Mouth Pain in Horses

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Mouth pain in horses, specifically that caused by bits, is evaluated as a significant welfare issue. The conscious experiences of pain generated within the body generally, its roles, and its assessment using behaviour, as well as the sensory functionality of the horse's mouth, are outlined as background to a more detailed evaluation of mouth pain. Bit-induced mouth pain elicited by compression, laceration, inflammation, impeded blood flow, and the stretching of tissues is considered. Observable signs of mouth pain are behaviours that are present in bitted horses and absent or much less prevalent when they are bit-free. It is noted that many equestrians do not recognise that these behaviours indicate mouth pain, so that the magnitude of the problem is often underestimated.

Keywords: "bit blindness" ; bitted to bit-free behaviour ; conscious noxious experience ; gum ; tongue and lip pain ; oral lesions ; pain grimace ; pain-induced breathlessness ; anxiety and fear ; remedial strategy

1. Mouth Pain in Horses

The exceptional sensitivity of oral tissues to noxious stimulation [1] highlights the importance of understanding the various ways common riding or driving practices would stimulate oral nociceptors sufficiently to cause horses significant pain. The types of stimuli considered here are compression, laceration, inflammation, impeded tissue blood flow, and tissue stretching, and the practices considered are the use of bits and, briefly, tongue ties. Disease-related dental pain is not considered.

1.1. Bit-Induced Nociceptor Stimulation and Pain

1.1.1. The Interdental Space

Bridles are usually adjusted so that the bit is in contact with a largely tooth-free segment of the gums on each side of the mandible, i.e., behind the incisors and in front of the premolars in the so-called "interdental space" [2][3][4][5]. The gums are modified periosteum, i.e., the membrane that surrounds bone, and are richly supplied with nociceptors [1][6]. Accordingly, rein tension transmitted as bit pressure applied to the mandibular gums can readily generate intense pain, especially as the pressure per unit area of direct bit–gum contact is amplified by the round cross-section of the bit and the usually narrow upper edge of the interdental mandible [2][7][3][8].

The magnitude of this amplification can be estimated by utilising the following information.

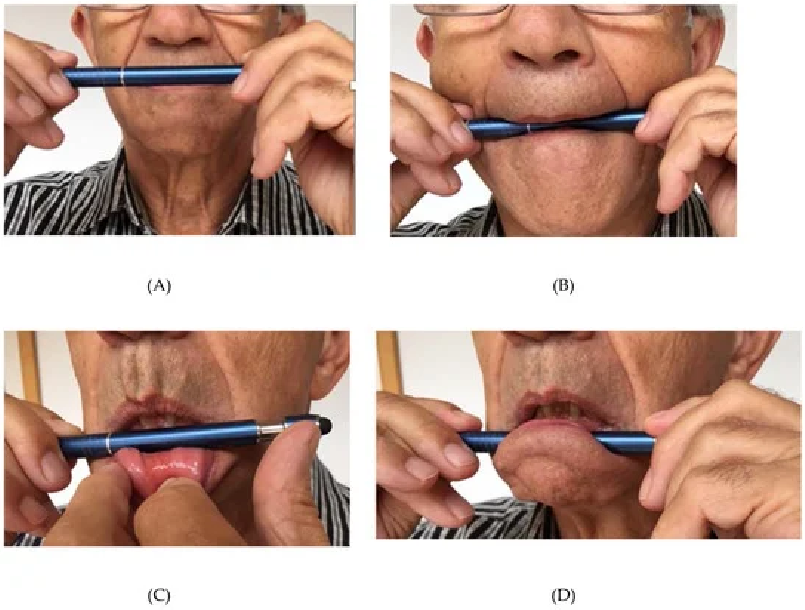
(1).The established relationship between tension (T, units N), mass (m, units kg) and gravitational acceleration (g = 9.8 metres/sec^2), which is "T = mg" or "T = 9.8 m" [9].

(2).Known rein tensions in various situations. Examples include zero N (Newtons) with a loose rein, maxima of 51 to 166 N, and mean values that ranged from 9 to 59 N [10][11][12][13][14][15].

(3).An estimated area of bit–gum contact on the interdental space (CA_{bg}) of 0.387 cm^2 [16], which is equivalent to a 6.22 × 6.22 mm square.

The mass equivalent (kg) of rein tension (N) may be calculated using a different form of the above equation, namely "m = T / 9.8", and the mass per unit cross-sectional area (kg/cm^2) using "m / 0.387". Thus, the mass equivalents of the above values are a minimum of zero kg, a range of maxima of 5.2 to 16.9 kg, and a range of overall mean values of 0.9 to 6.0 kg, respectively. The related figures for mass per unit area are zero kg/cm^2 for the minimum, 13.4 to 43.7 kg/cm^2 for the range of maximum values, and 2.3 to 15.5 kg/cm^2 for the range of overall mean values. The estimated amplification factor is 2.58. Apart from the "loose rein" minimum, and a report of estimated mean bit pressures that were mostly between 0.93 and 1.1 kg/cm^2 [17], most of the above bit pressures would be painful, some of them exceptionally so. It is therefore of interest that, with one exception [15], bit-induced pain was not mentioned in any of the above papers on rein tension [10][11][12][13][14][17][18].

Readers may gain a personal insight into the likely intensity of such pain by conducting on themselves what has come to be known as the "Mellor pen-test". This test is intended to simulate the compressive effects of bit pressure applied to the gums of the interdental space of a horse. It involves applying pressure to the barrel of a pen placed against the gums below the front incisor teeth of the lower jaw (**Figure 1**). In common with the experiences of audiences totaling at least 450 addressed by the author to date (e.g., see [19]), it is anticipated that the vast majority of readers will find that intense pain may be generated by low pressures.



(A) (B) (C) (D)

Figure 1. The 'Mellor pen test." This simulates bit pressure applied to the gums of the interdental space of the horse. Gums are exquisitely sensitive to painful stimuli, including compression. Rein tension transferred to the bit in contact with the gums of the interdental space causes pain. (**A**) Position 1: Hold the pen in front of your mouth; (**B**) Position 2: Open your mouth, place the pen where the upper and lower lips meet on each side, and then push the pen towards the back of your throat. No gum contact, no significant pain; (**C**) Position 3a: Roll your bottom lip down and locate the pen on your gum, below your central incisors; (**D**) Position 3b: Now release your lip and with both hands holding the pen, apply compressive pressure to your gum, carefully increasing the pressure in steps from very low until the pain is too intense to continue. How much compression-induced pain could you stand?

As a further exercise, first access a set of top-loading kitchen scales for weighing up to at least 3kg. With an index finger pointing down vertically, place its *tip* (not the distal fingerprint surface) on the weighing tray so that the bone of the terminal phalanx bears most of the pressure; and then press directly downward to hold the scale readings successively at 1, 2 and 3 kg, taking a break between each level. Bearing in mind that the fingertip is much less immediately susceptible to pain-inducing pressure than are the exquisitely sensitive gums, readers should note how long they can maintain these scale readings before pain compels withdrawal. Now compare these scale levels with the values for bit pressure per unit area (kg/cm^2) given above and note that 3 kg/cm^2 is considerably less than most of them.

Finally, the reader may also wish to imagine lying flat on their back on a raised platform with sufficient space under it to suspend a small carry-on aircraft flight bag. The bag is attached to light reins fixed to each end of a metal bit located, as with the "Mellor pen test", on the mandibular gums below the front incisor teeth (**Figure 1**). Now imagine that the weight of the bag is increased from 2 up to a 7 kg carry-on maximum. Then, imagine that the weight is increased progressively to a 20 kg maximum for stowed luggage, noting that this is less than half the figure of 43.7 kg/cm^2 derived from the 166 N maximum rein tension referred to above.

It is anticipated that the combined results of these three exercises will speak for themselves.

The mandibular periostitis (bone spur formation) observed in the interdental space of horses wearing bitted bridles and its absence or virtual absence in free-roaming or feral equids, when taken together, provide evidence of significant traumatic impacts of bit use. Three postmortem studies of equid mandibles illustrate this: (1) interdental bone spurs were found in ~88% of 32 working horses but there were none in 28 Przewalski horses [20]; (2) interdental space roughness was reported in 48% of 87 Warmbloods or trotters, in 25% of eight donkeys, but only in 7% of 68 zebra [8]; and (3) spurs were observed in ~61% of mandibles from 66 domestic horses, but none were seen in 12 feral and Przewalski horses [2]. In addition, live assessment of oral lesions revealed that 28–30% of 50 polo ponies and 50 racehorses had interdental bone spurs, which were generally more severe in the racehorses [21]. Finally, in the first postmortem study mentioned above, the erosion of enamel and dentine of the first mandibular premolar, indicative of bit wear, was observed in 62% of 29 working horses [20]. Likewise, in the third postmortem study above, premolar erosion was observed in 61% of the 66 domestic horse mandibles, such that, overall, 88% of those mandibles exhibited either bone spurs or premolar erosion, or both [2].

The formation of bone spurs in affected horses is apparently due to inflammation associated with repeated incidents of bit-induced bruising, laceration, and/or ulceration of the interdental gums [2][22][23][24]. Such gum lesions reportedly occurred in 26% of 261 Trotters observed after a race [25], increased from 8% before to 31% after events in 77 competition horses [26], and were more common and severe in racehorses than polo ponies [21]. All such lesions are painful [6], and human experience would suggest that the intensity of that pain would be increased when there is further direct compressive contact between these lesions and a bit. Likewise, in view of the dense nociceptive innervation of the dentine and, to a lesser extent, the tooth pulp [27], further compressive bit contact with significantly worn teeth (mentioned above [2][20]) would also be likely to increase the intensity of any associated pain.

1.1.2. The Tongue

The tongue, being densely supplied with mechanoreceptors [1], exhibits exceptional tactile sensitivity which underlies its haptic functions of delicate investigation and selective manipulation of food and other objects both inside and outside the mouth. It is also well supplied with nociceptors, although a reported low responsiveness of horses to severe lacerations in the mobile rostral portion of the tongue, amounting in some cases to near amputation [3][28], suggests that nociceptor density in the tongue may be less than in the periosteal gums of the interdental space [1][6][29]. However, this does not imply that the tongue is insensitive to painful stimuli, because injuries such as puncture wounds, abscesses, or ulcers located caudally in the tongue can apparently cause enough pain to seriously impede chewing and swallowing [28].

Nevertheless, several observations suggest that the tongue may be somewhat protected from bit-induced penetrative injuries. Studies that reveal significant bit-related injuries at multiple oral sites report no or very low occurrences of significant tongue lacerations or ulcers [21][25][26][30][31]. The tough keratinized squamous epithelial lining of at least the dorsal surface of the tongue [32] may contribute to this, but it might also make bruises from non-penetrative bit-related compression more difficult to detect.

Bruising of the tongue would likely occur at its lateral edges when the horse uses it to partially cushion the interdental gums against significant bit pressure. Under bit pressure, the tongue may lie ventrally across the full width of the oral cavity covering the interdental gums on each side, such that, at its edges, the tongue may become painfully compressed between the bit and the mandible [7][26][33]. Although this might reduce the overall pain experienced, it would not eliminate it. This is because narrow under-the-bit compression across the width of the tongue between its lateral edges would still be painful, and some pain-inducing nociceptor stimulation may still occur within the highly pain-sensitive interdental spaces , despite cushioning by the tongue.

Another strategy apparently deployed by horses to ameliorate bit-induced pain is to manoeuvre the tongue to lie above or behind the bit [7][34][35]. The position above the bit would potentially enable the frenulum and adjacent sublingual tissues to absorb some of the bit pressure generated by rein tension. Although this would itself be painful, this strategy may be sufficient to reduce the bit pressure applied directly to the interdental gums and/or to the premolars for the outcome to be a net reduction in pain. That a significant proportion of horses utilize this “tongue over the bit” strategy is indicated by the relatively frequent use of tongue ties to prevent them from doing so [35][36][37]. Thus, 72% of Thoroughbred trainers in Australia reportedly used tongue ties with over 30% of horses wearing a tongue tie at least once [35]. Moreover, once applied to a racehorse, a tongue tie was used in 84% of their subsequent races. Overall tongue tie use was greater in jumps races (45%) than in flat races (32%) [37]. In the United Kingdom, tongue ties were used over a 2-year period in 5% of horses, and after being used once they were applied in an average of 77% of the races run by those horses during the following year [36]. Advocates for this intervention often proffer the justification that “tongue-tied” racehorses are more responsive to the bit and are therefore easier to control, and/or that they are less susceptible to compromised breathing resulting from dorsal displacement of the soft palate which impedes their racing performance [35][36][37][38][39]. Note however that contrary evidence exists, which shows that bit-induced mouth pain makes many horses difficult to control [7].

Nevertheless, regarding the greater purported sensitivity to the bit and effectiveness of control, advocates of this intervention reason that: (1) bit-induced mouth pain is used to control potentially unruly horses; (2) some horses relocate their tongues over the bit to alleviate the pain; (3) “tongue over the bit” horses are less responsive to the bit and are therefore harder to control; and (4) when tongue ties are used to restore a “bit over the tongue” configuration, responsiveness to the bit and effectiveness of control return. However, so does a greater intensity of bit-induced pain. It therefore follows that tongue tie use enables its advocates to impose on horses, or threaten them with, bit-induced pain at noxious intensities designed to achieve the sense of control they seek. Note in addition that use of tongue ties is itself aversive and likely adds significantly to the pain.

Tongue ties are usually applied by grasping the tongue, drawing it sideways out of the mouth, winding the tie around the tongue one or more times and securing it below the mandible ventral to the interdental space; the purposes are to hold the tongue flat against the ventral surface of the oral cavity and to stop it from being retracted [40]. Nylon stocking, leather, or rubber bands are used. It is common for a length of tongue beyond the tie to protrude from the horse’s mouth. Problems with tongue tie use, reported by nearly a quarter of Australian Standardbred trainers, include lacerations, bruising and swelling of the tongue, difficulty swallowing, and stress behaviours [40][41]. It is proposed here that the stress behaviours indicate pain-related aversion to the tie. The likely sources of significant pain include the following: lengthwise over-stretching of the tongue during application of the tie; compression of the tongue directly under the tie; impeded blood flow to the rostral tongue while the tie is in place and its restoration when the tie is removed (ischaemic pain); and pain linked to any bruising and lacerations. In addition, the tie narrows the tongue medially, which prevents it from overlying the interdental space on each side, thereby increasing the likelihood that, under rein tension, the bit would have direct contact with the highly pain-sensitive periosteal gums .

1.1.3. The Commissures of the Lips and the Buccal Mucosa

The incidence of commissure lesions has been reported in several studies. (1) Acute lesions were apparent in 64% of Finnish trotters, where blood was visible on the bit or the wound in 10% that had the most severe lesions [25]. (2) About 9% of Danish horses in dressage, show jumping, eventing, and endurance competitions had commissure lesions, some of which were accompanied by visible blood [31]. (3) In 50 polo ponies and 50 racehorses, commissure ulcerations numbered 15 and 53, respectively, where both the prevalence and severity of the lesions were greater in the racehorses than the polo ponies [21]. The prevalence in these racehorses was later estimated to be ~25% [25]. (4) Mild, apparently older lesions, both inside the commissures and in the adjacent buccal mucosa, were found in 26% of Icelandic horses prior to prescribed gait competitions, and a further 4% had severe lesions in the buccal mucosa [26]. And (5), buccal ulceration or evidence of previous ulceration adjacent to maxillary molars was apparent in 94% of ridden Swedish horses [30]. These observations and the finding that no fresh lesions were observed in brood mares that had not recently been used wearing a bitted bridle [30] implicate bit use as a cause [25].

Commissure and adjacent buccal bruising, laceration, ulceration, and bleeding provide clear evidence of prior damaging impacts of bit pressure on the nociceptors of the internal mucosal and external lip tissues sufficient to cause significant pain. Moreover, this pain would be intensified by bit and/or molar tooth pressure on any recently formed lesions. A further indication of high bit pressure on the commissures is the readily observable stretching of the lips to up to double their resting non-bitted length when rein tension is applied [42][7][43][44][45]. Note that this stretching, whether short-lived or sustained, would itself cause pain. The reader may confirm this by repeating the “Mellor pen test” position 2 (**Figure 1**B), but instead of applying little pressure, for this purpose the pen should be pushed carefully towards the back of the mouth as far and for as long as the induced lip-stretching pain will allow.

1.2. General Comments and Summing up

The reported post-race prevalence of lesions over the full range of severity at all oral sites was 84% in Finnish trotters [25], 88% in Swedish trotters [30], and in three studies of Icelandic horses after competition events it was 60% in 2012, 33% in 2014, and 43% in 2016 (for references see [25][26]). To date, with few exceptions (e.g., [25]), key publications that have dealt specifically with bit-induced oral trauma either did not mention pain at all or made only fleeting reference to it (e.g., [2][8][9][10][11][12][13][14][15][17][18][19][20][21][26][30][31]. Nevertheless, it is apparent from the preceding analysis that the principal welfare issue here is pain.

All oral sites referred to above are richly supplied with nociceptors and are susceptible to bruising, laceration and ulceration. The prevalence of these lesions clearly indicates that, notwithstanding many riders’ specific intentions to the contrary, rein tensions transmitted to the bit may often cause tissue trauma and associated pain at intensities that are of welfare concern. Note, in addition, that the periosteal gums of the interdental space are especially sensitive to noxious stimulation. In fact, they are so sensitive that low bit pressures which would not produce detectable lesions can still cause significant pain, as indicated by the “Mellor pen test” (**Figure 1**), and higher pressures that do produce visible lesions would cause marked to extremely severe pain.

It is noteworthy that once lesions at any oral site have developed, repeated direct contact with the bit would magnify the intensity of the resulting pain [46][47], whether the bit pressure is transient or sustained, is applied abruptly or slowly, or repeatedly oscillates up and down during the rhythmic step phases of the trot or canter [10][11][12][13][14][15]. Moreover, inflammatory reactions in and around the lesions would likely lead to the development of pain hypersensitivity due to decreases in nociceptor stimulus thresholds within the lesions and nearby tissues (see [46][47] for details of how pain experience changes after injury). Moreover, the persistent aggravation of lesions and the nearby inflamed tissues by repeated bit contact would delay healing and resolution of any associated pain (see [25] for references]). Finally, protracted, repetitive, and noxious oral stimulation may lead to a more widespread and lasting hypersensitivity in the form of trigeminal neuralgia, which, recognised behaviourally, manifests as recurring episodes of sudden, sharp, and exceptionally intense pain experienced in various facial locations remote from the mouth [42][48][7][49], episodes which may be triggered at both oral and non-oral locations [50][51].

It is beyond the scope of this review to consider the impact of bit design on these phenomena. Suffice it to say here that oral contact sites and thus the location and severity of lesions appear to depend on particular design features of different bits and how the bits are used [3][5][21][25][26][30][31][34]. However, with some exceptions (e.g., [5][34]), many investigations are handicapped by having to rely on horses that have been made available by owners who supply them wearing their own tack when participating in various independently scheduled equestrian activities, so that rigorous comparisons of the specific impacts of different bit types can be difficult.

2. Behavioural Indices of Mouth Pain in Horses

As noted above, behaviour is often used to indicate when animals, including horses, are in pain. Some behavioural responses to mouth pain may be identified easily as being due to noxious oral stimuli, whereas the link with other responses may not be as obvious. This is because indicative behaviours may involve the mouth, tongue, lips, nostrils, eyes, ears, head, neck, trunk, legs, and/or tail, as well as changes in posture, gait, and the vigour and character of locomotory activity. The available information for the present analysis, summarised in **Table 1**, has been presented with three overlapping orientations: first, behaviours of bitted horses, especially those involved in competitive athletic events; second, behavioural changes when horses are transitioned from being bitted to bit-free; and third, bit-free behaviour, in particular that of domesticated horses wearing halters or no tack, and that of wild, free-roaming horses. [**Table 1** near here]

Table 1. Some behavioural indices of bit-related mouth pain in horses.

Indicative Pain-Related Behaviours in Ridden Bitted Horses
Mouth: **resists bridling; fussing with the bit, persistent jaw movements, chewing; crossing the jaw; slightly open or gaping mouth; teeth grinding, holding the bit between the teeth; tongue persistently moving or protruding from the mouth, tongue placed above the bit or retracted behind it; excessive salivation or drooling.** ***Head-neck:*** **sudden evasive movements due to abrupt increases in rein tension; side-to-side or up-down head shaking, jawline above horizontal; head tilted, stiff necked; rein-induced low jowl-angle, neck arched, nasal plane at or behind the vertical; reaches forward so rider uses longer rein.** ***Pain face:*** **identifiable nostril flare, lip positions, ear positions, eye white visibility and facial muscle tension.** ***Body movement/gait:*** **stiff or choppy stride, hair trigger responses, crabbing; difficult to control, hesitant to move forward, difficult to stop, side-stepping from straight-line motion; bucking; rearing; tail swishing. Refs: [52][53][54][55][43][44][15][34][41][45][56][57][58][59][60][61][62][63][64][65][66][67][68]; plus YouTube archive videos [a]**
Bitted to Bit-Free Changes in Ridden Horse Behaviour
Mouth: **all bit-related mouth behaviours absent; quiet, closed mouth, tongue inside mouth and appropriately placed; little or no teeth grinding; no drooling.** ***Head-neck:*** **head shaking absent; lower head-neck position and wider jowl angle; head, neck and spinal column properly aligned longitudinally.** ***Pain face:*** **no indications of mouth-related pain in healthy animals.** ***Body movement/gait:*** **calm, relaxed and cooperative demeanour; engaged, lively, energised and exhibits vitality of fitness; head freedom supports balanced, aligned and smooth rhythm of motion; tail movement in synchrony with spinal movement. Refs: [42][69][70][7][57][58][59][60][61]; plus YouTube archive videos [a]**
Behaviours of Bit-Free Horses at Rest or When Running Free
As expected, domesticated horses wearing loosely-but-snugly fitted bit-free bridles do not display any of the bit-related behaviours noted above while standing at rest or engaging in exercise ranging from walking to galloping; nor do horses wearing halters while standing in stalls or moving freely in turnout paddocks. Likewise, neither do wild, free-roaming horses when standing alert or when walking, trotting, cantering and galloping during roundups. Refs: [71][72]; YouTube archive videos of bit-free domesticated horses, and of ~150 free-roaming, wild Brumbies (Australia), Camargue horses (France), Kaimanawa horses (New Zealand) and Mustangs (USA) [a]

[a] Google "YouTube plus the named activity or event for competition horses", or "stipulate documentaries and roundups about bit-free, wild or free-roaming horses", then follow links to the numerous filmed records [73].

On the basis of detailed behavioural observations (**Table 1**), a bit in a horse's mouth at zero rein tension might appear to be accepted by the horse or may merely be tolerated as a mild irritant. However, as rein tensions rise, the bit clearly becomes increasingly aversive because the horse is confronted with escalating inescapable pain. Abrupt, highly aversive increases in rein tension often occur when a sharp change of direction or speed is elicited, for example, during competitive events requiring agility such as barrel racing, calf roping, and polo matches [73]. Though somewhat less abrupt, frequent changes in rein tension commonly occur during competitive cross-country and show jumping events [73]. In contrast, elevated rein tensions are often sustained for at least the first half of flat races, steeplechase, and harness races until the horses are "given their heads" to accelerate towards the finish line, after which they are again "reined in" when jockeys seek to reduce their speed to a walk [73]. Some pain-induced behaviours may also be apparent during events that primarily focus on deportment and demeanour at low speed, in particular dressage and some draft horse competitions [73]. However, it is not suggested here that throughout every ride horses would continuously experience significant pain, but it is clear that under the circumstances just described highly aversive levels of pain would be experienced with the rein tensions known to be used.

It is recommended that readers assess the behavioural evidence outlined in **Table 1** for themselves and draw their own conclusions. YouTube videos in particular are a rich resource [73]. Filmed independently, they provide objectively observable records of equine behaviour in all of the circumstances referred to above, and many more. Likewise, equine events are regularly screened on television. Finally, whether they participate as equestrians or not, readers who personally attend these events or who are recreationally involved with less formal equine activities may make their own direct observations of the behaviour of horses wearing bitted and bit-free bridles, halters, or no bridles at all.

It should be noted that the bit-free bridles referred to here are those that are loosely and comfortably fitted and are used in ways that are intended to be pain-free (e.g., [7][58][74][75]). At their best, therefore, they do not replace the control of horses via bit-induced mouth pain with control via rein tension conveyed to rigid or tight bridle straps in contact with sensitive parts of the face or head, such as the muzzle, nose, jaw, and/or poll [69][76][77]. Accordingly, their use contrasts sharply with the consequences of firm-handed rein pressure on the bosal-like nosebands of hackamore bridles [78][79], or on other bit-free bridles designed with tightly fitting or rigid nosebands or straps [74][76][77].

Those readers who engage in an exploration of the pain-related behaviours noted in **Table 1** will quickly discover that most horses do not display all of them at once, or over an extended period. For example, among the 69 such behaviours identified by the riders of 66 horses that were changed from bitted bridles to a bit-free bridle, before the change only 57 exhibited the most prevalent combination of behaviours described as "hates the bit", 43 were "not controllable", 37 engaged in "head shaking", 33 were "difficult to steer", 32 engaged in "choppy striding", 31 in "tail swishing', 29 in "hair trigger responses", 25 had their "mouth gaping open", 24 had "anxious eyes", 23 "grabbed the bit", 20 "bucked", and 12 had their "tongue over the bit" [7]. Nevertheless, 65 of the 66 horses exhibited aversion to the bit in a total of 69 ways, which were considered to express their immediate responses to the bit-related pain and/or their frustration at thwarted attempts to avoid it [7]. In contrast, and importantly, these behaviours and others referred to in **Table 1** were absent or rarely observed in ridden horses transitioned from wearing bitted to bit-free bridles, and in domesticated or free-roaming wild horses wearing no tack.

It is widely acknowledged among equestrians that some horses show just a few signs of aversion to the bit; what is not acknowledged is that every horse has the potential to be averse to the bit as a foreign body in its mouth and that horses have many ways of expressing that aversion [7]. In part, this lack of acknowledgement is due to what the present author calls "bit blindness". This is a descriptive term, not a critical or pejorative one. Its purpose is to highlight a widespread lack of recognition that the distinctive behaviours described here (**Table 1**), which are observable almost every day, are in fact specific indices of bit-induced mouth pain. Note however that such "bit blindness" really reflects a misinterpretation. It arises because bit use and the associated behaviours have been part of human–horse interactions for at least four millennia [80]. Thus, it is suggested here that a pervasive familiarity has led to a perception that these regularly observed behaviours are natural to the horse, being little to do with the presence of a bit. The persistence of this perception down the years has quite understandably influenced the vast majority of equestrians who are active today. A similar phenomenon has been observed with dairy cattle. Apart from the most severe cases, dairy farmers markedly underestimated the proportion of lame cows in their herds. After being shown the behavioural signs of less severe lameness, many of them said, "I thought cows just walked that way" [81][82][83]. Once fully recognised, however, the signs of bit-induced mouth pain in horses, as with lameness in dairy cows, cannot be "unseen". Nevertheless, resolute defenders of the previously prevalent view might even then use minimising, distracting, or euphemistic words or phrases to divert attention from what these behaviours actually indicate [83]. When these behaviours are considered in the context of the whole analysis conducted here, their meaning is clear—equestrians whose approach is to firmly control horses using bitted bridles will often, even if unintentionally, cause them pain, sometimes very severe pain.

3. Welfare Implications of Bit-Induced Mouth Pain in Horses

The evidence-based analysis conducted here shows unequivocally that bit-induced mouth pain is likely to be a significant cause of welfare compromise in the majority of conventionally bridled horses. Moreover, the greater the rein tension, whether abruptly applied, short-lived, sustained, or cyclical, the greater will be the following factors: the noxiousness of the immediate pain experience; the likelihood of tissue trauma and the associated continuing pain; the intensity of any pain elicited by later bit contact with the tissues injured previously; and the time required for those lesioned tissues to heal. Nevertheless, as already stated, it is not suggested here that throughout every ride horses would continuously experience significant pain, but it is clear that under most of the competitive circumstances described above, highly aversive levels of pain would be experienced with the stronger rein tensions known to be used.

Yet, there are even wider welfare consequences than the direct impacts of the pain experience itself. They relate to specific behaviours elicited by the bit-induced pain and involve the following factors: the horse's open mouth; its tongue relocated over the bit or retracted behind it; and when initiated by the rider or driver, the presence of low jowl angles maintained by firm application of rein tension. In animal welfare terms, they all lead to compromised breathing and unpleasant, sometimes exceptionally unpleasant sensations of breathlessness, experienced by people as suffocation [84]. The reader is referred to the previous full account of these phenomena [73] in order to access the 164 published sources that underlie the following brief explanation.

3.1. Respiratory Consequences of an Open Mouth and Relocation of the Tongue above or behind the Bit

Unlike people, dogs, ruminants, and most other mammals, horses are "obligate nasal breathers". For fully effective respiration they must breathe through their noses and, being exceptional athletes, the physiological demands on their respiratory systems are substantial. For example, in order to meet the oxygen demands of vigorous muscular activity when at full gallop, Thoroughbred racehorses must breathe in and out 110–130 times a minute, achieving total airflows of 1800–2000 L/minute, which represent a 25–27 fold increase on the values at rest. This is equivalent to breathing in and out 180–200 10 L buckets of air every minute. To achieve this, the respiratory passages need to be as widely open as possible, as even minor obstructions disproportionately impede airflow in accord with Poiseuille's Law [85]. This is largely achieved by the creation of negative pressure in the oral cavity and oropharynx by swallowing with the mouth closed, and keeping it closed [56][86][87]. This negative pressure holds the soft palate firmly down onto the root of the tongue deep in the throat (**Figure 2**), and requires the establishment of airtight seals at the lips with the mouth closed and, deep in the throat, with the larynx fitting tightly into the soft palate orifice (the ostium intrapharyngium) (see the legend of **Figure 2** for a more detailed explanation). If one or both of these seals is broken, air enters the oral cavity and oropharynx, freeing the soft palate to balloon up into the nasopharynx, where it vibrates at each breath, impeding airflow. A bit-induced mouth opening, even a small opening, breaks the lip seal, and the bit-induced bulging of the tongue deep in the throat can also break the palato-laryngeal seal [56][86][87]. Palatal instability results, and this may progress in steps of increasing severity to an extreme of palato–laryngeal disengagement in which the soft palate is drawn above the epiglottis, partially or completely blocking airflow during inspiration and impeding it on expiration [56][86][87]. Clinically described as dorsal displacement of the soft palate (DDSP), this upper airway impediment to airflow initiates a cascade of pathophysiological changes in the lower airways [73]. Recognised as exercise induces pulmonary haemorrhage (EIPH), proposed to be one feature of negative pressure pulmonary oedema (NPPO) [73][86], these changes include increased airflow resistance in the lower airways and/or impeded respiratory gas exchange in the alveoli [88][89][90]. It is these effects that generate the subjectively unpleasant, and therefore welfare-compromising experiences of breathlessness, which human patients with NPPO describe as intense feelings of suffocation [84].

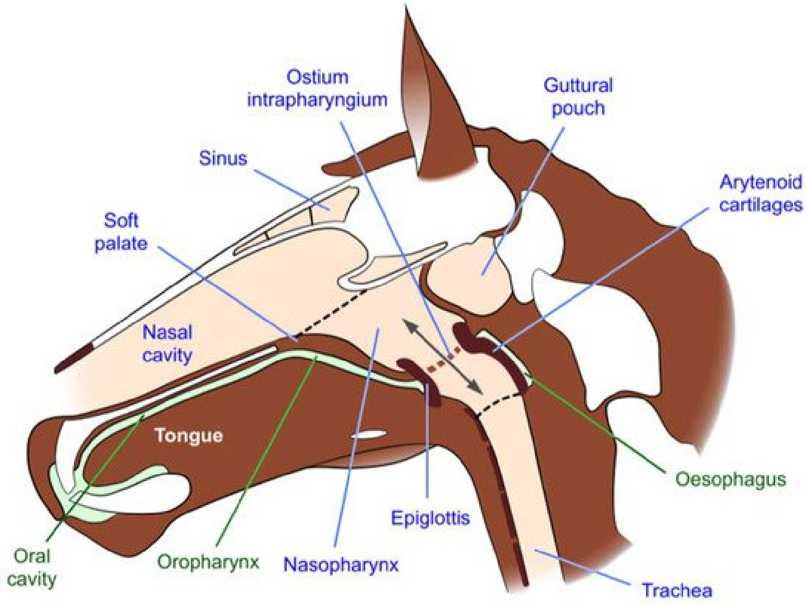


Figure 2. Diagram of the relationship of the soft palate and the larynx of the horse while breathing with its mouth closed (modified from [56] with permission). The larynx (the "button") fits tightly into the ostium intrapharyngium (the "buttonhole") of the soft palate, creating an airtight seal so that air cannot enter the oropharynx. This, and closed lips, enables a negative pressure to be maintained in the oral cavity and oropharynx, which holds the soft palate against the root of the tongue, thereby widening the nasopharyngeal airway. Disengagement of the soft palate and larynx and/or loss of the lip seal dissipate the negative pressure in the oral cavity and oropharynx, which then allows the soft palate to rise, vibrate with each breath, and impede nasopharyngeal airflow. The double-headed arrow indicates the directions of airflow. Reproduced from [73], also published by *Animals*.

3.2. Respiratory Impacts of Low Jowl Angles Maintained by the Firm Application of Rein Tension

The jowl angle is the angle of intersection of the leading edge of the neck and the line of the lower jaw. The jowl angle of a horse at rest and unconstrained by rein tension would normally be about 90° or slightly more. When galloping, it may cyclically extend its head-neck to jowl angles that approach 120° [56]. This straightens and widens the nasopharynx and disproportionately reduces nasopharyngeal airflow resistance (Poiseuille's Law: [85]); it also stretches and straightens the extrathoracic trachea, which makes it less susceptible to dynamic collapse during inspiration. On the other hand, jowl angles of less than 90° are accompanied by reduced cross-sectional areas of the nasopharynx, which disproportionately, and markedly, increases airflow resistance and decreases airflow rates [56][85], as well as alveolar gas exchange [73]. The extent of compromised breathing at jowl angles of ~33° when the nasal plane is nearly vertical, or of < 33° when the nasal plane is behind the vertical as in the Rolkur position [91], is likely to generate intense feelings of breathlessness.

It is apparent that the unnaturally low jowl angles seen during dressage, and the extreme of Rolkur, are achieved by high rein tensions causing significant mouth pain [15][92][93]. This is also likely with the low jowl angles often observed, albeit transiently, during different phases of show jumping and other events (**Table 1** and YouTube videos). However, the threat of a return of marked bit-related pain experienced during early dressage and other training may motivate the horse to cooperatively adopt these lower jowl angles in response to lower rein tensions than were originally required. The following observation is consistent with this suggestion. Dressage riders maintained higher mean bit pressures of ~6.6 kg/cm^2 by continuously applying rein tension, whereas, when the required jowl angles were maintained by reins of constant length secured to a surcingle frame, the horses self-selected lower mean bit pressures of ~2.1 kg/cm^2 by marginally reducing their jowl angles themselves (bit pressures were calculated from reported rein tension data of [15]). Nevertheless, although the lower self-selected bit pressures would also have been painful, albeit less so, the low jowl angles would still have compromised airflow and likely generated unpleasant experiences of breathlessness [73][84].

3.3. Pain-Related Conflict Behaviours and Summing up

Conflict behaviours are characterised as a response of horses that are apparently having difficulty coping with mental or physical discomfort, reflected in some form of resistance to handling or training cues and/or to equipment [94]. All such behaviours are absent in wild, free-roaming horses [95][72], but are characteristic of the ridden horses (**Table 1**). Typical examples of these conflict behaviours include head shaking, mouth gaping open or resisting bit contact, tugging or pulling the reins out of rider's hands, and excessive tail swishing during ridden activities [15][62][63][64][67]. It is apparent that these behaviours are the same as some of those elicited by bit-induced mouth pain (**Table 1**), which suggests that mouth pain may be at least one of several factors that underlie conflict behaviours. It is suggested here that anxiety in anticipation of pain, and fear whilst experiencing it, especially if the pain is intense, may be additional emotional constituents of conflict behaviours. Moreover, anxiety may also accompany the experience of suffocating breathlessness in circumstances when it is anticipated, and fear when it actually occurs [96][84].

The above observations support the conclusion that, in addition to the direct impacts of bit-induced mouth pain, the associated negative subjective experiences of breathlessness, anxiety and fear are also likely to be components of the associated animal welfare compromise [73][97].

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