developed to display and record the loadcell output at a sampling rate of 10 Hz. Foam padding was wrapped around the USB DAQ which was supported on a stirrup strap on the subject’s neck, Figure 2. The loadcell was also wrapped in foam to act as a cushioning pad and to dampen temperature fluctuations.

Insert Figure 2

Three test exercises were used with the subject while fitted with a normal tightness noseband (2 fingers could be placed beneath the noseband). The subject was offered by hand, ad-lib access to hay, a molasses and grain concentrate feed mix (Horse and Pony Cooked Mix, Gowla, Tipperary, Ireland) offered in a bucket at waist height, and was given simultaneous voice and rein cues to backup. Recording of data was continued both during the presentation of food and following the withdrawal of food when
mastication continued for between 2 and 3 minutes. The whole sequence was repeated three times. The microvolt output of the system was converted directly to force using the calibration factor (5.86 μV/N). Tests were simultaneously recorded using a camcorder mounted on a tripod (Toshiba Camileo x400).

Following a procedure similar to that outlined in Casey et al. 2010 based on well established principles in bandaging and wound treatment (Thomas, 2002), the pressure applied by the noseband to the underlying tissue at any point along the internal surface of the noseband (assuming a noseband with flat inner surface) may be calculated using LaPlace’s Law which, from the perspective of noseband studies, may be expressed as

\[ P = \alpha \kappa F/W, \]

where \( \alpha \) is a unit conversion factor having a value of one for Pascals (Pa, or N/m\(^2\)), \( \kappa \) is the curvature which to a first order approximation is simply the reciprocal of the local radius of curvature, \( R \) (m), of the noseband (in the plane of the noseband), \( \kappa = 1/R \) (m\(^{-1}\)). \( F \) (N) is the longitudinal force in the noseband obtained experimentally using the loadcell. The force is assumed to be uniform around the noseband. This is a reasonable assumption since the noseband is free to slide over the supporting tissue. \( W \) (m) is the width of the noseband. It is more convenient to use units of cm for \( W \), cm\(^{-1}\) for \( \kappa \), and mmHg for pressure (rather than Pa) in which case \( \alpha \) has the value 75.

**Equation 1.**

\[
P = \frac{75 \kappa (cm^{-1}) F (N)}{W (cm)} \text{ mmHg}
\]

A flexible curve ruler (Premier, http://www.silkes.ie/store/product/20556/FLEXIBLE-CURVE-60CM/) was used to obtain profiles of the dorsal and ventral portions of the animal’s nose at a position corresponding to that of the noseband, see photo insert to **Figure 4a** below. The curve ruler may be contoured to the target anatomical feature by gently pressing it against the tissue. On removal, it retains a reasonably faithful impression of the body part. The ruler was then used to transfer the partial nose profile onto graph paper to facilitate digitization, see **Figure 4a**. One could use the graph paper grid to aid manual extraction of a regularly spaced set of x-y data points to provide a spatial representation of the profile. However, the software package FindGraph (© UniPhiz Lab), which has a high resolution curve extraction tool, was used here to digitize the profile from a scanned image (1 to 1 aspect ratio). This generated an x-y
data set for each profile based on calibration points marked on the profile. The use of pre-marked calibration points (only two required per profile) allowed verification of faithful profile transfer.

A point by point curvature may be generated by first obtaining a mathematical function which fits the x-y data set for a particular profile. This is easily done using standard packages such as MS Excel (allows up to 6th order polynomial). Higher order fits are available through more specialist packages such as QTI Plot (© Ion Vasilief) used here. The analytic expression, so obtained for the profile section may be used to generate a point-by-point radius of curvature value using Equation 2, which gives the radius of curvature, $R$, in terms of the first and second order derivatives of the profile (prominence, $y$) with respect to $x$.

Equation 2

$$R = \left(1 + \left(\frac{dy}{dx}\right)^2\right)^{3/2} \frac{d^2y}{dx^2}$$

The Maple computer algebra package (© Maplesoft, Canada) was used to develop a Maple worksheet to calculate the first and second order derivatives of the analytical polynomial expression for the profile and through substitution into the above expressions for radius-of-curvature, provide a curvature data set, $\kappa(x)$.

Results

Representative data segments for the three test conditions are shown in Figure 3. The peak forces are caused by expansion of the jaw against the fixed circumference noseband, thereby increasing the tension (longitudinal force per unit width) in the noseband. Closing the jaw relieves the tension. The oscillatory nature of the load-cell response correlates with the opening and closing of the jaw or indeed any other oral activity that modulates the size of the tissue mass enclosed by the noseband. An average peak force value of 50 N was indicated for hay eating, Figure 3a. The value for feed eating was closer to 40 N while the subject was picking up feed with the lips but
dropping to 20 N or lower for feed mastication, Figure 3b. Higher than average peaks for both hay (62 s and 72 s approximately, Figure 3a) and feed eating (65 s and 80 s approximately, Figure 3b) would appear, from video footage, to correspond to movement of the food bolus within the mouth. The anomalously large peaks occurring when feedstuff was first offered (45 s) and later during feeding (78 s, approximately), Figure 3b, correspond to the subject biting at the grain in the bucket. The results for the step back exercise depended strongly on animal compliance with the paired cues of voice and rein tension. The data plotted in Figure 3c shows peaks corresponding to head tossing at 509 s and 511 s approximately, where the subject threw his head up and back in advance of being given simultaneously the voice and rein cues to step back. Large peaks (in excess of 200 N) are seen where he resists the cue (at 512 and 513 s approximately, Figure 3c). However, average peak values for compliance with the step back cue were closer to 25 N or less and were indistinguishable from normal mouth action. Once step back commenced noseband force dropped close to zero. Large forces similar to those shown in Figure 3c, i.e. values in excess of 250 N, were generated when the subject lowered his head towards the ground while opening his mouth. Since these forces are outside the calibration range (100 N) the data serves to indicate only very large forces but caution should be exercised in relation to the absolute values indicated.

Insert Figure 3

The results for average peak force values reported here for eating appear to be consistent with previous studies which found that the amplitude of mouth opening movement is influenced by feed type with hay resulting in greater excursions of the mandible than concentrate feeds (Bonin et al, 2007). In addition, mastication of concentrated feed was found, here, to follow a strongly periodic, constant amplitude pattern, whereas mastication of hay was punctuated by pauses and irregular peak sequences.

The digitized data points representing the actual dorsal and ventral profiles of Figure 4a are plotted in Figure 4b and Figure 4c respectively, along with the best fit polynomial curves for each data set. A seventh order polynomial was found to give a very good fit to both profiles (Correlation coefficient, $R^2 > 0.99$). The corresponding curvatures, calculated as outlined above from the polynomial curves, are also plotted in Figure 4b and 4c. The curvature for the dorsal profile is entirely positive indicating that the slight
profile depression either side of the sagittal plane has been smoothed out by the profile
transfer and curve fitting process. In contrast, the pronounced profile depression around
the sagittal plane for the ventral profile is clearly resolved and produces a corresponding
negative curvature, Figure 4c.

Insert Figure 4

By substitution of the curvature data into Equation 1 and using the average of the peak
force values measured directly for each test condition used in the study, e.g. 50 N
(eating hay), 40 N (eating feed concentrate), 25 N (step back), as $F$, it is possible to
infer a sub-noseband peak pressure profile for each test. These are plotted, for the dorsal
profile case, in Figure 5. While the peak curvature in the region of the mandibular rami
$(\kappa \approx 0.62)$ is almost double the value at the lateral nasal margins $(\kappa \approx 0.34)$, the wide
rectangular pad that contacts the mandible ($W = 4.5$ cm) reduces the overall effect of
this increased curvature and so peak pressure values at the mandibular rami are likely to
be only larger by a third than the peak values at the lateral nasal margins, i.e.

$\frac{0.62}{0.34} \times \frac{33}{45} = 1.33.$

Insert Figure 5

Discussion

While noseband force and tension measurements may provide useful animal behaviour
insights, the utility of such measurements would be extended considerably if the data
could be transformed into localised pressure values occurring at interfaces between the
noseband and key anatomical sites such as the mandibular rami, lateral margins of the
nasal bone and soft tissue covering the vestibular surface of the molar teeth. Following
an approach used previously to infer pressure variations under a nominally constant
tension bandage based on limb profiles extracted from MRI scan sections of a human
leg (Casey 2010), profile curvature and force data were combined in order to provide a
lower estimate of the in vivo pressures likely to occur at some of these sites under a
normal tightness fit horse noseband.

Although the load-cell in the current design is crude, it demonstrates the feasibility of
using such a device to establish in vivo bridle noseband forces. The configuration
reported here allows noseband tightness to be adjusted. Extra holes were punched in the
noseband strap to allow shortening of the strap to compensate for the inclusion of the
linked loadcell. However, the leather strap was not looped through the D-ring so one
might argue that the tightening functionality of the crank noseband has been moderated. In future work, this may be overcome by replacing the chrome/steel D-ring with an aluminium analogue with integrated strain gauges. The noseband was tightened only to the recommended level of tension (two fingers could fit comfortably beneath the noseband). Therefore, it seems likely that, although tight, this noseband would have to have been substantially tighter to adequately emulate competition conditions. Given that mouth opening is unwanted in dressage, the likelihood of horses with truly clamped jaws being able to chew is remote.

The flexible curve ruler method of profile extraction is simple and reasonably effective but is limited to partial nose profiles. Nevertheless, the actual profile shows both positive (convex profile element) and negative (concave profile element) curvature. Positive curvature arises where the centre of curvature is inside the tissue or support body. The noseband will rest on the tissue in such regions. Negative curvature arises where the centre of curvature is outside the tissue. In such regions, the noseband will ‘hammock’ between prominences on either side (O’Brien and Casey, 2002), i.e. it will not be in contact with the tissue underneath and so cannot apply any pressure. In effect the load is redistributed or concentrated at the prominences. The curvature plots identify very clearly where such critical load bearing regions are likely to occur. For instance, the curvature peaks at the lateral edges of the nasal plane identifies these locations as likely to be subject to concentrated forces.

It is useful to have an analytic expression representing the profile to allow point-by-point calculations of curvature and pressure prediction. A seventh order polynomial gives an excellent fit to the profile sections (correlation coefficient, $R^2 > 0.99$) but lower order fits, e.g. 4th order, may be adequate. A similar approach could be used with full profiles, if available, using parameterised curves. It was clear from observation of the dorsum of the nose at the noseband site that the midline of the nasal plane was depressed relative to the edges of the nasal bones. A standard workshop Vernier callipers depth gauge was used to measure the sagittal indentation at the midline and showed that it was approximately 2.5 mm below the edges of the nasal bones. However, the curve ruler method of profile extraction tends to smooth out such small undulations (see dorsal profile, Figure 3a). The polynomial fit algorithm introduces further smoothing unless higher order terms are used, i.e. greater than 4th order. Increasing the order can, however, amplify digitization artefacts associated with the profile transfer process.
The noseband applied pressure is expected to be maximal at regions of high curvature (Equation 1). The pressure values predicted here are most likely conservative estimates of the actual pressures under the noseband. In the current analysis, we assumed that the noseband has a flat transverse inner profile. The actual inner transverse profile of the noseband is more complex (see insert to Figure 1). For example, there is a central convex prominence with a radius of curvature of about 2 cm corresponding to a transverse localised curvature of 0.5 cm\(^{-1}\). This is similar in value to the peak curvatures in the longitudinal direction. A compound curvature may be calculated if necessary. However, in simple terms, the transverse curvature will add to the longitudinal curvature producing pressures significantly in excess of what has been calculated here. Thus the transverse convex profile reduces the effective width of the noseband making it more severe than would be expected from simple width measurements. Combined with this, the hammocking effect will tend to further increase pressures at anatomical prominences.

The predicted peak pressures ranged from 200 mmHg to 400 mmHg but, as is clear from the head tossing data, considerably larger pressures are likely to arise. Acute pressures can produce nerve damage and other complications in humans (see McEwen and Casey, 2009 and references therein). As such, these preliminary data strongly suggest the need for more research in this domain. Clearly, one could deploy an array of pressure sensors at the tissue-noseband interface in order to measure the noseband applied pressure profile directly. However, the continuum/connective nature of tissue and leather makes it difficult to measure interface pressures since most commercially available pressure sensors are designed for gas and fluid applications. These difficulties are accentuated in regions of high curvature – precisely the regions of interest here (Casey, 2011). A useful strategy may be to use a combination of force/tension measurement with an integrated noseband loadcell and pressure sensor deployment at a site such as the wide/flat mandible pad which offers the best prospects for reliable pressure measurement. One could use the single pressure measurement as a datum level from which pressures at other sub-noseband anatomical sites could be ‘indexed’ based on actual force measurements and known or measured anatomical profiles. While a load-cell with a range of 100 N may be adequate for ‘gentle’ test conditions such as those used here, it is likely that devices with considerably expanded range will be required to reliably quantify the noseband forces arising during routine exercise and competition conditions.
The refinement of at least two steps involved in this study should provide a means of establishing reliable quantitative noseband-applied pressure data. First, MRI sections and other imaging techniques could be used in a more detailed study. However, given the merits of a mechanical approach, it is likely that an extra-large mechanical profile gauge (see for instance, http://www.fine-tools.com/kontur.htm) or a non-contact profilometer could be used to obtain full profile data and determine sub-noseband tissue profiles more exactly. Second, a two or four-gauge bridge system and a D-Ring dynamometer/load-cell would improve the device’s performance and temperature stability without modifying the functionality of the crank.

We anticipate that these developments will permit the capture of combined pressure and force noseband data for simple stationary activities such as chewing hay, chewing grain, licking and crib-biting, all of which can be prompted reliably by various treatment protocols (McGreevy 2004). Similarly this approach could be used to gauge the pressure level that deters a horse from attempting to yawn or chew. A wireless version of the load cell similar to wireless pressure measurement systems already developed (Casey, 2012) would allow measurements to be carried out while the animal is being exercised, schooled or competing in an arena.

Conclusions

Preliminary data from this approach to measuring pressures under a noseband are very promising. They strongly suggest the need for more research in this domain. The current approach should elucidate some of the welfare concerns in ridden horses but should also be of use in studies of general oral behaviours around foraging, as well as crib-biting and wind-sucking.
References


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Figure Captions

Figure 1 Single strain gauge on aluminium support linking the ventral strap to a D-ring of the noseband dorsal strap. The left insert shows the cross-sectional dimensions of the dorsal strap. The right insert shows a close-up of the loadcell.

Figure 2 Bridle fitted to subject with Emant DAQ covered in protective foam (A) and attached to a stirrup leather placed round the neck. The loadcell (B) was also covered in foam for wear comfort and to improve temperature stability.

Figure 3 Extracts of force (N) versus time (s) data for the three test conditions used in this study: (a) eating hay from hand at waist height; (b) eating feedstuff from a bucket; (c) subject resisting simultaneous voice and rein cues to step back. The dotted lines indicate the average peak heights in a selected region, judged by eye.

Figure 4 Plots of sub-noseband profile data: (a) dorsal and ventral profiles with \((x, y)\) digitization calibration points superimposed and photographic insert showing flexible ruler and graph paper after transfer of profile; (b) plot of 7th order polynomial best fit curve fitted to digitized dorsal nose profile \((y)\) data and corresponding curvature \((\kappa)\); (c) as in (b) but for the ventral profile data.

Figure 5 Predicted pressure values based on measured noseband force and noseband curvature for the dorsal profile of Figure 4: o - hay; □ - feed concentrate; ◊ - step back (little resistance).