Applied Animal Behaviour Science 190 (2017) 57–73

Contents lists available at ScienceDirect

Applied Animal Behaviour Science

journal homepage: www.elsevier.com/locate/applanim

The use of the technology in equitation science: A panacea or abductive science?

Hayley Randle[a,*], Menke Steenbergen[b], Kirsty Roberts[c], Andrew Hemmings[c]

[a] School of Animal and Veterinary Science, Charles Sturt University, Boorooma St., Wagga Wagga, 2650, NSW, Australia
[b] Dr. Starckelaan 10, 3734 XB, Den Dolder, The Netherlands
[c] Royal Agricultural University, Cirencester, Gloucestershire, GL7 6JS, UK

ARTICLE INFO

Article history:
Available online 27 February 2017

Keywords:
Equitation science
Experimental design
Objective evidence
Technology
Abductive science
Welfare

ABSTRACT

Equitation encompasses a range of activities in which horses interact closely with humans. The need to ensure both horse management and equitation practice is ethical and sustainable is becoming emphasized globally. Robust and rigorous measurement is critical to objective assessment of practice. This review describes the outcomes of technology application within generic equine science and specific equitation science studies including heart rate monitoring, electromyography, infrared thermography, pressure algometry and remote recording of behaviour and cognitive functioning. The impact of pressure and tension applied by saddles, girths, head gear and gadgets is considered along with subtle behavioural measurements such as eye blink rate, behavioural switching and laterality, some of which reveal aspects brain functioning that have direct relevance to training. Well designed, reliable technology certainly has the potential to provide researchers with a panacea to problems relating to accuracy, precision and experimenter bias, ushering in a 'golden age of equitation'. However, to reach this stage careful consideration must be given to experimental logistics such as sample selection, device calibration and data processing. A series of potential drawbacks with the use of Technology are identified including managing noise and increasing signal strength, dealing with practical implementation issues and managing the volume of data in order to conduct appropriate analysis to reach meaningful conclusions. Technology users are warned against the temptation to engage in Abductive Science when discussing the output of equitation science methodologies. Putting good research into practice, and vice versa, is crucial to future-proofing equitation and horse welfare.

1. Introduction

Equitation Science is a discipline that specifically aims to promote and encourage the application of objective research and advanced practice which will ultimately improve the welfare of horses in their associations with humans (International Society for Equitation Science Mission Statement, accessed 2016). Equitation is traditionally defined as the 'art of riding' (Norman on Xenophon, 2006) but following the publication of numerous studies examining and quantifying the interaction between horses and humans engaging in a wide-range of equestrian pursuits this may now be better described as the 'art and science' of riding.

Equitation involves a range of activities in which horses interact closely with humans. Equestrian disciplines may be world-wide for example racing and most of the olympic horse sports such as dressage, show jumping, eventing, or country specific (e.g. tolting; campdrafting, reining, agility). Equitation may involve a horse being ridden or being worked by a human either being driven, or in-hand such as vaulting and more recently horse agility. A substantial number of horses have traditionally been used in educational and leisure environments such as in riding schools and colleges and trekking centres respectively. Particulary in the US and UK, many animals are being recruited to rehabilitation organisations that offer equine assisted activities in which horses are used to directly provide physical therapy (hippotherapy, Mutoh et al., 2016), equine-assisted therapy (EAT, Gehrke et al., 2011; Holmes et al., 2012), equine-facilitated psychotherapy (EFP, Lac, 2016) and/or equine-assisted learning (EAL, Burgon, 2011) for humans. Whilst the use of many of these horses is regulated, either by a discipline specific organisation such as British Dressage (BD), the British Horse Racing Association (BHRA), broader organisations such as Equestrian Australia (EA) or use-based organisations such as the

* Corresponding author.
E-mail address: hrandle@csu.edu.au (H. Randle).

http://dx.doi.org/10.1016/j.applanim.2017.02.017

Riding for the Disabled (RDA), the Association of British Riding Schools (ABRS) and the Australian Horse Riding Centres (AHRC), many are not. Overarching bodies such as the British Horse Society (BHS) and the Australian Horse Industry Council (AHIC) work at national industry levels to directly and indirectly address equine welfare issues. Horse welfare is coming under increased scrutiny world-wide with growing focus on the need to produce equine- and country- specific codes of practice relating to use and management for example during transport (Padalino et al., 2016), housing (Dalla Costa et al., 2016) and competition (Williams and Randle, 2017). The need to ensure that horse management and equitation practices are ethical and sustainable (Randle, 2010, 2016; Waran and Randle, 2017) is emphasized globally. Finally, the direct interaction between equid and human is particularly important because of the physical, physiological and related pyschological effects and impacts on the horse.

Explanation of the nature and nuances of relationships between humans and animals, and in particular with horses, is prone to anthropomorphism, that is the tendency to attribute human traits, emotions and intentions to non-humans (Randle, 2010). Whilst authors such as Kiley-Worthington and Lea (1996) emphasize the divergence in thought between technical and lay views (in the equitaiton context—experimental equitation scientists and horse practitioners), they acknowledge the merit of controlled constructive anthroporphism when describing human-animal relations. However the general consensus remains that when unmanaged anthroporphism leads to subjectivity and rapidly undermines the credibility of potentially extremely important research findings. Whilst it can be argued that an element of anthropomorphistic explanation is virtually unavoidable due to the long-standing relationship between horse and man, researchers and practitioners alike must be strongly encouraged to only reach conclusions that are based on objectivity and real evidence. Data collected on how the horse reacts, responds and performs within equitation, should always be objective if evidence-based conclusions are to be reached that can ultimately be used to improve horse welfare.

When discussing equitation and equestrian activities there is much focus on the physcial interactions between the horse and rider. Understandably, non-scientific every-day language is frequently used to describe the interaction between horse and rider particularly during training and competition situations. Riders are often encouraged to undertake tasks such as 'shifting their weight' and to work towards goals such as 'developing feel' and 'achieving a contact'. But, these actions and goals are rarely quantified, difficult to describe objectively, virtually impossible to define (especially globally) and consequently at best executed in a manner that varies from rider-rider, session–session and even from attempt-to-attempt. It is known that inconsistent application of signals can cause confusion and therefore conflict related behaviours in the horse with a consequent negative impact on welfare (Waran and Randle, 2017).

The statement '*What we can measure, we can manage*' emphasized by Waran and Randle (2013 and 2017) explains the importance of measuring, assessing and evaluating equitation theory and practice. A wide range of measurements can be taken from the horse and/or rider, including physical data such as pressure and tension, physiological measures such as heart rate and temperature and behavioural measures such as bolting, stereotypies and specific actions such as chewing, swallowing and blinking. Regardless of the aspect of equitation (and the horse-human relationship) being investigated, robust and rigorous measurement is critical to objective assessment of practice. The collection and analysis of equitation-related data should therefore align with the basic principles of scientific measurement (Holmes and Jeffcott, 2010) and where technologies exist utilize proven validated protocols (Pierard et al., 2015). This paper overviews of a range of aspects of equitation that have been explored and the technologies used to obtain empirical data.

2. Research and scientific measurement in equitation

Research is typically defined as the systematic investigation into, and study of, materials and sources in order to establish facts and reach new conclusions (Randle, 2009). Within the framework of Equitation Science, an overriding purpose of research should be to examine aspects of equestrian- and equitation- practice in order to identify and ultimately differentiate between practice that is not acceptable (i.e. has a negative impact on horse welfare) and practice that is (i.e. does not have a negative impact on horse welfare and preferably also improves it).

Equitation science research is likely to involve live animals and humans, therefore researchers must ensure that the global principles of ethical research are adhered to. It is imperative that horse use in these studies is governed by the 3 Rs of ethical research, namely Replication, Reduction and Refinement (see Rollin, 2009; Russel and Burch, 1959). Although this will normally be achieved through compliance with compulsory ethical procedures of the institution at which the experimenter is based, within equitation there is an increased likelihood of testing subjects recruited opportunistically (also known as convenience sampling whereby subjects are recruited from naturally occurring groups, e.g. a particular type/group of horse riders), therefore safeguards should implemented to ensure that equitation testing is not be conducted ungoverned. As equitation also involves humans appropriate human-ethics approval must also be secured along with a fitness to participate questionnaire as part of risk management (e.g. the Physical Activity Readiness Questionnaire, PAR-Q, Duncan et al., 2016), with special attention paid to the involvement of minors and less able bodied individuals. Questionnaire based studies are becoming increasingly popular as accessibility to global participants has increased through social media and world-wide electronic platforms, however these too should be scrutinized and gain ethical approval prior to launch.

All research that is conducted should adhere to a widely accepted set of measurement principles. The most important of the basic principles that should be considered when conducting equitation science research are summarised in Table 1. Equitation Science researchers should also establish the most appropriate time- and subject-sampling method to use in order to ensure representative data are collected. These are defined in Martin and Bateson (2007). A priority is that the experimenters ensure that they collect sufficient data to be representative whilst avoiding the effects of horse-, rider- and/or experimenter- fatigue described in Table 1 due to over-use. Particular attention should be paid to the confounding factors that may also influence the outcome of Equitation Science studies.

The use of automatic recording technology may be appealing on the basis of a perceived reduced work load (but this is rarely the case with data transcription, collation and reduction frequently taking up to three times as long as the duration of the raw material recorded, Martin and Bateson, 2007), whether information is recorded directly (e.g. rein tension) or provides a method for data capture for later transcription (e.g. video material). Regardless of recording method and technology used, it is important to adhere to a further set of four scientific measurement principles (Validity, Reliability, Accuracy and Precision) to ensure that the data are measured well (Table 2). Fig. 1 displays four scenarios based on achievement of these scientific measurement principles taking into account the impact of systematic and random errors which may well arise from the use of technological equipment for data recording. Only when the measurement recorded is accurate (i.e.

Table 1
Basic principles of experimental design in equitation studies.

Principle	Reason within equitation context
Control condition	In order to compare the experimental/test condition to a non-manipulated, often industry specified/accepted known.
Control potential confounding factors through the use of appropriate strategic sampling methods to recruit subjects	Horse sex, age, breed, past experience, plane of nutrition, housing conditions, stage of training may all effect outcomes. Aspects of the test environment e.g. arena location, size, surface type, presence/absence of other horses, equipment used, direction of travel can all influence outcome.
Replication	A single measurement is insufficient for reaching scientific conclusions.
Randomisation	Allocate subjects to test conditions randomly. Samples of horses are rarely uniform in either genotype or phenotype and some performance related behaviours are demonstrate phenotypic plasticity therefore randomisation is especially important.
Control order effects	The order in which individuals are tested can influence outcomes. Additionally horse, rider and experimenter fatigue needs to be managed. Cross-over designs and wash-out periods should also be used in comparison testing.
Manage experimental conditions	Ensure that the test environment is conducive to testing. In most situations a familiar environment is preferable to a novel environment. It is imperative to ensure that individuals that are not accustomed to being isolated are provided for. Where novel equipment is applied for testing ensure that the subjects are accustomed to its presence on their bodies and/or in their environments prior to data recording.
Independence of measurements	Ensure that measurements taken are independent of each other. This is particularly important in order to avoid measuring the same thing twice.
Avoid experimenter bias	Potentially significant in horse-based trials, especially if the subjects (horses) are known to the experimenter. Equine subjects are difficult to anonymise due to large phenotypic features such as colour and/or markings and also frequently reputation and common use of behavioural descriptors to describe an individual.
Implement blind- or double-blind testing	Implement a blind test situation (e.g. in a equitation scenario) where the rider is naïve to the experimental condition in which they are taking part. Alternatively implement a double-blind test whereby neither the participant nor the experimenter are aware of the condition is being tested.

Table 2
Principles of scientific measurement and data collection.

Principle	Definition
Accuracy	How well the measured value corresponds with the true value
Systematic Error	*Systematic error is a series of errors in accuracy that are consistent in a certain direction.*
Precision	How free the measurements are of recording errors.
Random Error	*Random error is statistical fluctuations that are introduced by imprecision in measurement.*
Validity	How well the measuring device/measured value measures what it supposed to.
Reliability	How stable the measuring device is and how well the measured value detects changes in the actual value.

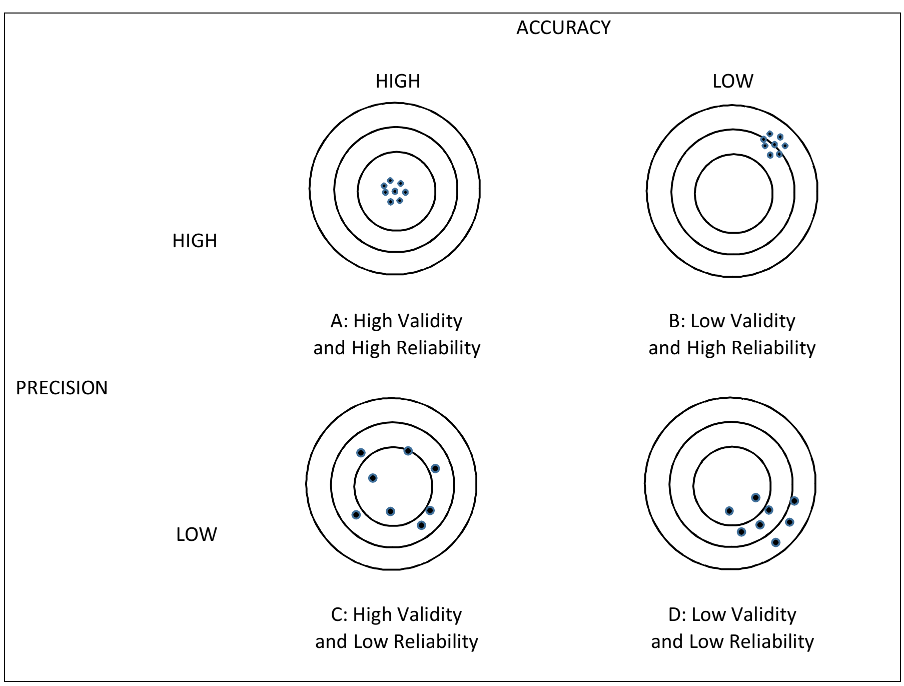

Fig. 1. Relationship between principles of scientific measurement.
In A: both random error and systematic error are small; overall this leads to a valid measurement and results that can be considered reliable. In B: random error is small and systematic error is large; this means that the result is reliable but lacks validity therefore is of little use. In C: random error is large and systematic error is small; this means that the result lacks reliability despite high validity, therefore is of little use. In D: both random error and systematic error are large; this means that the result lacks validity and reliability therefore is of little use.

systematic error is small) and precise (i.e. random error is small) can the data obtained be considered valid and reliable and therefore warrant statistical analysis in order to reach truly evidence-based conclusions.

3. Use of technology in equine research

Since its inception around a decade ago Equitation Science has undergone substantial growth. Randle and Button (2008) outlined potential areas for research (Fig. 2) and at the present time many of these have been investigated using either technology acquired from other disciplines and purposely invented equipment. The areas identified are generally those that are impacted by equipment (tack) that is used on the horse for control and performance. A range of technologies have been used including tension and pressure recording equipment, heart rate monitors, electromyography and temperature (including infra-red thermography), accelerometers, gait analysis and sensitivity testing equipment. Videography has been in use for decades, as have remote data loggers, however these too have entered a new era with availability of (mostly free) smart phone applications (apps) that allow real time manipulation of data (e.g. slow motion video replay) and immediate data capture. Other technologies are focussed on the rider and improving rider performance, typified by equipment that provides real-time feedback, however whilst this is useful in the practice context, providing information to subjects whilst they are participating in a trial can be counterproductive as they immediately alter their behaviour or over-compensate in an attempt to correct their behaviour (Randle and Button, 2008).

The set of studies refered to in this review is by no means exhaustive. The technologies used have largely been borrowed from other sciences and industries, for example sports science (Chaudhari et al., 2014; Nicol et al., 2014), working animals (Hennermann, 2009) and the building industry (Meola and Carlomagno, 2004). The use of technology within horse-related research can be broadly divided into equine science ~ physiological measures, behavioural studies and measurements at the horse-rider interface. Although the results of these studies will be reported in separate sections below, it is important that multiple measures are used to gain an accurate representation of equitation-related events, for example Heart Rate measures may be used to support (Hall et al., 2014), or even challenge (Randle et al., 2015), behavioural behaviour-based results and vice versa.

3.1. Use of technology in equine science/welfare science

Many studies have used physiological measures as direct or indirect indicators of an individual's physcial and/or pyschological state fitness and performance.

3.1.1. Heart rate monitoring

Heart rate monitors (HRMs) enable cost efficient, non-invasive measurement of cardiovascular function (Sloet van Oldenborg-Oosterbaan et al., 1988) under a range of field conditions including training and competition (Hinchcliff et al., 2008). HRMs have also been used to obtain heart rate data as an indicator of the mental state of the animal as it attempts to cope with its immediate environment (Ille et al., 2014) and events within it such as proximity of, and interaction with, humans (Randle et al., 2015). Measures of heart rate, including Heart Rate Variability (HRV), have been used as indicators of autonomic activity and to provide insight into higher neural function, in particular in relation to the anxiety-related activity behaviour in humans (e.g. Social Anxiety Disorder, Gaebler et al., 2013) and horses (Visser et al., 2002; Rietman et al., 2004), whilst mean heart rate values were measured in experiments seeking to ascertain the anti-stress effects of massage in the horse (McBride et al., 2004). Interestingly Hansen et al. (2004) found that HRV variables (as an inferred measure of prefrontal cortex activity) correlated with both the results of athletic performance test and a working memory test in humans. It is therefore reasonable to use HRV measurements as a proxy measure of brain activity during cognitive testing.

Many early studies presented heart rates simply in terms of mean (HR_{mean}), minimum (HR_{min}) and maximum (HR_{max}) values and at best only simple comparisons (between experimental conditions) could be made. More recent studies, particularly those examining physiological response to stress (von Borell et al., 2007), report Heart Rate Variability (HRV) values as this approach allows separate analysis of heart rate setting due to the Sino Atrial Node (SA Node) and the autonomic nervous system consisting of the Sympathetic and Parasympathetic elements (Carlson, 2010). Overall, HRV reflects the magnitude of inter-beat intervals and the most commonly quantified variable is the distance between 'R-Waves' often referred to as the RR interval (Gehrke et al., 2011). Furthermore, following frequency domain analysis a bias towards Low Frequency (LF) activity has been considered by some authors to reflect sympathetic dominance (Montano et al., 2009) due to factors such as stress whilst High Frequency (HF) measurements signal activation of the para sympathetic branch (Schmidt et al., 2010) such as that normally associated with rest and relaxation. The balance between LF and HF activity therefore has potential to reveal changes in mental state, although a recent a re-analysis and review of previous work cast doubt over the precise interpretation of LF data (Reyes del Paso et al., 2013).

Research using HRMs has been published and used to inform industry practice e.g. (Schmidt et al., 2010) reported significantly decreased RR intervals in transport-naïve horses subjected to road transportation concomitant with a short rise in the HRV standard deviation. It was concluded from the initial increase in sympathetic activity, which decreased throughout both individual journeys and cumulative journeys, that there was habituation to transport. However, at the same time, the lack of apparent differences in LF/HF values was attributed to deterioration of the HRM recording efficiency and quality due to movement during transport.

The echocardiogram (ECG) provides the most accurate measurement of heart activity, but ECG units are prohibitively expensive for most equine researchers and certainly the majority of horse practitioners. As with any measuring equipment data must be validated prior to use. In order to validate the HRM for equine use, there must be a strong correlation between data obtained by ECG and the HRM. Marchant-Forde et al. (2004) found significant discrepancies between HRM and ECG measurements in pigs, although Kingsley et al. (2005) demonstrated an acceptable level of agreement between the two devices even with increasing levels of exercise. However, in their investigation of HRM/ECG agreement in the horse Parker et al. (2009a) reported better agreement when the horse was static (as reported by Ille et al., 2014) but discrepancies existed during movement. Parker et al. (2009a) proposed that the primary source of error leading to reduced agreement between HRM and ECG data, and therefore the validity and reliability of the Heart rate measures, was the loss of contact between the electrodes and the skin, particularly when the horse was moving. However the application of additional fixing agents (such as Superglue™ as successfully utilized by Gehrke et al., 2011 in their comparison of free-ranging nocturnal versus diurnal HRV values in horses used for EAT) and recent improvements in electrode technology (e.g. new conductive materials and electrode microprocessors) could improve the consistency of contact and consequently the reliability of the data generated.

Some researchers e.g. Becker-Birke et al. (2013) have successfully compared dynamically collected horse HRV during dressage and show-jumping competitions. An empirical investigation into

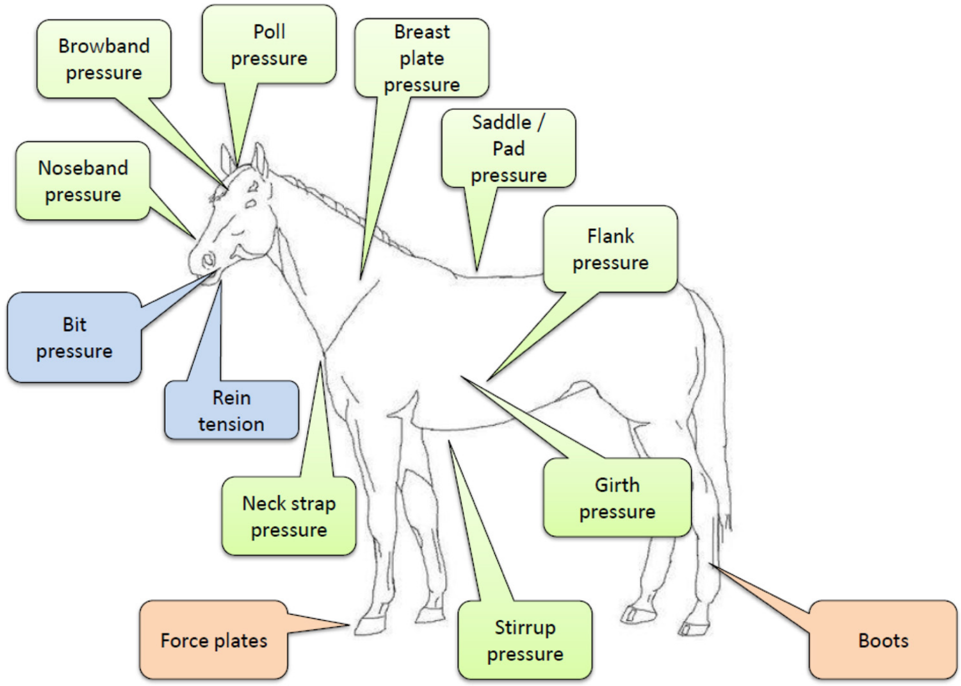

Fig. 2. Potential areas for equitation science research.

optimal electrode attachment is therefore recommended as valuable. It is important to remember that measurement limitations could call into question the validity of the data obtained and subsequently the conclusions reached.

3.1.2. *Electromyography*

Telemetric surface EMG is an emerging technology that has the potential to aid understanding of horse muscular function and improve performance (Williams et al., 2014). Surface EMG offers a non-invasive tool which can quantify muscle activity onset and offset of contractions, examine relationships between defined events and muscle performance and monitor muscle workload and adaptation over time (Hug et al., 2010). Surface EMG has been used to ascertain the relative contribution of key muscles during grid work in showjumpers (St George and Williams, 2013), specific muscle recruitment during the different gaits (Robert et al., 2002), and within this to compare lateralisation (Williams et al., 2014), assess the effect of back pain on epaxial muscle function (Groesel et al., 2010) and quantify muscle fatigue in racehorses (Colborne et al., 2001). However as with other recording devices relying on sensor placement, problems with contact may occur due to the prescence of aretfacts such as dirt, hair and irregular skin surface due to unspecified contaminants, all of which contribute to noise in the resulting data and potentally impaired reliabilty of data measurement (de Luca et al., 2010).

3.1.3. *Infrared thermography (IRT)*

IRT is an imaging technique producing maps of body surface temperature changes which may indicate inflammatory, vascular or neurological disorders and has been used in equine medicine (Soroko and Howell, 2016). However methodological problems exist due to the need to assess carefully prepared subjects within controlled test environment and the rigorous adherence to an imaging protocol (Tunley and Henson, 2004; Turner et al., 1983).

Thermal maps can be used to qualitatively highlight and identify areas of atypical/abnormal body temperature, either a visible increase which is usually clinically associated with inflammation (Eddy et al., 2001; Palmer, 1980) or a notable decrease which often results from reduced tissue perfusion (Casey et al., 2014; Turner, 1991). However the use of IRT in situations such as these is probably questionable as clinically speaking the skin is generally the last tissue to show macroscopic damage (Nola and Vistnes, 1980) and, when it does, the underlying muscles are already traumatised (von Peinen et al., 2010). Hennermann (2009) demonstrated that IRT may be better suited to preventative use. IRT generated heat maps were used to successfully redesign sled dog harnesses to reduce the amount of rubbing. Within equitation studies IRT has been used to assess tack fit, for example Arruda et al. (2011) reported substantial asymmetry in saddle fit in the region of the thoracolumbar column after training in over half the 129 show jumping test. Furthermore, only 51.2% of the panels of the saddles were in 76% or above contact with the horse's back and at rest 39.5% had a heat point compatible with a pressure area from the saddle. Whilst not necessarily quantifiable to the naked eye, this information would ideally prompt the (re-)assessment and remediation of saddle fit. Allin et al. (2013) used IRT to investigate the physiological effect of neck straps and saddle handles, two different stabilising aids commonly used by novice children when learning to ride. A strict testing protocol was followed prior to IRT testing and showed that neck straps had a significant impact on pony club ponies causing potential damage to the area at the base of the neck on all ponies tested.

Eye temperatures measured using IRT have been used to assess the effect of application of potentially aversive on horses after links being found between the application of an aversive procedure (disbudding) in cattle and a decrease in eye temperature by Stewart et al. (2008). The use of eye temperature in horses may well be preferable to other parts of the body such as ear pinnae and limbs which may be subject to other factors such as coat colour. Both McGreevy et al. (2012) and Fenner et al. (2016) reported increased eye temperatures in association with tightly fitted nosebands.

Despite the visual appeal of IRT, it remains widely agreed that due to its limited specificity, sensitivity and reproducibility, and the fact that temperature recording should last the duration of the stimulus/test condition (Pierard et al., 2015), Palmer's (1980) proposal that IRT use should be limited to non-quantitative diagnosis and complementary scenarios and that in-depth and longitudinal research is required to confirm the reproducibility of the technique (Meola and Carlomagno, 2004).

3.1.4. Pressure algometry (PA), Von Frey filaments (VFF) and Von Frey filament anaesthesiometry (VFA)

Artificial methods of mechanical quantitative sensory testing used to obtain semi-objective measurement of somatic sensations including pain within clinical scenarios (Serup et al., 2006; Briley et al., 2015) could potentially also be used within equitation science. In Pressure Algometry a tactile pressure stimulus is applied in a controlled manner to assess sensitivity of a given area to nociceptive signalling However owing to its blunt, non specific application, PA is not suitable for stimulating specific areas and not surprisingly its main use has been limited to assessment of tenderness in myofascial tissues and joints (Serup et al., 2006). There are also questions over the reliablity of PA results, as pressure is applied manually and therefore can be variable and typically ceases when a criterion is reached (which may be indicated by a subjective measure such as a verbal or behavioural response). Ideally the application of pressure using a PA should record both the rate of pressure application and the peak pressure applied. It is widely believed that until this is achieved the reliability of PA is questionnable (Serup et al., 2006).

Similar to Pressure Algometery, it is possible to measure psychosomatic response—via tactile sensitivity (Serup et al., 2006). Designed to assess somatic response to 'light' pressures, Von Frey Filaments (VFF) (originally different diameters of horse hair) buckle when a pre-calibrated level of pressure is applied mechanically. Since a greater force is needed to bend stiffer VFFs, skin noxioceptors can also be excited, and as a consequence VFFs can be used to assess tactile pain in addition to sensitivity. Although VFFs have been used successfully to assess pain sensation in humans (Lambert et al., 2009), their use in equine-based studies (e.g. Krauskopf and König von Borstel, 2016) should be questionned primarily because their function is susceptible to environmental changes such as humidity and ambient temperature (Noble et al., 2014). The reliability of VFF results gained in the laboratory has been further improved with development of the Electronic Von Frey Anaesthesiometer (EVF) which has enabled improved consistency in application of pressure to elicit a response governed by known intensities, durations and frequencies that a human operator cannot reliably achieve.

Briley et al.'s (2015) comparison of the use of PA and EVF for assessing psychosomatic pain in healthy dogs showed that although higher sensory thresholds were returned for PA than EVF, both devices produced repeatable somatosensory information over time, and are considered valid assessment tools. Therefore, serious consideration should be given over to the application of this technology within the equitation science investigations.

3.1.5. Accelerometer, gyroscopes and inertial sensors

EquitatIon is a dynamic activity and the horse's abiltity to move in an unhibited manner is central to performance, hence much research attention has been applied to equine locomotion (Back and Clayton, 2013), with particular focus on anomalies which may arise from internal (e.g. health issues) and external (e.g. surface type and rider attrtibutes) factors. An accelerometer is an electromechanical motion sensor and is used to measure acceleration forces, these may be static (typically the force of gravity) or more likely in equitation, dynamic and sense movement (Mutoh et al., 2016). Accelerometry has been used extensively in locomotion research looking at the relative acceleration and deceleration of identified parts of both the horse and rider either in isolation (e.g. Gandi et al., 2014) or in combination (e.g. Symes and Ellis, 2009). Gyroscopes are also movement sensors which record rotation. These are often combined into various products that carry out Inertial sensing i.e. allow the simultaneous recording of the relative position, orientation and velocity of a moving object, whether attached to a horse, rider or specific part of either—typcially an identified anatomical structure of the horse or rider or other object. Gandi et al. (2014) fitted inertial sensors to horse riders to assess their motion patterns when riding and uncovered substantial asymmetric differences in external hip rotation with most riders showing greater rotation to the right than to the left. A more recent study by Mutoh et al. (2016) demonstrated that quantitative parameters derived from portable motion sensors could be used to quantify the effect of hippotherapy on patients with Cerebral Palsy. The data revealed both immediate and long-term improvements in the ability of children and adolescents with cerebral palsy to walk after undergoing hippotherapy.

3.2. Use of technology in behaviour-based studies

Technology such as remote data loggers has proved valuable in collecting behavioural data. In addition to helping to avoid the effects of subjectivity during data capture and recording, it can also allow the identification and determination of component parts of individual behaviours that would not be possible due to the limitations of the human eye especially in conditions where data are recorded contemporaneously.

3.2.1. Maintaining independence and objectivity using ethograms

Ethograms provide a list of categorised behaviours with which observational research can produce objective data (e.g. Jensen 1980; Kiley-Worthington, 1987, 1997; McDonnell, 2002). Behaviours have been recorded against ethograms both manually (e.g. Abbey and Randle, 2016) and using data recorders (e.g. Randle, 1995) for decades. However mobile apps have recently become available without prohibitive software licencing costs and many researchers now use these to collect behavioural data but these are restricted to a maximum number of behavioural categories that are generally treated as exclusive and therefore present an oversimplified view of behaviour. North et al. (2015) have proposed the development of a computer-aided Horse Automated Behaviour Identification Tool (HABIT) which will automate the recognition and analysis of horse–horse and horse-human behaviours in unconstrained individuals. Whilst this could help to avoid anthropomorphic interpretation of interactions concerns remain regarding the ability of the hardware and software to detect the multiple actions that make up a single classified behaviour (Kiley-Worthington, 1997).

Whilst some behaviours observed are broad, obvious and easily agreed upon, some comprise multiple components whilst others are almost imperceptible such as those associated with non-verbal individual's muzzles and eyes (e.g. Abbey and Randle, 2016). A recent surge of research activity has identified quantifiable visual behavioural measures of pain originaly within the veterinary industry which has led to production of Composite Pain Scales (CPS) for example for horses suffering from orthopaedic (Bussières et al., 2008) and somatic and visceral conditions (van Loon et al., 2010). More recently Dalla Costa et al. (2014) published the Horse Grimace Scale (HGS). These scales have emphasized the importance of facial expressions noted by Kiley-Worthington (1987). The need for a universal ridden-horse ethogram has been highlighted by Hall et al. (2013) and Mullard et al. (2016) amongst others. Recent research by Abbey and Randle (2016) used a ridden horse ethogram incorporating detailed facial behaviours to assess the welfare of horse in an educational environment. Behavioural analysis demonstrated that equine students' awareness of the horses cogntitive and physical limitations had a positive effect of the behaviour and consequently the welfare of the horses that they rode.

3.2.2. Behavioural initiation rate

In an effort to generate metrics not always available from ethogram data Randle (2008) recorded a battery of behaviours associated with horses engaged in a cognitive problem solving task, then from these derived two additional measures: Behavioural Intensity (BI—the number of individually identifiable behaviours performed towards the task within a set time period) and Behavioural Diversity (BD—the number of different types of behaviour exhibited whilst engaged in the problem solving task). Individuals that solved the task exhibited greater BI than those that did not. Similarly Roberts et al. (2016) considered Behavioural Initiation Rate (BIR—the rate at which animals switch between different behaviours) a useful measure when investigating underlying neural function in the horse due to its relationship with the activity of the dorsal striatum (Garner and Mason, 2002; Garner, 2006). Indeed, an earlier study by this group reported increases in BIR and enhanced rate of learning in the stereotypy performing horse (Roberts et al., 2015). Given the similarity to BI findings reported by Randle (2008) together these findings offer additional insight into the linkage between brain function and learning within this species.

3.2.3. The use of automated systemsin cognition studies

Liquid Crystal Display (LCD) screens and automated tasks such as operant conditioning panels and electronic feeders have been used under various testing conditions with a range of species including rodents (Bussey et al., 2012), cows (Büchel and Sundrum, 2014), sheep (McBride et al., 2016) and humans. The CANTAB® battery consists of an array of diverse human cognitive tasks that can be used to effectively identify specific cognitive impairments that may indicate sub clinical pathoogy (Cambridge Cognition, 2016 see also Mendl et al., 2009). Semi-automated systems are used with horses during cognitive testing although many devices still require significant human intervention during operation and data collection and in some instances the full scope of the data is not realised as discussion of neural correlates is not entered into (Gabor and Gerken, 2012; Hanggi and Ingersoll, 2009). Remote testing of this kind has resulted in valuable results regarding the role of dopamine within striatal structures for motivation, memory and learning with relevance to drug addiction in humans (Canales, 2005), and certainly has potential to shed light on dopamine related disorders of the horse such as Pituitary Pars Intermedia Dysfunction (PPID) and stereotypy performance (McFarlane, 2007; McBride and Hemmings, 2009). For example, technology that enabled automation of extinction learning tasks in the horse (Hemmings et al., 2007) has, in agreement with post mortem data (McBride and Hemmings, 2005), linked striatal dopamine dysfunction to the performance of crib-biting behaviour in this species. Further development of cognitive probes via the development of fully-automated neurocognitive systems for the horse would be highly beneficial, not only to allow the early identification of horses at risk of PPID and stereotypy, but also to better understand such pathways for the individual, and apply training regimes appropriately according to cognitive ability. Preliminary work examining the application of a fully-automated neurocognitive system in horses is well underway, with promising results (Roberts, unpublished data).

3.2.4. Assessment of behaviour that is not immediately obvious to the human eye

Technological solutions can be usefully applied where it is not possible to make accurate observations due to the limitation of human vision. Analysis of a series of photographs taken by 24 cameras 69 cm apart taken in succession 1/25th s apart, parallel to a horse galloping at 58 km/h by photography student Eadweard Muybridge in 1878 led to the fundamental discovery that there is a point in the gallop stride where all four of the horse's feet are off the ground and as a result the previously unquestioned paintings of horse galloping with all four legs outstretched by Stubbs and other esteemed artists are technically incorrect. Some equine behaviours such as blinking, chewing and swallowing have been suggested to be possible indicators of stress but are notoriously difficult to observe never mind quantify accurately. It may be possible to determine their meaning/s with the use of appropriate technology.

3.2.5. Spontaneous eye-blink rate (SBR)

It is agreed that research into Equine Neurocognitive Function is fundamental to fully understanding equine welfare (Hemmings et al., 2007; Parker et al., 2008, 2009b; Roberts et al., 2016), but the methods previously used to examine the effects of neurotransmitters such as dopamine could only be conducted post-mortem (McBride and Hemmings, 2005). In primates Spontaneous Blink Rate is described as the bilateral paroxysmal brief repetitive eye closures that occur continuously and in the absence of obvious external stimuli, and is unaffected by external stimuli such as light, heat or humidity (Karson, 1983; Taylor et al., 1999). This simple behavioural measure has been successfully used to determine the prescence of hypodopaminergic conditions (such as Parkinsons) where SBR is reduced (Agostino et al., 2008) and hyperdopaminergic disorders such as schizophrenia and stereotypy-performing conditions where an increased rate of SBR is evident (Kaminer et al., 2011; Roebel and MacLean, 2007).

SBR has recently been used as a behavioural indicator of dopaminergic dysfunction in horses where individuals with Pituitary Pars Intermedia Dysfunction (PPID, Cushings; McFarlane, 2007) showed reduced SBR (Roberts et al., 2015; Stephenson et al., 2014). Similarly, horses performing oral stereotypies also demonstrate significantly reduced SBR compared to control animals (Roberts et al., 2015). Given that first, blink rate is ordered by dopaminergic systems of the dorsal striatum (see Roberts et al., 2016 for review) and second, equine post mortem investigations have revealed decreased activity in this structure, it would appear that SBR is a promising non-invasive indicator of striatal function. Typically only the left eye of the horse is observed in SBR studies due to the difficulty of observing both of the horses eyes simultaneously due to their lateral positioning (Roberts et al., 2016), automated systems which allow simultaneous quantification of SBR in both eyes would be an advantage in this regard.

3.2.6. Chewing and swallowing

Chewing behaviour has been postulated to be an indicator of stress (Onishi et al., 2014) and anxiety (Ono et al., 2015) and has been related to cognitive processing speed (Hirano et al., 2013). In addition, chewing has been linked to increased gut activity in humans due to the salivation and swallowing that follows and has a stress relieving function in humans validated by reduced concentrations of salivary cortisol (Smith, 2009), although this depends on the quality of the chewing (Nishigawa et al., 2015). Giusto et al. (2014) induced chewing in horses using a snaffle bit with toggles attached to encourage interaction with the bit. This led to consistent chewing for up to 20 min, with increased salivation and swallowing leading to significantly increased gut activity only 3 mins post chewing. It is possible that as Giusto et al. (2014) suggest, bit chewing may equate to gum chewing in humans and function as a coping mechanism mediated through decreased cortisol concentrations and increased gut activty.

An assessment of the occurence and extent of chewing behaviour would therefore be useful and allow comparison of weflare of for example horses ridden in different equipment. However, chewing in the ridden horse may not be desirable and masked by the application of equipment used specifically to prevent the behaviour (see Fenner et al., 2016). Given the difficulty in accurately observing chewing and swallowing behaviour with the human eye, there is a case to be made for the use of technology to allow remote data capture.

One of the strengths of Equitation Science is that it is multidisciplinary and makes increasing use of proven technologies from other sciences. A range of technologies have been used to monitor jaw movements in grazing cattle including mechanical pressure sensors, acoustic sensors and electromyography sensors (Andriamandroso et al., 2016) and the data generated rergarding the occurrence of different aspects of grazing behaviour (ie. biting and chewing) correlate significantly with concurrent behavioural observations (e.g. Ungar and Rutter, 2006; Tani et al., 2013) and of been of use in estimated feed intake studies (Leiber et al., 2016). Early equipment comprised pressure-sensors and transducers integrated into nosebands that on stretching and contracting when the animal (cows) makes a jaw movement produced changes in electrical resistence and an analogue signal, which was then processed using pre-defined algohythmns to determine the type of behaviour recorded (Rutter et al., 1997). More recent technology has incorporated of audio measurement and accelerometry. For example Smart Collar Recording tags are being used extensively to monitor cow rumination in a number of trials, and comprise a collar fitted around the cows throat, held in place by a weight. Anecdotally this technology has been piloted on horses and has generated some potentially useful information. But improvement in fitting is needed to avoid the contact issues that have proved problematic for other technologies. Arguably the application of measurement to a horse's head would be less intrusive than to a livestock individual for example due to previous experience and habituation to equipment being fitted to the head, or indeed other parts of the body. Many of these devices also work with GPS sensors in order to be able to produce simultaneous spatial maps.

3.2.7. Locomotor laterality

Within equitation there is interest in laterality (*the dominance of one side of the brain in controlling particular activities or functions, or of one of a pair of organs such as the eyes or limbs*) and sidedness (*preference for one side of the body, pair of limbs over another*) in both horses and riders as these are seen to hinder the quest for even-ness whereby both the horse and rider (ideally in combination) are able to perform tasks (mainly movements) equally well in either direction (i.e. to the left and to the right). In an early attempt to quantify laterality in horses Warren-Smith and McGreevy (2010) fitted human pedometers to the forelimbs of 6 pasture kept horses and recorded data over 40 h (8 h/day for 5 days). Two horses showed signifant left limb preference whilst preferences for the remainder were unclear and cast some question over the suitablity of the application of pedometers designed for humans to assess horse laterality. A more extensive study conducted by Francis (2016) compared the data (i.e. number of steps) from two different types of pedometers (spring lever arm technology versus piezoelectric technology) fitted in different positions on the horse (left and right foreleg, left and right scapular and chest) and with concurrent video of the fore limbs (taken with a GoPro Hero 3 camera with 180° field of view, 720p, 120 fps) fitted to a girth on the horse. All pedometers yielded significantly different numbers of steps compared with the video footage for all positions and types, casting further doubt on the use of measuring equipment designed for use with a bi-ped on horses. Similar conclusions were reached following McLeod and Lee's (2016) investigation of the accuracy of using human-based activity detectors (FitBit™) when applied to canines, reporting generally poor detection (only 20% of steps detected) which also varied with size of dog.

3.3. Use of technology in equitation-based studies

Much of the equipment that is has been designed and is widely used to improve horse performance lacks underpinning evidence-based reesarch (Cornelisse et al., 2001). The need for objective measures of the multifaceted physical interaction between horse and human has been emphasized since the discipline of equitaiton science emerged, and a number of devices now exist that can remotely measure data that will be able to be used to objectify aspects of the horse-human interaction and can subsequently be used to assess and inform horse welfare and indeed potentialy human safety. Physics involves the study of matter and its motion through space and time, focussing on concepts such as energy and force (Halliday et al., 2014) and is therefore fundmentally important when applied, often in conjuction with aspects of engineering (Wright and Askeland, 2015) and materials science (Hall, 2014), to equitation allowing the measurment of the motions and reactions of the horse, the human and their interaction. Devices now exist that can measure tension and pressure exerted on various parts of the horse and, albeit to a lesser extent, the rider (Nicol et al., 2014), during equitation activities. These sensors are integrated into specifically designed testing equipment such as saddle pressure testing pads and rein tension gauges and are becoming relatively inexpensive to purchase. It is likely however that as these products/measuring tools become more affordable and accessible over time, McGreevy et al.'s (2014) desire for the integration of 'smart textiles' and technology into every day riding equipment will become more likely. This will enable riders to receive live feedback and enable them to contemporaneously alter their practice accordingly. This section provides a brief overview of equitation related research conducted on first, the horse and second, the rider.

3.3.1. Horse related measures using technology

Devices now exist to directly and indirectly measure the impact of virtually all equipment used on horses. It is also used to assess existing fit and contributes to the design of new equipment that improves the welfare of the horse (Hennermann, 2009; Murray et al., 2013, 2015).

3.3.1.1. Saddles, saddle pads and stirrups. Most horses are ridden or driven with some form of 'saddle' (Belock et al., 2012). Anything placed on an individuals' back has the potential to cause pressure which is further influenced by the stability of the rider (Peham et al., 2010) and weight being carried (de Cocq et al., 2006). Taditionally the saddle is constructed around a wooden tree structure intended to distrbute the weight of the load being carried, although modern day alternatives include semi-rigid and treeless designs. Pressure pads incorporate arrays of force multiple sensors and generate information that allows the identification of pressure peaks and ranges of movement to be determined. Saddle pressure recording devices produce two measures, Maximum Overall Force (MOF) and Centre of Pressure (COP) with typical MOF values reported of 302.4N in walk, 254N in trot and 172N in canter (Fruehwirth et al., 2004).

All measuring equipment has physical limitations and pressure pads are not excluded; only pressure that is applied perpendicularly to the pad is captured meaning that pressures applied at < or > 90° are not (Clayton et al., 2013). Whilst riders aspire to achieve an upright riding position (Boden et al., 2013), few manage this meaning that the total pressure applied to the horses back is not captured and that data produced are likely to be an under-estimate. Despite these limitations pressure pads have been used successfully in the assessment and monitoring of saddle fit (Murray et al., 2013) and associated equitation related practice, for example Geutjens et al. (2008) demonstrated that mounting from the ground reults in significantly more pressure applied to the horses back compared to mounting from a low block (35 cm high) especially in the region of the horse's withers. Ramseier et al. (2013) confirmed that icelandic horses experience greater weight on their backs due being ridden more caudally particually when ridden in icelandic and english saddles, and also that use of the treeless saddle cushion also resulted in increased pressure, but at the withers. This result agrees with Belock et al.'s (2012) finding that treed saddles distributed pressure more evenly widely than treeless saddles. Even bareback riding results in concentrations of pressure on the horses back, primarily under the riders' ischial tuberosities (Clayton et al., 2013). Byström et al. (2010) examined the materials used for flocking, finding that horses wearing saddles with foam panels exhibited longer stride lengths when tested than those wearing saddles with tradional flocking. Similarly Nicol et al. (2014) found reduced pressures on the horses back when saddle flocking incorporated air pads.

Further research has been conducted on saddle-related equipment. Hawson et al. (2013) highlighted the addition of mutliple layers of padding between the saddle and the horse's back to address deficits in saddle fit, however this needs to be done correctly as although Giblett et al. (2015) reported thicker saddle pads can decrease the pressure on the horses back, Dyson and Greve (2016) demonstrated that saddle pads exerted additional unwanted pressure on the spinous processes. Kotschwar et al. (2010) found that when comparing gel, leather, foam and reindeer fur pads using MOF and the distribution of pressure in longitudinal and transversal directions, only the latter significantly reduced the pressure on the horses back when worn under a correctly fitted saddle. Both Giblett et al.'s (2015) finding of a differential decrease in pressure throughout the saddle with increasing saddle pad thickness, and Dyson and Greve (2016) observation of non uniform flocking resulting in bridging of the saddle (where a clearly identified area exists under the saddle where the saddle fails to consistently contact the horse's back in a uniform and pressure-consistent manner) aligns with de Cocq et al.'s (2006) warning over the indiscrimate use of pressure recording devices to assess saddle fit whereby factors such as panels (left, right) and region (cranial, middle, caudal) are overlooked.

The assessment of the contribution to overall pressure by auxillary equipment is important to avoid an underestimation of pressure and also modify to improve fit. Van Beek et al. (2012) found that riders imposed more force on the stirrups during rising than sitting trot, and importantly that a combination of stirrup and saddle force data can provide additional information on the total loading of the horse by a rider.

3.3.1.2. Girths. Research focussing on the impact of the girth on the horse's ability to inhale and exhale, particularly during performance related tasks, has established that girth tensions of less than 10 kg at rest are optimal (Bowers and Slocombe, 2000) although most studies report girth tensions exceeding 10 kg during performance (Bowers and Slocombe, 1999). However a question remains as to whether greater girth tension results in an increase in speed (as a learned response to avoid pressure, which fails to be rewarded by release). Wright (2011) found greater speeds and stride lengths were seen with girth tension of 5.9 N and above.

It is not clear whether greater girth tension occurs at the sternum (Bowers and Slocombe, 1999) or behind the horses' elbows (Murray et al., 2013). As with other items of tack there is interest in producing equipment that improves the horse's 'comfort' and consequently for some, ability to perform (Murray et al., 2013, 2015), typically through the addition of padding and/or elastic. Bowers and Slocombe (2005) confirmed that tensions are lower when the materials used to construct the girth have elastic properties. Murray et al. (2013) evaluated the effect of the pressures and tensions exerted with different designs of girth on the performance of competition horses using gait analysis technology. A girth speifically designed to reduce pressure in the horse's elbow region (as evidencd by lower peak pressures and reduced areas of maximal force) was associated with enhanced dressage performance as judged by greater fore-limb and hind-limb extension, and hock flexion. Earlier research by Byström et al. (2010) demonstrated that using a 'V' fitting for girth attachment to the saddle also resulted in increased stride length.

3.3.1.3. Bridles and head gear. Horses are frequently moved and positioned according to the human's requirements using pressure applied to some form of head gear all of which applies some pressure to one or more parts of the head. Traditionally bridle design was based primarily on function and purpose and did not necessarily take into account the anotomical protruberances, moving parts and the location and distribution of nerves on the horse's head. As pressure and tension sensing technology has developed it has become possible to quantify the absolute and relative pressures exerted by the components of head gear. The bridle that is put on the horses head typcially comprises one or more of the following components, head piece, brow band, side pieces by which the bit can be attached, and noseband. Murray et al. (2015) evaluated peak pressure measurements associated with the head piece and noseband to design a bridle that avoids pressure points (allowing a uniform pressure to be achieved), avoiding causing the horse discomfort and improving performance (measured using gait parameters).

3.3.1.4. Nosebands. Nosebands are an optional part of head gear and may be either incorporated or an optional extra (McGreevy et al., 2012) and their use in competition is frequently mandatory (Doherty et al., 2016). Reasons given for noseband use vary and include aesthetic, bit stablisation, increasing sensitvity to the bit and preventing the horse engaging in undesirable behaviours such as mouth opening, chewing, yawing and teeth grinding (Fenner et al., 2016), all of which may be indicative of an active attempt by the horse to cope with a suboptimal situation (Giusto et al., 2014). It is likely that tongue movement wihtin the oral cavity reduces pressure (Manfredi et al., 2005). To what extent this is prevented by the application of a tight/restrictive noseband is worth considering given both Cornelisse et al.'s (2001) and Chalmers et al.'s (2013) research into the effect of tongue-ties (a piece of equipment used to prevent a horse from getting his **tongue** over the bit, passed through the mouth and **tied** below the chin) in horses during exercise and standing respectively. Use of a tongue-tie has a measurable effect on upper airway structure and horses respond by either protruding or depressing the tongue following mechanical restriction.

The tightness of nosebands is currently unregulated, and frequently many of them are fitted excessively tightly with no space between the noseband and the horses face (Doherty et al., 2016). The application of tight nosebands (especially of a crank design) has significant physiological affects including imparied vascular perfusion and increased eye temperature (McGreevy et al., 2012). Recent calcuations by Casey et al. (2014) using LaPlaces law revealed pressures of up to 200–400 mm Hg which are known to cause permanent nerve damage in humans. It is suggested that the application of tightly fitted equipment places the horse in a situation in which pressure is unavoidable/inescapable and therefore has a psychological effect. Fenner et al. (2016) demonstrated a positive relationship between the tightness of nosebands (loose versus one-fingerversus two-finger) and the occurrence of a post inhibitory rebound effect characterised by chewing, yawing (moving the jaw from side-to-side), yawning and other suggested/proposed stress-relieving behaviours following (noseband) removal. The use of technology has revealed effects on the horse that were previously non-visible to the human eye, highlighting that the use of nosebands requires careful thought, monitoring and management.

3.3.1.5. Bits. Bits are used in equitation to deliver signals to the horse and arguably 'gain control'. Whilst there has been much discussion regarding the merits of riding horses with (bitted) or without bits (bitless), until recently little research existed examining the pressures caused by the bit on the horse's oral cavity. An increasing number of bits are available and are broadly categorised under a number of bit 'families', differentiated largely by their construction and action. That very few of the practitioners using these bits truly understand the impacts of the mechanical actions (applied forces) on the horse, is evidenced in part by the number of horses suffering from bit-related lesions especially in competitions (e.g. Björnsdótti et al., 2014).

Early research by Clayton and Lee (1984) using fluoroscopic imaging examined the position and action of the bit in the horse's mouth and demonstrated differences in actions of single and double jointed bits in relation to the bit's 'working angles' and resulting impact on the tongue within the horse's oral cavity. These findings are supported by more recent research using in-line data loggers inserted into the reins and parts of the bridle, measuring the force applied and force resulting respectively, in order to establish how the force and pressure is dissipated (Benoist and Cross, 2016a).

Bits comprise a mouth piece and rings to which the mouthpiece is attached, and are attached to the bridle and reins in a number of configurations, depending largely on the intended action. The design of each component relates to intended function and action can be further manipulated through a range of practical factors such as placement within the horse's mouth, thickness and the materials from which the device is constructed. Many modern mouth pieces have joints designed to reduce pinching the horses tongue, reduce leaning, increase sensitivity and responsiveness, and to encourage salivation (e.g. Giusto et al., 2014). Recent research by Benoist and Cross (2016a) has also explored bit action via working angles of the various components that rotate during use. Within equitation tradition assumed knowledge arises and bit choice is no exception. The Dr Bristol bit is described as double-jointed as its mouthpiece incorporates a flat lozenge, and unlike the commonly used double-jointed French Link which is thought to lie flat on the horse's tongue when rein pressure is applied, the link in the Dr Bristol is believedto be perpendicular to the horses tongue when acting, and therefore it is considered to exert a 'severe action'. However Benoist and Cross (2016b) demonstrated that the link in the Dr Bristol is almost parallel (8°) to the horses tongue when in use compared to the French link which is around 123° with the flat edge becoming embedded into the fleshy tongue. This highlights the limitations of using assumed knowledge to make bitting decisions and the need for empirical assessment of the mouth-bit interface. Benoist and Cross (2016a) also highlight the need for a greater understanding of the basic principles of physics. Historically mechanistic descriptions of bit actions have been based on the assumption that the horse's mouth is capable of behaving as a perfect fulcrum, when in reality this is not possible, or as simple, due the corners of the horse's mouth being deformable. Poll pressure is also a focal area for bit research particularly in relation to the action of levered bits. Using tension sensors Benoist and Cross (2016b) demonstrated found the action of the hanging cheek snaffle (Baucher) bit, commonly believed to apply pressure to the poll, was in fact pressure-relieving.

Some consider the use of bits a welfare concern (e.g. Cook, 2014), however research into the effectiveness of bitless bridles has mixed results. Quick and Warren-Smith (2009) reported positive HR, HRV values and behavioural measures that supported the use of bitless bridles whilst others have not (e.g. Scofield and Randle, 2013). Regardless of public opinion and product marketing the important point is that the technology exists to measure the pressures due to rein use exerted on the different parts of the bitless bridle, and these studies should be conducted before a particular form of equipment is adopted or indeed rejected on the basis of tradition, current popular practice and discipline related expectation (Hill et al., 2015).

3.3.1.6. Rein tension. Horses receive signals from the handler/driver/rider's hands via the reins and the bit (if one is used) and equipment worn on the head (e.g. bridle, head collar). Management of the application and release of tension on the reins and consequently pressure on the horse is crucial in order to interact with the horse effectively and without compromising welfare. A light 'physcial connection' between the horse and rider is aspired to, for many reasons including promoting muscle engagement and optimal welfare, however this is not always posssible due to learned responses (eg. leaning on bit), the use of certain equipment and/or physcial problems. Riders find it difficult to quantify the amount of tension they apply; both Clayton et al. (2005) and Randle et al. (2013) found that riders over-estimated the amount of tension they were applying to the horse. Additional challenges are faced by judges of disciplines such as dressage, where assessment of tension muct be accomplished through visual observation alone (Cartier d'Yves and Ödberg, 2005).

Rein tension in ridden horses varies with every stride (Preuschoft et al., 1999; Clayton et al., 2005) and follows regular patterns depending on the gait. The overall rein tension recorded is a sum of that caused by the rider and that of the horse in response. With this in mind recent studies attribute 29% and 20% of the overall tension to the rider, and 27% and 7% to the horse in walk and trot respectively (Egenvall et al., 2015). Further data indicate that the rider contributes 19% to minimum rein tension observed in canter but nothing to the maximum values suggesting that the rider has little influence on the basic rein tension pattern at canter (Egenvall et al., 2016). A range of maximum forces have been published including 43N in walk, 51N in trot and 104N in Canter (Clayton et al., 2005). Earlier Preuschoft et al. (1999) reported forces between 20 and 49 N in horses ridden recreationally and greater values of up to 137N during competition. Unsurprisingly different tensions are used for specifc actions and movements; Warren-Smith et al. (2007) reported an average maximum force of 13.8N to elicit a halt response and an average minimum force of 3.9N when requiring the horse to move in a straight line. However, whilst typical rein tension values can be derived from published studies, a value or range of values that is considered acceptable has yet to be ascertained and agreed. Since the reins are used to deliver a signal to the horse it can be argued that there needs to be some pressure and values of around 1N have been proposed (Clayton, *personal communication*) [noting this does not account for other signals delivered to the horse by the rider/handler such as the rider's seat which are outside the scope of this review]. Rein tension data traces comprise peaks—which represent the maximum force used via the rein and troughs, the size of which are thought to provide a quantified 'value' for what is equestrians refer to contact (connection between the horse and rider). As well as minimum, maximum and average tension values, two other measures that can be derived from data traces are important and inform practice within the training scenario. These are the consistency with which the reins are used (signals applied) as evidenced by the uniformity of the peaks, and also the speed with which the tension applied is released following the horse performing the required response. This is evidenced by a steep drop from a higher pressure (applied as a signal) to a lower pressures (as the reinforcement).

Various aspects of rein tension have been studied and found to be related to horse and rider related variables, including asymmetry and ability, the equestrian discipline working in, head gear design (Preuschoft et al., 1999) and other equipment used such as martingales (Heleski et al., 2009; O'Neill and Randle, 2015). The physical properties of the reins themselves also has an effect on overall rein tension. Greater tensions are seen with reins made of leather and lesser tensions with webbing reins (Randle et al., 2010)., Insertion of elastic into reins had a negative impact on the abilty to release tension (Randle and Abbey, 2014).

3.3.1.7. Other equipment—gadgets and auxiliary items. A wide range of studies have used pressure, tensionand force sensing technology to assess the effects on the horse. For example some types of blanket (rug) exert potentially damaging pressure on withers (Clayton et al., 2010; Holmes and Jeffcott, 2010). Performance and veterinary research has used pressure plates sucessfully in assessment of equine biomechanics and led to changes in training methods (e.g. Van Weeren et al., 2010) with immediate application to industry practice. McGreevy et al. (2013) derived a mean force value of 46.90 ± 5.39 N for the impact of whip strikes to the race horse from a data set of 288 whip strikes taking into account variables influencing the mechanics of strike delivery in horse racing, including jockey backhand/forehand, which hand was used and jockey handedness. These findings were used to inform industry practice and have resulted a whip ban in some Australian states.

3.3.1.8. Head neck position (HNP). There has been much attention to the head-neck position for horses used in equitation in training, warm-up and competition phases. Although dressage has received the most public attention restricted HNPs such as those that typify rollkür occur in many other disciplines and even every day riding. A Fédération Equestre Internationale (FEI) workshop in 2005 indentified likely adverse physiological, anatomical, psychological and behavioural effects on the horse put into rollkür (Zebisch et al., 2014). Assessment of any equitation related practice suffers from anthropomorphism therefore the importance of providing reliable and objective meaures is imperative, especially for such a seemingly global practice. Although many variants exist, HNP is broadly categorised as on the vertical (OTV—where the horses nose is vertical/rostral to the poll; 90°), behind the vertical (BTV—were the nose is <90°) or in front of the vertical (>90°) (e.g. Lashley et al., 2014). A longitudinal study by Randle and Venables (2012) using manually derived horse HNP angles from static images published by the FEI, revealed a non significant reduction in horse head angle in FEI dressage competitions following the FEI workshop suggesting that it had no lasting impact on industry practice. Likewise Lashley et al.'s (2014) analysis of stills captured from video of the 1992 Olympic Games and the 2008 Word Cup Final using computer based angle measurement indicated that the BTV HNP was still very common in 2008. Unpublished data using the Venables and Randle (2016) methods on an extended data set covering 1992–2016 confirms that this is still the case (Kent, unpublished data).

3.3.2. Rider related measures using technology

The human plays an integral role within equitation and therefore his/her actions require as much in-depth examination and investigation as that of the horse. Findings such as Symes and Ellis's (2009) that rider assymetry can manifest in a number of ways, including differential leg length, shoulder angle and axial displacement, Boden et al.'s (2013) that rider deviation from the ideal Ear-Shoulder-Hip-Heel (ESHH) vertical alignment can be improved by undertaking rider-specific exercises, and Hampson and Randle's (2015) that completing an 8-week rider core fitness programme designed to improve rider symmetry has a positive effect on horse peformance, emphasize the need to examine the effects of these on the health and welfare of the (ridden) horse. Rider positioning can only be improved with feedback, and control of the lumbopelvic region is important. Applications (Apps) that use inertial sensors in smart mobile phones have been developed to record lateral (side-to-side) and anteroposterior (front-to-back) and posterioanterior (back-to-front) deviation from an upright position have proved useful in improving human performance in other sports (e.g. baseball, Chaudhari et al., 2014) and would certainly have application within ridden equestrian disciplines.

The importance of the wider interaction between horse-rider and equipment, such as the saddle, has also been investigated (e.g. Hampson and Randle, 2014) but it can be challenging to disentangle direct effects such as the fit of the saddle and indirect effects such as the effect the saddle has on the rider which then impacts on the horse (Greve and Dyson, 2013). It is crucial to determine which aspects contribute to which outcome, if it is going to be possible to make evidence-based decisions on equipment use, and assess and if necessary, improve horse welfare. Interestingly whilst orthopaedic scientists Nicol et al. (2014) confirmed previous research findings that the use of 'air' in saddle flocking decreases the pressure on the horse's back by around 25% when in motion, they also discovered a concomitant increase of at least 20% in the pressure exerted on the rider. Given that it is known that horse riding predisposes humans to degenerative spinal injury (Tsirikos et al., 2001) and that asymmetric riders have a negative impact on horse back health and performance, this finding is particularly important and highlights an area of equitation research that has been neglected even with all of the technology available.

4. The scope of technology use in equitation science

Historically equitation has lacked the support of scientifically measured data that could provide objective evidence of whether specfic practices have a positive or negative impact on horse welfare (Waran and Randle, 2017). The application of technologies from other disciplines to allow the assessment of horse-related activities may be considered a panacea, that is, a solution or remedy for all difficulties, enabling those working with horses to enter a 'golden age of equitation' (McLean and McGreevy, 2010; Randle, 2010). However as Holmes and Jeffcott (2010) point out, technology *can* be put to good use, but only once the issues that accompany it are carefully considered, and specific questions are posed to enable it to be used effectively as a diagnostic tool. The reader is also referred to Table 2 which outlines key principles of scientific measurement.

4.1. Disentangling actual data from noise to increase signal strength

Remote recording inevitably results in noise due to other variables present at time of measuring. Control of his aspect is not always clarified in equitation studies, but the importance should be emphasized given the potential for background noise to be incorrectly recorded as the target behaviour, as demonstrated by Tani et al. (2013) who found that background noise led to an over-estimate of chewing behaviour in cows. Noise in equitation science data sets can result from a number of equine-related factors, including age, sex, breed, gait tested (walk, trot, canter), direction of movement (e.g. straight, on bend, on circle), rein direction (clockwise, anticlockwise), test environment surface type, presence/absence of conspecifics or particular humans, familiarity with test environment, horse and/or rider level of experience. The contribution of the subject as an additional independent factor also be should be statistically acknowledged given data can be generated that are reliable within subjects but not between subjects (Leiber et al., 2016). It is only once all possible contributing factors that can influence the data recorded are taken into account that the improved signal strength suggested by Holmes and Jeffcott (2010) can be achieved.

4.2. How much data are enough?

This is an age-old question the answer to which should be factored into the experimental design within an ethical framework that takes into account the second of the 3Rs (Reduction; Russell and Burch, 1959 and especially Rollin, 2009). Once the required number of subjects is determined, ethical approval secured and experimental testing commences, the use of technology to collect information rapidly generates large volumes of data, which will only be of value if dealt with correctly. Whilst the use of technology is seemingly an effective use of data collecting opportunities, an enormous and potentially unmanageable volume of real-time data is produced that needs considerable reduction before analysis. To put this statement into context, Holmes and Jeffcott (2010) calculated that a saddle pressure sensor pad with 224 sensors recording at 30 Hz generates 6720 measurements per second, meaning that recording for a single 10 s stride generates 672,000 data points. Similarly rein tension studies by O'Neill and Randle (2015) and Randle (2014) generated 100 tension readings per second, for two separate reins, so for a 10 s stride resulted in 2000 readings. When multiple consecutive measurements are taken with short between-measurement intervals the researcher must also take care not to fall foul of repeated measurements yielding a skewed data set.

The nature of the data distribution should be confirmed prior to statistical analysis. Testing for normality will allow the researcher to determine an appropriate form of statistical analysis. Equitation data sets are typically characterised by skewed distributions, for example a set of rein tension data is likely to possess a large proportion of values of zero, or just above. Data may be transformed in order to achieve a normal distribution (Martin and Bateson, 2007) but this is not always achievable or indeed preferable, and should be conducted judiciously.

4.3. Sample sizes

Samples of <10 are considered small (e.g. Holmes and Jeffcott, 2010) yet these are seen frequently in published peer-reviewed equitation science reports; this may be partly due to the preliminary nature of a study or the cost implications of using more subjects. As with many veterinary studies, some Equitation Science research only involves a single subject (e.g. Casey et al., 2014) and should be considered a 'case study'. Although some reports are rightly published as Short Communications (i.e. reporting pilot findings) they may however be treated with the same importance as full as a published report of studies conducted with a more appropriate sample size. However as Pierard et al. (2015) point out, the value of research, especially that involving small sample sizes, can be enhanced by the application of consistent methodology and reporting enabling results to be compared across studies.

4.4. Comparability between studies: replication

Both literal and constructive replication (Martin and Bateson, 2007) is criticially important in an emerging academic discipline such as Equitation Science. The need to generate a body of baseline findings is important as these can be used both independently and in combination for meta-analysis purposes. This can only be achieved with sound experimental designs and comprehensive and detailed reporting, particularly of methodologies, testing environments, measurement protocols and comprehensive details of the actual equipment used. Testing protocols for Equitation Science studies are discussed in Pierard et al. (2015) as a result of a workshop attended by some key Equitation Science researchers in 2012. Interestingly there is no agreement over replication within data collection sessions although Andriamandroso et al. (2016) identified the importance of identifying key data collection windows during the day. e.g. am or pm. Dyson and Greve (2016) consider the same-day replication used by Murray et al. (2013) as a source of introduced error, whilst other researchers favour repeated testing within a day in order to avoid the effect of uncontrollable external factors such as the weather, especially if testing is taking place outdoors.

4.5. Controls

The requirement for a control-condition be problematic for Equitation Scientists. First, it may be difficult to secure a representative comparison control group due to the lack of knowledge/control of the husbandry and history of (potential) subjects. Second, there may be an ethical dilemma posed by deliberately preventing subjects from being recruited to an experimental group that *may* improve their welfare, or on the contrary, placing them in a test-group that *may* result in impaired welfare. Arguably this consideration should not apply in fully hypothesis driven research, however those with the ultimate responsibility of the horse's welfare may be unwilling to sanction an individual horse's participation in an actviity that has the potential to impair his/her welfare (Abbey, personal communication).

Some studies e.g. Abbey and Randle (2016) use horses as their own controls, typically when investigating before and after conditions, however care must be taken to ensure that order effects through increasing familiarity with the test environment/tasks are carefully thought out and planned around when designing the experiment. In other studies subjects are tested under two or more test conditions but time is limited or access to resources (e.g. horses, testing environment) or testing equipment may be restricted. In these a well-planned and carefully implemented cross-over design (half the subjects tested first in condition A and then cross-over to condition B; whilst the other half of the subjects are tested in Condition B first then cross-over to condition A) can be used. In these cases it is important to have a sufficiently long wash-out period between testing the two experimental conditions.

4.6. Representativness of the data recorded

A recurring theme within equitation science research is the need to validate technically recorded information with actual occurrences (Andriamandroso et al., 2016; Francis, 2016). This should be the first step in any study, conducted during a pilot phase, before commencing main data collection, but is rarely reported in research reports.

Some equitation science research has utlized substitutes for live horses. Although mechanical horses are becoming more life-like, and their use as a replacment for live horses could be preferable to meet R1 (Replacement; Rollin, 2009), and it is a very good way of removing the within subjects variable emphasized by Leiber et al. (2016), limitations exist. For example in rein tension studies there is a variable proportion of overall rein tension that is attributed to the action of the horse (Egenvall et al., 2015, 2016). Is this replicated by the mechanical horse? And does it vary by gait? Similarly some equitation science research has been conducted on treadmills rather than real-life undulating and at times unpredictableterrain (e.g. Kotschwar et al., 2010) so may not provide a comprehensive account of the effects of the variable under investigation, for example saddle fit.

4.7. Practical issues relating to validity and reliability of data collected

4.7.1. Sensor contact

A range of practical issues have been discussed throughout this review. Many remote devices depend on a close and stable contact between sensors and the horse or rider, the security of which may vary depending on whether measurements are static or dynamic. Contact issues typically relate to the preparation of the subject's skin (clean, clipped, use of adhering agents).

4.7.2. Device power

One of the most common reasons for failed or unpredictable data collection is lack of power. It is important to ensure that recording device batteries are fully charged prior to data collection and hold sufficient energy to last the duration of the data collection session. It is advisable to purchase spare batteries so that a charged one is always available for use mid-trial. Lithium batteries have improved this situation but can be subject to weather related variables, extreme temperatures may impact on battery recharge time and life.

4.7.3. Wifi, cross-talk and GPS

Many devices relay data 'live' to a screen (smart phone, tablet, laptop, TV/projector) via wifi which may suffer difficulties due to subjects moving out of range. Furthermore, the use of multiple recording devices in a group-test environment may result in cross-talk leading to impaired data collection. Interference may also result from riders carrying mobile phones whilst on-trial. Some recording devices require an active GPS link throughout the data collection session which generally means that data collection is limited to an outside envrionment.

4.7.4. Videography and positioning

The use of videography may seem to be the most simple form of data collection but not only is it time consuming in terms of transcription, it also requires the most careful location of video in relation to the subjects whilst on trial. Subjects are typically filmed from a perpendicular position, or directly behind or in-front to ensure that comparable data are collected for different subjects. If a zoom function is used, prescribed values should be set to ensure consistency in later data extraction.

4.7.5. Calibration, care and wear-and-tear

Much of the equitation science measuring equipment that is available requires regular calibration prior to use (Chaudhari et al., 2014; Dyson and Greve, 2016) and typically between uses e.g. rein tension gauge manufacturers recommend recalibration which takes around 1 min after a specified number of uses, whilst manufacturers of saddle pressure monitoring pads recommend recalibration after a set number of hours of use). The time and costs associated with the recalibration process need to be factored in when planning experimental trials (Hawson, personal communication). Interestingly Hampson and Randle (2015) found that a number of studies using pressure sensing technology had not explicitly recalibrated equipment sufficiently frequently consequently casting some doubt over the validity and reliability of some published findings. Daily care and maintainence of equipment, avoidance of damage and taking into account age and expected working life is also important when conducting longitudinal trials (Chan et al., 2005; Silva et al., 2010).

4.7.6. Financial considerations

Most research using technological equipment is costly. Researchers should be aware of additional costs to the initial outlay, including maintenance costs, software licencing costs and updates. In a practical level researchers need to be aware of the effects of laptop (or other) Operating System updates which may render the specific technology software unusable.

5. Cavalier data collection and analysis

Holmes and Jeffcott's (2010) concern over the seemingly uncontrolled acquisition of equitation-related data may still be valid especially as the increasing accessibility of remote recording devices and combined with inexpensive or even free availability of apps strongly encourages opportunistic data collection. Published research indicates that apps are revolutionizing normal classroom-based learning (Ahmed and Parsons, 2013) and promoting engagement with diverse audiences especially when associated with sensing technologies (Zydney and Warner, 2016). Whilst the use of apps is useful for informing practice it can however lead to 'opportunistic' data collection to explore 'what if' questions (Keogh et al., 2016) in the absence of a sound and planned experimental design that is based on the fundamental principles of hypothesis driven deductive and inductive experimentation (Holmes and Jeffcott, 2010) and cause a fall into the trap of Abductive Science. Rather than conducting sound, reliable and repeatable research in which hypotheses are developed to explore pre-determined objectives, Abductive Science is characterised by the *post-hoc* identification of objectives after hypotheses (Ahmed and Parsons, 2013).

Assuming Equitation Science researchers are conducting carefully planned deductive and inductive research, care should be taken when establishing hypotheses. The two senior authors of this review (HR and AH) have observed an increasing occurrence of directional alternative hypotheses being tested with two-tailed statistical analyses. Likewise some flexing of the interpretation of probability values is becoming evident; with P values that are near to, but not less than 0.05, being interpreted as if they were truly significant. These simple statistical methodological errors should be avoided at all costs if the outcomes of equitation science research is to be taken seriously and treated with the respect and credence that is required.

6. Conclusion—is the use of technology a panacea or a case of abductive science?

Holmes and Jeffcott (2010) asked if Equitation Scientists are counting the right things? Based on the number of peer reviewed published studies the answer to this is probably yes, but only if studies benefit from careful experimental design, rigorous data management and robust statistical analysis in order to measure the data well. This review has demonstrated the range of areas in which technology has been used in equitation related investigations and discussed the problems that can occur with its use, particularly the volume of data generated and the temptation to engage in Abductive Science. It is clearly very easy to assign likely meaning to findings where an incomplete data set exists (which may be derived from hypothesis testing) and to put forward the most likely explanation based on the evidence in front of us. As long as equitation science researchers using technology to measure equitation related data, only conduct studies that align with the key principles of scientific research, ensuring that random and systematic error are low, hence accuracy, precision, validity and reliability high, then the use of technology in equitation related research may well be a panacea. Einstein's statement "*Not everything that can be counted counts, and not everything that counts can be counted*" summarises the current status of equitation science research. Putting good research into practice, and vice versa, is crucial to future-proofing equitation and horse welfare.

References

Abbey, A., Randle, H., 2016. Equitation pedagogic practice: use of a ridden horse ethogram to effect change. J. Vet. Behav.: Clin. Appl. Res. 15, 80.

Agostino, R., Bologna, M., Dinapoli, L., Gregori, B., Fabbrini, G., Accornero, N., Berardelli, A., 2008. Voluntary, spontaneous, and reflex blinking in Parkinson's disease. Mov. Dis. 23, 669–675.

Ahmed, S., Parsons, D., 2013. Abductive science inquiry using mobile devices in the classroom. Comp. Educ. 63, 62–72.

Allin, K.A., Stacey, E., Randle, H., 2013. Investigation of the effect of balancing aids on the skin temperature of the ridden. J. Vet. Behav. Clin. Appl. Res. 8, e1–e2.

Andriamandroso, A.L.H., Bindelle, J., Mercatoris, B., Lebeau, F., 2016. A review on the use of sensors to monitor cattle jaw movements and behavior when grazing. Biotechnol. Agron. Soc. Environ. 20, 273–286.

Arruda, T.Z., Brass, K.E., de la Corte, F., 2011. Thermographic assessment of saddles used on jumping horses. J. Equine Vet. Sci. 31, 625–629.

Büchel, S., Sundrum, A., 2014. Technical note: evaluation of a new system for measuring feeding behavior of dairy cows. Comput. Electron. Agric. 108, 12–16.

Back, W., Clayton, H.M., 2013. Equine Locomotion, second edition. Saunders Ltd., U.S.

Becker-Birke, M., Schmidt, A., Lasarzik, J., Aurich, J., Möstl, E., Aurich, C., 2013. Cortisol release and heart rate variability in sport horses participating in equestrian competitions. J. Vet. Behav. Clin. Appl. Res. 8, 87–94.

Belock, B., Kaiser, L.J., Lavagnino, M., Clayton, H.M., 2012. Comparison of pressure distribution under a conventional saddle and a treeless saddle at sitting trot. Vet. J. 193, 87–91.

Benoist, C.C., Cross, G.H., 2016a. Reaching equestrians through an on-line academy to implement a new thought process for humane bitting using applied physics. J. Vet. Behav.: Clin. Appl. Res. 15, 87.

Benoist, C.C., Cross, G.H., 2016b. Assessment of poll pressure induced by a baucher/hanging cheek snaffle. J. Vet. Behav.: Clin. Appl. Res. 15, 91–92.

Björnsdótti, R., Frey, S., Kristjansson, R., Lundström, T., 2014. Bit-related lesions in Icelandic competition horses. Acta. Vet. Scand. 56, 40.

Boden, E., Randle, H., Brigden, C., 2013. The effects of rider specific pilates on rider position from a later view: a six week study. In: Peters, D.M., O'Donohue, P. (Eds.), Performance Analysis of Sport IX. Routledge Publishing, London, pp. 239–246.

Bowers, J., Slocombe, R.F., 1999. Influence of girth strap tensions on athletic performance of racehorses. Equine Vet. J. Suppl. 30, 52–56.

Bowers, J., Slocombe, R.F., 2000. Tensions used on girths on thoroughbred racehorses. Aust. Vet. J. 78, 567–569.

Bowers, J., Slocombe, R.F., 2005. Comparison of girth materials, girth tensions and their effects on performance in racehorses. Aust. Vet. J. 83, 68–74.

Briley, J.D., Williams, M.D., Freire, M., Griffith, E.H., Lascells, B.D., 2015. Feasibility and repeatability of cold and mechanical quantitative sensory testing in normal dogs. Vet. J. 199, 245–250, http://dx.doi.org/10.1016/j.tvjl.2013.10.025.

Burgon, H.L., 2011. 'Queen of the World': experiences of 'at-risk' young people participating in equine-assisted learning/therapy. J. Soc.Work Pract. 25, 165–183.

Bussey, T.J., Holmes, A., Lyon, L., Mar, A.C., McAllister, K.A.L., Nithianantharajah, J., Oomen, C.A., Saksida, L.M., 2012. New translational assays for preclinical modelling of cognition in schizophrenia: the touchscreen testing method for mice and rats. Neuropharmacol 62, 1191–1203.

Bussières, G., Jacques, C., Lainay, O., Beachamp, G., Leblond, A., Cadoré, J.-L., Desmaizières, L.-M., Cuvelliez, S.G., Troncy, E., 2008. Development of a composite orthopaedic pain scale in horses. Res. Vet. Sci. 85, 294–306.

Byström, A., Stalfelt, A., Egenvall, A., Von Peinen, K., Morgan, K., Roepstorff, L., 2010. Influence of girth strap placement and panel flocking material on the saddle pressure pattern during riding of horses. Equine Vet. J. Suppl. 38, 502–509.

Cambridge Cognition, 2016. Cognitive Research [online]. Available from: http://www.cambridgecognition.com/academic/cantabsuite/tests [Accessed 28.5.2016].

Canales, J.J., 2005. Stimulant-induced adaptations in neostriatal matrix and striosome systems: transiting from instrumental responding to habitual behaviour in drug addiction. Neurobiol. Learn. Mem. 83, 93–103.

Carlson, N.R., 2010. Physiology of Behavior, tenth ed. Allyn & Bacon, Boston.

Cartier d'Yves, A., Ödberg, O.F., 2005. A preliminary study on the relation between subjectively assessing dressage performances and objective welfare parameters. In: McGreevy, P.D., McLean, A.N., Warren-Smith, A.K., Goodwin, D., Waran, N. (Eds.), Proceedings of the First International Equitation Science Symposium. 26th–27th August 2005, Melbourne, Australia, pp. 89–110.

Casey, V., McGreevy, P.D., O'Muiris, E., Doherty, O., 2014. A preliminary report on estimating the pressures exerted by a crank noseband in the horse. J. Vet. Beh.: Clin. Appl. Res. 8, 479–484.

Chalmers, H.J., Farberman, A., Bernigham, A., Sears, W., Viel, W., 2013. The use of a tongue tie alters laryngohyoid poistion in the standing horse. Equine Vet. J. 45, 711–714.

Chan, C.B., Spierenberg, M., Ihle, S.L., Tudor-Locke, C., 2005. Use of pedometers to measure physcial activity in dogs. J. Am. Vet. Med. Assoc. 226, 2010–2015.

Chaudhari, A.M.W., McKenzie, C.S., Pan, X., Onate, J.A., 2014. Lumbopelvic control and days missed because of injury in professional baseball pitchers. Am. J. Sports Med. http://ajs.sagepub.com/content/42/11/2734 (accessed 09 12 2006).

Clayton, H.M., Lee, R., 1984. A fluoroscopic study of the position and action of the jointed snaffle bit in the horse's mouth. J. Equine Vet. Sci. 4, 193–196.

Clayton, H.M., Singleton, W.H., Lanovaz, J.L., Cloud, G.L., 2005. Strain gauge measurement of rein tension during riding: a pilot study. Equine Comp. Exerc. Physiol. 2, 203–205.

Clayton, H.M., Kaiser, L.J., Nauwelaerts, S., 2010. Pressure on the horse's withers with three styles of blanket. Vet. J. 184, 52–55.

Clayton, H.M., Belock, B., Lavaginio, M., Kaiser, L.J., 2013. Forces and pressures on the horse's back during bareback riding. Vet. J. 195, 48–52.

Colborne, G.R., Birtles, D.M., Cacchione, I.C., 2001. Electromyographic and kinematic indicators of fatigue in horses: a pilot study. Equine Vet. J. 33, 89–93.

Cook, W.R., 2014. A hypothetical, aetiological relationship between the horse's bit, nasopharyngeal asphyxia and negative pressure pulmonary oedema. Equine Vet. Educ. 26, 381–389.

Cornelisse, C.J., Holcombe, S.J., Derksen, F.J., Berbey, C., Jackson, C.A., 2001. Effect of a tongue-tie in horses during exercise. Am. J. Vet. Res. 62, 775–778.

de Cocq, P., van Weeren, P.R., Back, W., 2006. Saddle pressure measuring: validity, reliability and power to discriminate between different saddle-fits. Vet. J. 172, 265–273.

de Luca, C.J., Gilmore, L.D., Kuznetsov, M., Roy, S.H., 2010. Filtering the surface EMG signal: movement artefact and baseline noise contamination. J. Biomech. 43, 1573–1579.

Dalla Costa, E., Minero, M., Lebelt, D., Stucke, D., Canali, E., Leach, M.C., 2014. Development of the horse grimace scale (HGS) as a pain assessment tool in horses undergoing routine castration. PLoS One 9, e92281.

Dalla Costa, E., Dai, F., Lebelt, D., Scholz, P., Barbieri, S., Canali, E., Zanella, A.J., Minero, M., 2016. Welfare assessment of horses: the AWIN approach. Anim. Welf. 25, 481–488.

Doherty, O., Casey, V., McGreevy, P., Arkins, S., 2016. An investigation into noseband tightness levels on competition horses. J. Vet. Behav.: Clin. Appl. Res. 15, 83.

Duncan, M.J., Rosenkranz, R.R., Vandelanotte, C., Caperchioe, C.M., Rebar, A.L., Maeder, A.J., Tague, R., Savage, T.N., van Itallie, A., Mummery, W.K., Kolt, W.S., 2016. What is the impact of obtaining medical clearance to participate in a randomised controlled trial examining a physical activity intervention on the socio-demographic and risk factor profiles of included participants? Trials 17, 580, http://dx.doi.org/10.1186/s13063-016-1715-4.

Dyson, S., Greve, L., 2016. Saddles and girths: what is new? Vet. J. 207, 73–79.

Eddy, A.L., van Hoogmoed, L.M., Snyder, J.R., 2001. The role of thermography in the management of equine lameness. Vet. J. 162, 172–181.

Egenvall, A., Roepstorff, L., Eisersiö, M., Rhodin, M., van Weeren, R., 2015. Stride related rein tension patterns in walk and trot in the ridden horse. Acta Vet. Scand. 57, 89, http://dx.doi.org/10.1186/s13028-015-0182-3.

Egenvall, A., Roepstorff, L., Rhodin, M., Eisersiö, M., Clayton, H.M., 2016. Maximum and minimum peaks in rein tension within canter strides. J. Vet. Behav.: Clin. Appl. Res. 13, 63e71.

Fenner, K., Yoon, S., White, P., Starling, M., McGreevy, P., 2016. The effect of noseband tightening on horses' behavior, eye temperature, and cardiac responses. PLoS One 11, e0154179, http://dx.doi.org/10.1371/journal.pone.0154179.

Francis, E., 2016. An Investigation into the Validation of Pedometers to Detect Foreleg Steps in Horses at Walk and Trot. MSC Thesis. Plymouth University.

Fruehwirth, N.B., Peham, C., Scheidl, M., Schobesberger, H., 2004. Evaluation of pressure distribution under an English saddle at walk, trot and canter. Equine Vet. J. 36, 754–757.

Gabor, V., Gerken, M., 2012. Cognitive testing in horses using a computer based apparatus. Appl. Anim. Behav. Sci. 139, 242–250.

Gaebler, M., Daniels, J.K., Lamke, J.-P., Fydrich, T., Walter, H., 2013. Heart rate variability and its neural correlates during emotional face processing in social anxiety disorder. Biol. Psychol. 94, 319–330.

Gandi, E.A., Bondi, A., Hogg, R., Pigott, T.M.C., 2014. A preliminary investigation of the use of inertial sensing technology for the measurement of hip rotation asymmetry in horse riders. Sports Technol. 7, 79–88.

Garner, J.P., Mason, G.J., 2002. Evidence for a relationship between cage stereotypies and behavioural disinhibition in laboratory rodents. Behav. Brain Res. 136, 83–92.

Garner, J.P., 2006. Perseveration and stereotypy—systems level insights from clinical psychology. In: Mason, G., Rushen, J. (Eds.), Stereotypic Animal Behaviour Fundamentals and Applications to Welfare. , second ed. CABI International, Cambridge, pp. 121–153.

Gehrke, E.K., Baldwin, A., Schiltz, P.M., 2011. Heart Rate Variability in horses engaged in equine—assisted activities. J. Equine Vet. Sci. 31, 78–84.

Geutjens, C.A., Clayton, H.M., Kaiser, L.J., 2008. Forces and pressures beneath the saddle during mounting from the ground and from a raised mounting platform. Vet. J. 175, 332–337.

Giblett, J., Randle, H., Abbey, A., 2015. Effect of saddle pad thickness on the ridden horse's back. In: Heleski, C.R., Merkies, K. (Eds.), Proceedings of the 11th International Equitation Science Conference. 5th–8th August 2015, University of British Columbia, Vancouver, B.C., Canada, p. 62.

Giusto, G., Pagliara, E., Gandini, M., 2014. Effects of bit chewing on right upper quadrant intestinal sound frequency in adult horses. J. Equine Vet. Sci. 3, 520–523.

Greve, L., Dyson, S., 2013. The horse-saddle-rider interaction. Vet. J. 195, 275–281.

Groesel, M., Zsoldos, R.R., Kotschwar, A., Gfoehler, M., Peham, C., 2010. A preliminary model study of the equine back including activity of the longissimus dorsii muscle. Equine Vet. J. 42, 401–406.

Hall, C., Huws, N., White, C., Taylor, E., Owen McGreevy, P., 2013. Assessment of ridden horse behaviour. J. Vet. Behav.: Clin. Appl. Res. 8, 62–73.

Hall, C., Kay, R., Yarnell, K., 2014. Assessing ridden horse behaviour: professional judgment and physiological measures. J. Vet. Behav.: Clin. Appl. Res. 9, 22–29.

Hall, C., 2014. Materials: A Very Short Introduction (Very Short Introductions). Oxford University Press, Oxford (142 pp).

Halliday, D., Resnick, R., Walker, J., 2014. Principles of Physics, tenth ed. John-Wiley & Sons, Oxford.
Hampson, A., Randle, H., 2015. The influence of an 8-week rider core fitness program on the equine back at sitting trot. Int. J. Perform. Anal. Sport 15, 1145–1159.
Hanggi, E.B., Ingersoll, J.F., 2009. Long-term memory for categories and concepts in horses (*Equus caballus*). Anim. Cognit. 12, 451–462.
Hansen, A.L., Johnsen, H.H., Sollerskill, J.J., Stenvick, K., Thayer, J.F., 2004. Heart rate variability and its relation to prefrontal cognitive function: the effects of training and detraining. Eur. J. Appl. Physiol. 93, 263–272.
Hawson, L.A., Mclean, A.N., McGreevy, P.D., 2013. A retrospective survey of riders' opinions of the use of saddle pads in horses. J. Vet. Behav.: Clin. Appl. Res. 8, 74–81.
Heleski, C.R., McGreevy, P.M., Kaiser, L.J., Lavagino, M., Tans, E., Bello, N., Clayton, H.M., 2009. Effects on behaviour and rein tension on horses ridden with or without martingales and rein inserts. Vet. J. 181, 56–62.
Hemmings, A., McBride, S.D., Hale, C.E., 2007. Perseverative responding and the aetiology of equine oral stereotypy. Appl. Anim. Behav. Sci. 104, 143–150.
Hennermann, K., 2009. Thermal imaging, injury and the working dog. Mush. Mag., 8–9.
Hill, E., McGreevy, P.D., Caspar, G., White, P., McLean, A.N., 2015. Apparatus use in popular equestrian disciplines in Australia. J. Vet. Behav.: Clin. Appl. Res. 10, 147–152.
Hinchcliff, K.W., Kaneps, A.J., Geor, R.J., 2008. Equine Exercise Physiology: The Science of Exercise in the Athletic Horse. Saunders Elsevier, London.
Hirano, Y., Obata, T., Takahashi, H., Tachibana, A., Kuroiwa, D., Takahashi, T., Ikehira, H., Onozuka, M., 2013. Effects of chewing on cognitive processing speed. Brain Cognit. 81, 376–381.
Holmes, M., Jeffcott, L., 2010. Equitation science, rider effects, saddle and back problems in the horses: can technology provide the answer? (Editorial). Vet. J. 184, 5–6.
Holmes, C.M.P., Goodwin, D., Redhead, E.S., Goymour, K.L., 2012. The benefits of equine-assisted activities: an exploratory study. Child Adolesc. Social Work J. 29, 111, http://dx.doi.org/10.1007/s10560-011-0251-z.
Hug, F., Turpin, N.A., Guével, A., Dorel, S., 2010. Is interindividual variability of EMG patterns in trained cyclists related to different muscle synergies? J. Appl. Physiol. 108, 1727–1736.
Ille, N., Erber, R., Aurich, C., Aurich, J., 2014. Comparison of heart rate and heart rate variability obtained by heart rate monitors and simultaneously recorded electrocardiogram signals in nonexercising horses. J. Vet. Behav.: Clin. Appl. Res. 9, 341–346.
Jensen, P., 1980. An ethogram of social interaction patterns in group-housed dry sows. Appl. Anim. Behav. Sci. 6, 341–350.
Kaminer, J., Powers, A.S., Horn, K.G., Hui, C., Evinger, C., 2011. Characterizing the spontaneous blink generator: an animal model. J. Neurosci. 31, 11256–11267.
Karson, C.N., 1983. Spontaneous eye-blink rates and dopaminergic systems. Brain 106, 643–653.
Kent, E. unpublished. An updated retrospective analysis of head and neck angles in elite dressage horses: 1979–2015. Honours Project Report, Duchy College, UK.
Keogh, J.W.L., Espinosa, H.G., Grigg, J., 2016. Evolution of smart devices and human movement apps: recommendations for use in sports science education and practice. In: Special Issue ASTN-Q Conference, Research & Innovation in Sports Technology, August 2016. Journal of Fitness Research, pp. 14–15.
Kiley-Worthington, M., Lea, S.E.G., 1996. Can animals think? In: Bruce, V. (Ed.), Unsolved Mysteries of the Mind Tutorial Essays in Cognition. Erlbaum Taylor & Francis, Hove, Sussex, pp. 211–244.
Kiley-Worthington, M., 1987. Behaviour of Horses in Relation to Management and Training. Newton Abbot, J.A. Allen.
Kiley-Worthington, M., 1997. Equine Welfare. J.A. Allen, Newton Abbot.
Kingsley, M., Lewis, M.J., Marson, R.E., 2005. Comparison of polar 810 s and an ambulatory ECG system for RR interval measurement during progressive exercise. Int. J. Sports Med. 26, 39–44.
Kotschwar, A.B., Baltacis, A., Peham, C., 2010. The effects of different saddle pads on forces and pressure distribution beneath a fitting saddle. Equine Vet. J. 42, 114–118.
Krauskopf, K., König von Borstel, U., 2016. Relationship between rideability and tactile sensitivity assessed via algometer and von-frey filaments. J. Vet. Behav.: Clin. Appl. Res. 15, 87.
Lac, V., 2016. Horsing around: gestalt equine pyschotherapy as humanstic play therapy. J. Hum. Psychol. 56, 194–209.
Lambert, G.A., Mallos, G., Zagami, A.S., 2009. Von Frey's hairs—a review of their technology and use—a novel automated von Frey device for improved testing for hyperalgesia. J. Neurosci. Methods 177, 420–426.
Lashley, M.J.J.O., Nauwelaerts, S., Vernooij, J.C.M., 2014. Comparison of the head and neck position of elite dressage horses during top-level competitions in 1992 versus 2008. Vet. J. 202, 462–465.
Leiber, F., Holinger, M., Zehner, N., Dorn, K., Probst, J., Spengler Neff, A., 2016. Intake estimation in dairy cows fed roughage-based diets: an approach based on chewing behaviour measurements. Appl. Anim. Behav. Sci. 185, 9–14.
Manfredi, J., Clayton, J.M., Derksen, F.J., 2005. Effects of different bits and bridles on frequency of induced swallowing in cantering horses. Equine Comp. Exerc. Physiol. 2, 241–244.
Marchant-Forde, R.M., Marlin, D.J., Marchant-Forde, J.N., 2004. Validation of a cardiac monitor for measuring heart rate variability in adult female pigs: accuracy, artefacts and editing. Physiol. Behav. 80, 449–458.
Martin, P., Bateson, P., 2007. Measuring Behaviour: An Introductory Guide, second ed. Cambridge University Press, Cambridge.
McBride, S.D., Hemmings, A., 2005. Altered mesoaccumbens and nigro-striatal dopamine physiology is associated with stereotypy development in a non-rodent species. Behav. Brain Res. 159, 113–118.
McBride, S., Hemmings, A., 2009. A neurologic perspective of equine stereotypy. J. Equine Vet. Sci. 29, 10–16.
McBride, S., Hemmings, A., Robin-son, K., 2004. A preliminary study on the effect of massageto reduce stress in the horse. J. Equine Vet. Sci. 24, 76–81.
McBride, S.D., Perentos, N., Morton, A.J., 2016. A mobile, high-throughput semi-automated system for testing cognition in large non-primate animal models of Huntington disease. J. Neurosci. Methods 265, 25–33.
McDonnell, S.M., 2002. The Equid Ethogram: A Practical Field Guide to Horse Behavior. Eclipse Press, Kentucky (384 pp).
McFarlane, D., 2007. Advantages and limitations of the equine disease: pituitary pars intermedia dysfunction as a model of spontaneous dopaminergic neurodegenerative disease. Ageing Res. Rev. 6, 54–63.
McGreevy, P.D., Warren-Smith, A., Guisard, Y., 2012. The effect of double bridles and jaw-clamping crank nosebands on temperature of eyes and facial skin of horses. J. Vet. Behav.: Clin. Appl. Res. 7, 142–148.
McGreevy, P.D., Hawson, L.A., Salvin, H., McLean, A.N., 2013. A note on the force of whip impacts delivered by jockeys using forehand and backhand strikes. J. Vet. Behav.: Clin. Appl. Res. 5, 395–399.
McGreevy, P.D., Sundin, M., Karlsteen, M., Berglin, L., Ternström, J., Hawson, L., Richardsson, H., McLean, A.M., 2014. Problems at the human-horse interface and prospects for smart textile solutions. J. Vet. Behav.: Clin. Appl. Res. 9, 34–42.
McLean, A.N., McGreevy, P.D., 2010. Ethical equitation: capping the price horses pay for human glory. J. Vet. Behav.: Clin. Appl. Res. 5, 203–209.
McLeod, N., Lee, J.B., 2016. Gone to the dogs: canine activity step count, using technology designed for human movementSpecial Issue ASTN–Q conference. Research & Innovation in Sports Technology. August 2016. J. Fit. Res., 31–33.
Mendl, M., Burman, O.H.P., Parker, A.M.A., Paul, E.S., 2009. Cognitive bias as an indicator of animal emotion and welfare: emerging evidence and underlying mechanisms. Appl. Anim. Behav. Sci. 118, 161–181.
Montano, A.P., Porta, A., Cogliati, C., Costantino, G., Tobaldini, E., Rabello Casali, K., Iellamo, F., 2009. Heart rate variability explored in the frequency domain: A tool to investigate the link between heart and behavior. Neurosci. Biobehav. Rev. 33, 71–80.
Meola, C., Carlomagno, G.M., 2004. Recent advances in the use of infrared thermography. Meas. Sci. Technol., 15 http://dx.doi.org/10.1088/0957-0233/15/9/R01.
Mullard, J., Berger, J.M., Ellis, A.D., Dyson, S., 2016. Development of an ethogram to describe facial expressions in ridden horses (FEReq). J. Vet. Behav.: Clin. Appl. Res., http://dx.doi.org/10.1016/j.jveb.2016.11.005.
Murray, R., Guire, R., Fisher, M., Fairfax, V., 2013. Girth pressure measurements reveal high peak pressures that can be avoided using an alternative girth design that also results in increased limb protraction and flexion in the swing phase. Vet. J. 198, 92–97.
Murray, R., Guire, R., Fisher, M., Fairfax, V., 2015. A bridle designed to avoid peak pressure locations under the headpiece and noseband is associated with more uniform pressure and increased carpal and tarsal flexion, compared with the horse's usual bridle. J. Equine Vet. Sci. 35, 947–955.
Mutoh, T., Mutoh, T., Takada, M., Dourmua, M., Ihara, M., Taki, Y., Tsubone, H., Ihara, M., 2016. Application of a tri-axial accelerometry-based portable motion recorder for the quantitative assessment of hippotherapy in children and adolescents with cerebral palsy. J. Phys. Ther. Sci. 10, 2970–2974.
Muybridge, E., 1878. Sequencing galloping horse https://en.wikipedia.org/wiki/Sallie_Gardner_at_a_Gallop.
Nicol, G., Arnold, G.P., Wang, W., Abboud, R.J., 2014. Dynamic pressure effect on horse and horse rider during riding. Sports Eng. 17, 143–150.
Nishigawa, K., Suzuki, Y., Matsuka, Y., 2015. J. Prosthodont. Res. 59, 262–267.
Noble, G., Dodd, J., Nielson, S., Spurrell, B., Knight, P., 2014. Determining Forces Generated Using a Padded Whip and Impacts on the Horse. Australian Government Rural Industries Research and Development Corporation. RIRCD PUblication no 14/075, Canberra (52 pp).
Nola, G.T., Vistnes, L.M., 1980. Differential response of skin and muscle in experimental production of pressure sores. Plast. Reconstr. Surg. 66, 728–733.
North, S., Hall, C., Roshier, A.L., Mancini, C., 2015. HABIT: horse automated behaviour identification tool: a position paper. In: ACI@BHCI (Animal Compueter Interaction Workshop), British HCE, 13th–17th July 2015, University of Lincoln, Lincoln http://doi.org/10.13140/RG.2.1.3395.0881.
O'Neill, M., Randle, H., 2015. The effect of martingale attachments on rein tension in the ridden horse. In: Heleski, C.R., Merkies, K. (Eds.), Proceedings of the 11th International Equitation Science Conference. 5th–8th August 2015, University of British Columbia, Vancouver, B.C., Canada (p. 26).
Onishi, M., Linuma, M., Tamura, Y., Kubo, K., 2014. Learning deficits and suppression of the cell proliferation in the hippocampal dentate gyrus of offspring are attenuated by maternal chewing during prenatal stress. Neurosci. Lett. 560, 77–80.
Ono, Y., Koizumi, S., Onozuka, M., 2015. Chewing prevents stress-induced hippocampal ltd formation and anxiety-related behaviors: a possible role of the dopaminergic system. Comput. Electron. Agric. 92, 54–65.
Padalino, B., Radial, S.L., Hall, E., Knight, P., Celi, P., Jeffcott, L., Muscatello, G., 2016. Survey of horse transportation in Australia: issues and practices. Aust. Vet. J. 94, 349–357.

Palmer, S.E., 1980. Use of the portable infrared thermometer in equine practice. Am. Assoc. Equine Pract. 26, 327–333.

Parker, M., Redhead, E.S., Goodwin, D., McBride, S.D., 2008. Impaired instrumental choice in crib-biting horses (Equus caballus). Behav. Brain Res. 191, 137–140.

Parker, M., Goodwin, D., Eager, R.A., Redhead, E.S., Marlin, D.J., 2009a. Comparison of Polar® heart rate interval data with simultaneously recorded ECG signals in horses. Comp. Exer. Physiol. 6, 137–142.

Parker, M., McBride, S.D., Redhead, E.S., Goodwin, D., 2009b. Differential place and response learning in horses displaying an oral stereotypy. Behav. Brain Res. 200, 100–105.

Peham, C., Kötschwar, A.B., Borkenhagen, B., Kuhnke, S., Molsner, A., Batacis, A., 2010. Comparison of forces acting on the horse's back and the stability of the rider's seat in different positions at the trot. Vet. J. 184, 56–59.

Pierard, M., Hall, C., König von Borstel, U., Averis, A., Hawson, L., McLean, A., Nevison, C., Visser, K., McGreevy, P., 2015. Evolving protocols for research in equitation science. J. Vet. Behav.: Clin. Appl. Res. 10, 255–266.

Preuschoft, H., Witte, H., Recknagel, S., Bär, H., Lesch, C., Wüthrich, M., 1999. Effect of common head gear on horses. DTW. Dtsch. Tierarztl. Wochenschr. 106, 169–175.

Quick, J.S., Warren-Smith, A., 2009. Preliminary investigations of horses' (*Equus caballus*) responses to different bridles during foundation training. J. Vet. Behav.: Clin. Appl. Res. 4, 169–176.

Ramseier, L.C., Waldern, N.M., Wiestner, T., Geser-von Peinen, K., Weishaupt, M.A., 2013. Saddle pressure distributions of three saddles used for Icelandic horses and their effects on ground reaction forces, limb movements and rider positions at walk and tölt. Vet. J. 198 (Suppl. 1), e81–e87 (10.1016/j.tvjl.2013.09.038. Epub 2013 Sep 27).

Randle, H., Button, L., 2008. Fulfilling the educational aims of the international society for equitation science (ISES). In: Murphy, J., Hennessey, K., Wall, P., Hanley, P. (Eds.), Proceedings of the Fourth International Society for Equitation Science Conference. 1st–4th August 2008, RDS, Dublin (p. 103).

Randle, H., Venables, B., 2012. A retrospective analysis of high performance dressage horse head and neck angles 1979–2011. In: Randle, H., Waran, N., Williams, J. (Eds.), Proceedings of the Eigth International Society for Equitation Science Conference. 18th–20th July 2012, Edinburgh University, Scotland (p. 81).

Randle, H., Abbey, A., Button, L., 2010. The effect of different rein types on the rein tension applied when taking up a 'medium contact'. In: Hartmann, E., Zetterqvist Blokhuis, M., Fransson, C., Dolin, G. (Eds.), Proceedings of the Sixth International Society for Equitation Science Conference. 31 st July–1 st August 2010, Uppsala, Sweden (p. 37).

Randle, H., Abbey, A., Sears, K., 2013. Qualitative (perceived) versus quantitative (actual) assessment of rein tension: what lessons can be learnt? In: Heleski, C.R., Wickens, C. (Eds.), Proceedings of the 9th International Society for Equitation Science Conference. Delaware, United States (p. 37).

Randle, H., Challacombe, J., Abbey, A., 2015. The influence of handler experience on the behaviour of horses in an educational environment: heart Rate and Visual Analogue Scores. In: Heleski, C.R., Merkies, K. (Eds.), Proceedings of the Eleventh International Society for Equitation Science Conference. 5th–8th August 2015, University of British Columbia, Vancouver, B.C., Canada (p. 52).

Randle, H.D., 1995. Personality and Adoption in Beef Cattle (*Bos taurus*) PhD Thesis. Exeter University, Exeter.

Randle, H., 2008. Can a simple problem-solving task be used to assess Learned Helplessness in horses? In: Murphy, J., Hennessey, K., Wall, P., Hanley, P. (Eds.), Proceedings of the Fourth International Society for Equitation Science Conference. 1st–4th August 2008, RDS, Dublin (p. 64).

Randle, H., 2009. Research methods. In: Williams, J.M. (Ed.), The Complete Textbook of Animal Health and Welfare. W.B. Saunders, London.

Randle, H., 2010. Ethical equitation—a sustainable approach. J. Vet. Behav.: Clin. Appl. Res. 5, 167–169.

Randle, H., 2014. Is elastic fantastic? The impact of elastic inserts on rein tension. In: Winther Christensen, J., Ladewig, H., Peerstrup Ahrendt, L., Malmkvist, J. (Eds.), Proceedings of the Tenth International Society for Equitation Science Conference. 6th–9th August 2014, Vingsted Hotel and Conference Centre, Denmark (p. 50)add in Abbey, A. as the second author.

Randle, H., 2016. Welfare friendly equitation—understanding horses to improve training and performance. J. Vet. Behav.: Clin. Appl. Res. 15, vii–viii.

Reyes del Paso, G.A., Langewitz, W., Mulder, L.J., van Roon, A., 2013. The utility of low frequency heart rate variability as an index of sympathetic cardiac tone: a review with emphasis on a reanalysis of previous studies. Psychophysiol 50, 477–487.

Rietman, T.R., Stuart, A.E.A., Bernosconi, P., Stauffacher, M., Auer, J.A., Weishaupt, M.A., 2004. Assessment of mental stress in Warmblood horses: heart rate variability in comparison to heart rate and selected behavior parameters. Appl. Anim. Behav. Sci. 88, 121–136.

Robert, C., Valette, P., Purcelot, P., Denoix, J.-M., 2002. Effects of trotting speed on muscle activity and kinematics in saddlehorses. Equine Exerc. Physiol. 34 (s), 295–301.

Roberts, K., Hemmings, A., Moore-Colyer, M., Hale, C., 2015. Cognitive differences in horses performing locomotor versus oral stereotypic behaviour. Appl. Anim. Behav. Sci. 168, 37–44.

Roberts, K., Hemmings, A.J., Moore-Colyer, M., Parker, M.O., McBride, S.D., 2016. Neural Modulators of Temperament: a multivariate approach to personality trait identification in the horse. Physiol. Behav. 167, 125–131.

Roebel, A.M., MacLean, W.E., 2007. Spontaneous eye-blinking and stereotyped behaviour in older persons with mental retardation. Res. Dev. Disabil. 28, 37–42.

Rollin, B.E., 2009. Scientific autonomy and the 3Rs. Am. J. Bioeth. 9, 62–63.

Russell, W.M.S., Burch, R., 1959. Principles of Humane Experimental Technique. Methuen, London.

Rutter, S.M., Champion, R.A., Penning, M., 1997. An automatic system to record foraging behaviour in free-ranging ruminants. Appl. Anim. Behav. Sci. 54, 185–195.

Schmidt, A., Möstl, E., Wehnert, C., Aurich, J., Müller, J., Aurich, C., 2010. Cortisol release and heart rate variability in horses during road transport. Horm. Behav. 57, 209–215.

Scofield, R.M., Randle, H., 2013. Preliminary comparison of behaviors exhibited by horses ridden in bitted and bitless bridles. J. Vet. Beh: Clin. Apps. Res. 8, e20–e21.

Serup, J., Jemec, G.B.E., Grove, G.L., 2006. Handbook of Non-Invasive Methods and the Skin, second ed. CRC Press, London.

Silva, P., Mota, J., Esliger, D., Welk, G., 2010. Technical reliability assessment of the actigraph GT1M accelerometer. Meas. Phys. Educ. Exerc. Sci. 14, 79–91.

Sloet van Oldenborg-Oosterbaan, M.M., Hoven van der, R., Breukink, H.J., 1988. The accuracy of three different heart rate meters used for studies in the exercising horse. J. Vet. Med. 35, 665–672.

Smith, P., 2009. Chewing gum, stress and health. Stress Health. 25, 445–451.

Soroko, M., Howell, K., 2016. Infrared Thermography: Current Applications in Equine Medicine. J. of Equine Vet. Sci. http://dx.doi.org/10.1016/j.jevs.2016.11.002.

St George, L., Williams, J.M., 2013. Electromyographic evaluation of approach stride, jump stride and intermediate stride in selected superficial muscles of the jumping horse: a preliminary study. Comp. Exerc. Physiol. 9, 23–32.

Stephenson, B., Hemmings, A., Moore-Colyer, M., 2014. The use of eye blink rate (EBR) and changes in behaviour as potential early indicators of pituitary pars intermedia dysfunction in the horse. In: British Society of Animal Science, Annual Conference, University of Nottingham.

Stewart, M., Stafford, K.J., Dowling, S.K., Schaefer, A.L., Webster, J.R., 2008. Eye temperature and heart rate variability of calves: disbudded with or without local anaesthetic. Physiol. Behav. 93, 789–797.

Symes, D., Ellis, R., 2009. A preliminary study into rider asymmetry within equitation. Vet. J. 181, 34–37.

Tani, Y., Yokota, Y., Yayota, M., Ohtani, S., 2013. Automatic recognition and classification of cattle chewing activity by an acoustic monitoring method with a single-axis acceleration sensor. Comp. Electron. Agric. 82, 54–65.

Taylor, J.R., Elsworth, J.D., Lawrence, M.S., Sladek, J.R., Roth, R.H., Redmond, D.E., 1999. Spontaneous blink rates correlate with dopamine levels in the caudate nucleus of MPTP-treated monkeys. Exp. Neurol. 158, 214–220.

Tsirikos, A., Papagelopoulos, P.J., Giannakopoulos, P.N., Boscainos, P.J., Zoubos, A.B., Kasseta, M., Nikiforidis, P.A., Korres, D.S., 2001. Degenerative spondyloarthropathy of the cervical and lumbar spine in jockeys. Orthopedics 24, 24561–24564.

Tunley, B.V., Henson, F.M.D., 2004. Reliability and repeatability of thermographic examination and the normal thermographic image of the thoracolumbar region in the horse. Equine Vet. J. 36, 306–312.

Turner, T.A., Fessler, J.F., Lamp, M., Pearce, J.A., Geddes, L.A., 1983. Thermographic evaluation of horses with podotrochlosis. Am. J. Vet. Res. 44, 535–539.

Turner, T.A., 1991. Thermography as an aid to the clinical lameness evaluation. N. Am. Equine Pract. 7, 311–338.

Ungar, E.D., Rutter, S.M., 2006. Classifying cattle jaw movements: comparing IGER behaviour recorder and acoustic techniques. Appl. Anim. Behav. Sci. 98, 11–27.

Van Beek, F.E., de Cocq, P., Timmerman, M., Muller, M., 2012. Stirrup forces during horse riding: a comparison between sitting and rising trot. Vet. J. 193, 193–198.

Visser, E.K., Reenen van, C.G., Werf van der, J.T.N., Schilder, M.B.H., Knaap, J.H., Barneveld, A., Blokhuis, H.J., 2002. Heart rate and heart rate variability during a novel object test and a handling test in young horses. Physiol. Behav. 76, 289–296.

Waran, N., Randle, H., 2013. Advancing evidence based practice and learning in equitation. In: Heleski, C.R., Wickens, C. (Eds.), Proceedings of the 9th International Society for Equitation Science Conference. Delaware, United States (p. 24).

Waran, N., Randle, H., 2017. What we can measure, we can manage: The importance of developing robust welfare indicators for use in Equitation. J. of Vet. Behav.: Clin. Appl. and Res. THIS ISSUE Vol, pp–pp.

Warren-Smith, A., McGreevy, P., 2010. The use of pedometers to estimate motor laterality in grazing horses. J. Vet. Behav.: Clin. Appl. Res. 5, 177–179.

Warren-Smith, A.K., Curtis, R.A., Greetham, L., McGreevy, P.D., 2007. Rein contact between horse and handler during specific equitation movements. Appl. Anim. Behav. Sci. 108, 157–169.

Williams, J.M., Randle, H., 2017. Is the expression of stereotypic behavior a performance limiting factor in animals? J. of Vet. Behav.: Clin. App. and Res. Special issue Captive animal responses: contextualising stereotypic, abnormal and compulsive behaviours (in press).

Williams, J.M., Johnson, C.J., Bales, R., Lloyd, G., Barron, L., Quest, D., 2014. Analysis of temporalis and masseter adaptation after routine dental-treatment in the horse via surface electromyography. Comp. Exerc. Physiol. 10, 223–232.

Wright, W., Askeland, D.R., 2015. The Science and Engineering of Materials, seventh student international edition. CENGAGE Learning Custom Publishing, U.S.

Wright, S., 2011. Girth tensions and their variability while standing and during exercise. Comp. Exerc. Physiol. 7, 141–148.

Xenophon, 2006. (Translated by M.H. Morgan). The Art of Horsemanship. Dover Publications Inc., New York, United States. 208 pp.
Zebisch, A., May, A., Reese, S., Gehlen, H., 2014. Effect of different head-neck positions on physical and psychological stress parameters in the ridden horse. J. Anim. Physiol. Anim. Nutr. 98, 901–907.
Zydney, J.M., Warner, Z., 2016. Mobile apps for science learning: review of research. Comp. Educ. 94, 1–17.
van Loon, J., Back, W., Hellebrekers, L.J., van Weeren, P.R., 2010. Application of a composite pain scale to objectively monitor horses with somatic and visceral pain under hospital conditions. J. Equine Vet. Sci. 30, 641–649.
Van Weeren, P.R., McGowan, C., Haussler, K.K., 2010. Science overview: Development of a structural and functional understanding of the equine back. Equine Vet. J. 8, 393–400.
von Borell, E., Langbein, J., Després, G., Hansen, S., Leterrier, C., Marchant-Forde, J., Marchant-Forde, R., Minero, M., Mohr, E., Prunier, A., Valance, D., Veissier, I., 2007. Heart rate variability as a measure of autonomic regulation of cardiac activity for assessing stress and welfare in farm animals—a review. Physiol. Behav. 92, 293–316.
von Peinen, K., Wiestner, T., von Rechenberg, B., Weishaupt, M.A., 2010. Relationship between saddle pressure measurements and clinical signs of saddle soreness at the withers. Equine Vet. J. 42 (Suppl. 38), 650–653.