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Animal Welfare 2017, 26: 383-397
ISSN 0962-7286
doi: 10.7120/09627286.26.4.383

What can kinematics tell us about the affective states of animals?

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Abstract

An animal's welfare state is intrinsically linked to its affective state. Evidence suggests that sentient, conscious animals can experience a range of affective states, such as pain, fear or boredom as well as positive affects like joy, curiosity, satiation or lust. In the behavioural assessment of animal welfare, there is increasing recognition that it is not simply which behaviours an animal engages in but also the quality of its movement. Kinematics is an approach which is being more widely applied to the behavioural assessment of animal welfare. Kinematics is a field of mechanics that describes the movement of points on a body by defining these points in a co-ordinate system and precisely tracking how they change in terms of space and time. A major opportunity exists for using kinematic technology to inform our understanding of the emotional state of animals. This review argues that kinematics is a useful methodology for identifying and characterising movement indicative of an animal's affective state. It demonstrates that kinematics: i) appears useful in detecting subtleties in the expression of affective states; ii) could be used in conjunction with, and add extra information to, affective tests (for example, an approach/avoidance paradigm); and iii) could potentially, eventually, be developed into an automated affective state detection system for improving the welfare of animals used in research or production. Furthering our knowledge of animal affective states using kinematics requires engagement from many areas of science outside of animal welfare, such as sports science, computer science, engineering and psychology.

Keywords: *affective state, animal welfare, emotion, gait, kinematics, posture*

Introduction

An animal's welfare state can be defined as its subjective, affective appraisal of its environment (Boissy & Lee 2014). Affective state can be influenced by particular nutritional- , environmental- or health-related factors or by an animal's (in)ability to express certain behaviours (Webster 1994; Mellor & Beausoleil 2015). Evidence suggests that sentient, conscious mammals can experience a range of affective states including, but not limited to, negative affects such as pain, thirst, hunger, breathlessness, weakness, nausea, fear, depression, boredom and helplessness as well as positive affects like joy, curiosity, satiation and lust (Yeates & Main 2008; Green & Mellor 2011; Panksepp 2011a, 2016). In order to assess an animal's welfare, it is necessary to measure external manifestations of these internal affective states through physiology (Barnett & Hemsworth 1990; Rushen 1991), neurobiology (Panksepp 2011b), behaviour (Dawkins 2004) or, ideally, a combination of these.

There is increasing recognition within animal welfare science that it is not simply *which* behaviours an animal engages in but also *how* it behaves, or the quality of its movement, that provide us with information about an animal's affective state (Wemelsfelder & Mullan 2014). Which behaviours an animal displays can be measured using ethograms (Fraser & Broom 1997; Dawkins 2003). Preference tests (Mendl *et al* 2009; Boissy & Lee 2014), open-field activity (Luerzel *et al* 2016), movements in an elevated plus maze (Hunter *et al* 2015) or approach or avoidance behaviour (Aykac *et al* 2015; Pichova *et al* 2016; Powell *et al* 2016) provide insights into an animal's underlying motivation or affect. How an animal behaves, or the emotional quality underlying their movement, has primarily been assessed using 'whole body' or qualitative behavioural assessment (Wemelsfelder *et al* 2000; Wemelsfelder 2007). Experienced producers, stockspeople, animal handlers and pet owners have an excellent ability to read the body language of their animals to get an overall impression of their affective state (Wemelsfelder 2007; Minero *et al* 2009; Walker *et al* 2010; Rutherford *et al* 2012; Camerlink *et al* 2016), despite perhaps not being able to articulate what features or characteristics of the body lead them to that impression.

Kinematics is an approach which is being more widely applied to the behavioural assessment of how an animal moves and may be able to elucidate the characteristics that define an animal's emotional expression. Kinematics is a field of mechanics that describes the movement of points on a body by defining these points in a co-ordinate system and precisely tracking how they change in terms of space and time (Beggs 1983). Kinematic assessment has been performed in a number of ways but the three most utilised methods are the following. The most basic method is to use a markerless system, where the subject is filmed using a standard digital camcorder. Points of interest are tracked by manually superimposing markers onto still images taken (digitised) from video footage and using these to calculate kinematic parameters. An alternative is to use an optical capture system in which reflective markers are adhered to the subject and tracked using a multi-camera system emitting stroboscopic radiation. Optical systems often include software to automatically calculate marker co-ordinates. Finally, kinematic variables can be obtained indirectly by the position and timing of their foot strike as the animal walks over a force-plate. Kinematic systems are therefore able to measure types of movement and the quality of that movement across time and in a precise way.

The majority of research using kinematic methods on non-human animals has characterised gait according to speed of movement, jumping over obstacles, size of the animal or described other types of movement like flight (Abourachid & Laville 1997; Beaufrere 2009; Silva *et al* 2014; Jozwiak *et al* 2014; Huera-Huarte 2016; Oxland 2016). However, a major opportunity exists for using kinematic technology to inform our understanding of the emotional state of animals. Just as neuroimaging techniques, such as functional Magnetic Resonance Imaging, have provided additional information regarding the physical basis of emotions (Ferris *et al* 2011; Lindquist *et al* 2012; Fomberstein *et al* 2013), kinematics could provide extra information regarding behavioural aspects of emotion.

The aim of this review article is to demonstrate that kinematics is a useful methodology for identifying and characterising movement indicative of an animal's affective state. It will demonstrate that kinematics: i) appears useful in detecting subtleties in the expression of affective states; and ii) could be used in conjunction with, and add extra information to, affective tests (like, for example, an approach/avoidance paradigm). Each section of the review focuses on particular affective states, namely: pain, discomfort, boredom and depression, fear and anxiety, and curiosity and joy. The review concludes with a brief discussion of the considerations when using kinematics for basic science research and the possibility of automation.

Scope of the review

This review focuses on non-human mammals, although where there is very little information available human examples will be used. The review will note how an animal expresses a particular emotion behaviourally but will focus on methods of describing how an animal expresses that emotion through posture and movement. Therefore, studies using pedometers, accelerometers or other activity-monitoring devices are not included as they do not provide information on the quality of movement. For the same reason, kinetic studies using force-related variables or pressure measurements only are also excluded, however studies where force plates were used to calculate kinematic (but not force) measurements or where kinematic methods are used alongside force plates are included.

Pain

Pain is a negative experience with both physical and emotional aspects (Bateson 1991; Barnett 1997; Allen 2004). Pain can manifest behaviourally as attempts to avoid or escape from the noxious stimulus (Allen 2004), an increase in the frequency or alteration of vocalisation (Fraser & Broom 1997), a decrease in the time spent performing normal behaviours (Olechnowicz & Jaskowski 2011) and abnormal postures or altered locomotion (Molony & Kent 1997).

Lameness is a noticeable deviation from normal gait and may be a strategy employed by an animal to reduce stimulation to a pained area of the body (Van Nuffel *et al* 2015a). Changes in locomotion may also facilitate healing and limit further tissue damage by not disrupting tissue healing (Le Bars *et al* 2001; Fitzpatrick *et al* 2006). However, it is difficult to conclusively determine if an animal with an abnormal gait (the current definition of lameness) is in pain because gait abnormalities can also result from skeletal deformities (Maas 2009) or environmental factors, such as wet flooring (Carvalho *et al* 2007; Thorup *et al* 2007). For the purposes of this review, lameness will be defined as an indirect, observable, measure of pain because the studies described use animals afflicted by painful claw lesions, induced arthritic pain or injury so it is unlikely that other factors have a significant influence on gait characteristics in these cases. Furthermore, several studies of dairy cattle (Rushen *et al* 2007; Flower *et al* 2008) and chickens (Danbury *et al* 2000; Caplen *et al* 2013) have indicated an improvement towards normal gait characteristics when non-steroidal anti-inflammatory drugs were administered, indicating that pain was the biggest contributor to gait abnormalities in these cases. A future avenue of research could be to identify differences in lameness hypothesised to be due to pain and lameness hypothesised to be due to other factors.

Lameness detection frequently relies upon the visual observation of particular postural or locomotory changes. A visual scoring system may be employed whereby an animal is assigned a score. For example, dairy cows may be scored between 0, not lame, and 3 or 5, severely lame based on the visual observation of slower walking, irregular steps, and depending on the species, arched back, lowered head and head bob (Flower *et al* 2005).

Lameness detection using kinematics correlates fairly well with visual lameness scoring methods, with studies in dairy cows reporting 42% (Pluk *et al* 2012) and even 97% (Poursaberi *et al* 2010) agreement between the measures, or 47% agreement in swine (Stavrakakis *et al* 2014). Kinematics has quantified some of the key characteristics of lameness which can be summarised as slower walking speeds, shorter strides, not lifting the legs as high when walking and more pronounced back swaying. The specifics of a lame gait, however, differ slightly between species. Lame dairy cows (Flower *et al* 2005; Blackie *et al* 2013), pigs (Mohling *et al* 2014; Stavrakakis *et al* 2014; Conte 2015), sheep (Safayi *et al* 2015), and broiler chickens (Caplen *et al* 2012) have all been identified as walking

https://doi.org/10.7120/09627286.26.4.383 Published online by Cambridge University Press

slower. Both dairy cows and chickens take shorter, more inconsistent strides (Van Nuffel *et al* 2009, 2013; Poursaberi *et al* 2010; Caplen *et al* 2012). In contrast, dogs take longer strides as well as showing greater flexion in their femorotibial joint (DeCamp 1997). Only dairy cows have been quantitatively shown to arch their backs more when lame (Poursaberi *et al* 2010). Horses differ slightly again, showing more consistency in stride length when pain is induced, possibly because they are utilising the optimum pain-reduction strategy in the form of a particular walking style (Peham *et al* 2001). Finally, pigs show a more pronounced bobbing of the head (Stavrakakis *et al* 2015a).

Further, kinematic assessment has provided extra information about the nature of a lame animal's movement that visual observation alone cannot provide. Kinematics has been able to define which characteristics contribute to the visual observation of 'irregular steps' in dairy cattle, pigs and sheep. Observations include: the hind-limb not coming fully forward to the position of where the ipsilateral fore-limb had been (Song *et al* 2008; Blackie *et al* 2011, 2013), a smaller range of elbow swing, a higher step to stride ratio (Stavrakakis *et al* 2014), less range of motion in the legs (Pluk *et al* 2012), and not lifting their legs as high (Pluym *et al* 2013; Safayi *et al* 2015). In addition, gait characteristics differ slightly depending on whether the animal is bilaterally or unilaterally lame (Weishaupt *et al* 2004; Mohling *et al* 2014). Furthermore, kinematic assessment defined how the gait of sows changed with apparent increasing pain severity. Sows which were identified visually as mildly lame had a lower swing tarsal angle, lower stance tarsal angle and a higher amplitude of swing tarsal angle, representing a stiffness in how the animal walks, whereas a higher score was associated with greater differences in weight-bearing among the legs, representing an attempt by the animal to avoid exacerbating the pain (Conte *et al* 2014). Kinematics has also been used to highlight back postural changes that had not yet been specifically identified in any clinical assessment of pain. Namely, horses displayed increased extension of the caudal thoracic back following induced unilateral back pain (Wennerstrand *et al* 2009) and demonstrated initial compensatory lateral movements in the same direction (Wennerstrand *et al* 2004).

Another visual scoring system focuses on an animal's facial expression of pain or its grimace. Coding systems for facial grimacing have been recently developed in mice (Langford *et al* 2010), rats (Sotocinal *et al* 2011), rabbits (Keating *et al* 2012), horses (Dalla Costa *et al* 2014; Diego *et al* 2016) and sheep (McLennan *et al* 2016), including lambs (Guesgen *et al* 2016a). These studies have identified changes in facial action units, such as tightening of the eyes, bulging or flattening of the cheeks, changes in the position of the ears and tension in the mouth muscles. Animals are assigned a score for each facial action unit denoting the confidence of the scorer that the action unit is present (0 being not present, 1 moderately present, 2 obviously present). Another approach describes facial expressions in detail in terms of which muscles are used to initiate the expression (Wathan *et al* 2015). These coded expressions can then be assigned to situations where the animal is hypothesised to be experiencing a particular affective state, including pain, but this is yet to be done. While kinematic techniques have been used to describe and automatically detect facial expressions in humans (Poursaberi *et al* 2012), only one study has attempted to characterise animal facial feature changes quantitatively using rudimentary, kinematic-like, techniques (Guesgen *et al* 2016a). However, the authors noted issues with keeping the camera angle consistent relative to the moving head of the animal and difficulties quantifying depth from still images taken only from one angle (the front) (Guesgen *et al* 2016a). A head-mounted, three-dimensional optical kinematic system could overcome these challenges. A kinematic approach would not only help validate the grimace scales but also provide a sensitive system to reveal fine detail as to how facial features change depending on pain severity.

Discomfort

Discomfort as an affective state has not been well-defined in the animal welfare literature or elsewhere. Instead, it simply indicates an absence of comfort and has been used interchangeably with, or to allude to, a range of affective states, such as frustration, boredom, fear, anxiety or a milder form of pain (Gogoleva *et al* 2010; Mainau & Manteca 2011; Langhoff *et al* 2016; Stumpf *et al* 2016). Despite lacking a clear definition, one of the prevailing models of animal welfare, the Five Freedoms, seeks to relieve an animal of this state (Brambell 1965; Webster 1994; McCulloch 2013). In an attempt to begin to disentangle the term 'discomfort', it can be postulated that the term has a strong component of a physical sensation associated with it, in a similar way as pain does. Pain, for example, can be described in terms of its physical components using terms, such as 'stabbing' or 'radiating' as well as its affective components, such as unpleasantness or frustration. To further this idea, 'discomfort' is often listed separately from the equally vague term 'distress', which implies more of an emotional quality and perhaps also a more severe state.

Attempts to measure discomfort have taken three routes. The first is to measure restlessness, defined as increases in activities, such as walking, standing up/lying down or eating (Kutzer *et al* 2015). However, measuring restlessness simply as an increase in activity does not take into account the nuances that are implied by the term, particularly small movements like fidgeting (Teicher 1995). In addition, restlessness in animals can be seen in a number of circumstances including states of pain, anxiety, fear, or reproductive states, such as oestrus (Walton & King 1986; Kennedy & Ingalls 1995; Roelofs *et al* 2005) and disease (Bench & Schaefer 2012). Therefore, measuring discomfort only by counting the frequency or occurrence of a particular behaviour is not useful in distinguishing between different affective states or even between affective and physical states. However, there is an inherent ability for people to recognise and distinguish between different forms of discomfort in people and other animals by the quality of the person/animal's movement (Wemelsfelder 2007; Walker *et al* 2010; Rutherford *et al*

2012). It could, therefore, be argued that restlessness may be useful for elucidating what 'discomfort' means by analysing how a restless animal moves in situations that elicit frustration, boredom or anxiety. A useful way to do so would be a combination of a qualitative approach and the quantitative approach of kinematics.

Another other way in which discomfort has been measured is in reference to a mild form of pain. As noted in the previous section, no studies to date have used kinematics to quantitatively measure subtle changes in posture or facial expression according to pain severity. Two areas that have provided some information are sickness behaviour and the gait of broiler birds of differing body sizes. Sickness behaviour may be another indicator of discomfort, in the form of mild pain, in animals. Sickness behaviour is characterised by reductions in feeding, drinking or overall activity but these behaviours in themselves do not necessarily distinguish between physical illness and feeling unwell or uncomfortable (Weary *et al* 2009). It has been proposed that sickness behaviour may be a strategy employed by the animal to increase rest and mount an immune response to fight the illness (Dantzer 2004). If this is the case, it is predicted that the expression of sickness behaviour would vary depending upon an animal's motivation for food or drink (Dantzer 2004). Motivation is likely to be experienced (felt) by the animal (Dantzer 2004) or the affective state itself may drive behaviour (Panksepp 2011b, 2016). In this way, sickness behaviour could serve as a model for assessing discomfort. Preference tests or motivation tests (such as those described in detail in Kirkden & Pajor 2006) could provide insight into discomfort by highlighting the conflict between how uncomfortable or how hungry an animal feels. Kinematics could be used in addition to such tests to characterise sickness postures such as, in pigs, the tail pressed between the legs (Noonan *et al* 1994), or a hunched sitting posture (Taylor 1999).

Both restlessness and sickness behaviour could be monitored through tracking individuals in their home environment over time using individual positioning systems (Richardson 2015). Positioning technologies can automatically measure how much or little the animal moves, if the animals are isolated from other individuals or how often they go to the feeding area. Positioning systems do so by inferring movement through differences in pixels between consecutive images (Matthews *et al* 2016) or detecting breaks in a laser beam (Richardson 2015). While useful in measuring overall activity budgets, such systems do little to inform researchers about the affective state underlying the behaviour. For example, separation from the group could be an indicator of several different affective states, including depression, anxiety or discomfort. Instead, it may be more useful to combine motivational tests with kinematic assessment to determine the quality of approach movements or sickness postures.

The rapid growth of birds with a disproportionate amount of body mass in the breast tissue has been demonstrated to lead to skeletal abnormalities (Julian 1998) and described as potentially causing 'discomfort' or pain when walking (Bokkers & Koene 2003). Kinematics has demonstrated that a commercial broiler's gait is quantitatively different to that of a smaller, less selected for, variety. Commercial broiler breeds walk extremely slowly, have a wide base of support and make large lateral motions from the centre of mass (Paxton *et al* 2013). This 'cowboy' style of walking may be either: to help the bird compensate for instability; due to skeletal characteristics and different walking styles associated with the bird strain; or potentially to alleviate any mild pain associated with bearing weight on their legs (Paxton *et al* 2013). In contrast, ancestral jungle fowl, which are smaller and do not possess the disproportionate breast muscle mass, are more agile and walk more quickly, take longer strides and spend more time 'airborne' during their walk (that is, spend less time in the standing phase of the stride) (Caplen *et al* 2012).

Finally, discomfort may manifest as a form of stiffness, brought about through regular restriction of movement as is often the case in production animals confined to cages or stalls. For example, dairy cows kept in indoor tie-stall systems walk with less flexion in their hock and elbow joints, meaning they walk with straighter, stiffer legs (Herlin & Drevemo 1997). Aside from meeting the housing criteria put forth by welfare codes of practice there is currently no animal-centric measure of discomfort due to stiffness. Since most guidelines represent minimum standards for the space needed by an animal in a production or research setting, and due to cost limitations, variations exist in how these animals are housed. Furthermore, situations arise where production animals need to stand for extended periods of time, such as during transport or waiting to be loaded onto a truck. Both scenarios may elicit a state of discomfort over time and can therefore be used to better understand how discomfort is expressed through posture or gait. Kinematics again provides an excellent tool for doing so as the expression of discomfort in the described circumstances is likely subtle and difficult to detect through visual observation alone.

Boredom and depression

The difficulty with boredom as an affective state is that it is complex, with more than one definition and source (Wemelsfelder 2005). A working definition of boredom is a state in which voluntary attention to the surroundings or task are impaired (Wemelsfelder 2005). Animals may experience boredom or depression due to barren living conditions, inability to express particular behaviours or lack of choice or agency (Wemelsfelder 2005; Mellor & Beausoleil 2015).

The only attempts to measure boredom have been through the frequency of aberrant stereotypic behaviours where the animal tries to displace or cope with its boredom by displaying patterns of movement which are unchanging and repetitive (Mason 1991; Mason & Rushen 2006; Ijichi *et al* 2013). Attention is therefore focused on the repetitive task, rather than displaying a curiosity or engagement with the environment. A range of animal species show stereotypies potentially indicative of boredom, including laboratory rats and mice (Balcombe 2006), pigs (European Commission 1997), poultry

https://doi.org/10.7120/09627286.26.4.383 Published online by Cambridge University Press

(European Commission 2000), cattle (Ninomiya 2014), wild carnivores and elephants kept in zoos (Swaisgood & Shepherdson 2005), horses (Wickens & Heleski 2010; Hothersall & Casey 2012) and dogs (Hartigan 2000).

The issue with stereotypies, as with restlessness, is that they can be indicative of a number of underlying affective states including boredom but also frustration, stress or anticipation (Mason 1991; Mason & Latham 2004; de Vere & Kuczaj 2016). In addition, a lack of stereotypic behaviour does not necessarily denote a lack of boredom as individuals with a reactive coping style may also be bored but express this as a lack of any apparent behaviour (Ijichi *et al* 2013). Therefore, stereotypies alone are not a sensitive or specific enough measure to indicate boredom. In fact, recent reviews of stereotypies warn against using measures of stereotypy frequency to indicate welfare compromise (Mason & Latham 2004), let alone any particular affective state.

Instead, it may be useful to identify instances in which an animal displays a bored posture or pattern of movement and then characterise them. It has been suggested that a bored animal may appear uncomfortable, tense and listless at the same time (Wemelsfelder 2005). By taking a qualitative approach, researchers can identify which animals appear bored based on the quality of their behavioural expression, whether they are displaying boredom actively (stereotypies) or passively (lack of movement). Kinematics can add value to such an approach by allowing researchers to precisely define and characterise which postural characteristics lend themselves to an animal being classified as bored as opposed to frustrated or stressed.

To date, no studies have used kinematics to characterise a bored posture or pattern of movement in animals. The closest approximation, based on the working definition of boredom meaning interruption of voluntary attention, would be to consider kinematic measures of attention or inattention. For example, people with Attention Deficit Hyperactivity Disorder display a greater range of motion in the head, elbow and trunk areas when fidgeting while seated (Teicher *et al* 1996). This may be similar to a proactive coping style for boredom in animals. Another approach may be to track eye movement to measure engagement or interest in the environment, with less interest in the environment (anhedonia) potentially indicating boredom or sickness behaviour. In a study of people undertaking a computer-learning task, bored individuals fixated their eyes on fewer points in the environment, stared at an area outside that of interest and had a smaller pupil diameter than interested individuals (Charoenpit & Ohkura 2014).

Long term, boredom may develop into depression or a sense of helplessness (Sommers & Vodanovich 2000) where the animal appears to sit motionlessly with limbs bent abnormally or splayed and a drooping head (Beattie *et al* 2000; Wemelsfelder 2005). One study has described the posture of horses displaying depressive behaviour as a flattened back, where the angle between the withers, nape and back is approximately 180°, and an outstretched neck (Fureix *et al* 2012). Depressed horses were found also to close their eyes partially or fully, even when not resting (Fureix *et al* 2012). Depression may also be expressed in the way an animal walks. For example, people who are clinically depressed exhibit a slouched back and shoulders, a less-pronounced head bob, slow walking speed and less arm swing when walking (Michalak *et al* 2009). Boredom and depression could be described as 'low' affective states whose expression is more subtle than a state like pain. The detection and measurement of affective states without an obvious behavioural ethogram is difficult but kinematics may be able to elucidate the biomechanical or postural properties that underlie the expression of boredom and depression.

Fear and anxiety

Fear is a short-lived affective state prompted by a stimulus which is perceived as, or actually, imminently threatening (Davis *et al* 2010). In contrast, anxiety can be defined as a generalised, longer-lasting fearful state or mood where the animal is apprehensive about a potential threat in the future (Davis *et al* 2010). Instances when animals may experience fear include: in the presence of a predator (Clinchy *et al* 2013; Silva *et al* 2013), when challenged with a novel situation (Dalmau *et al* 2009; Richard *et al* 2010) or when handled (for example, during routine husbandry) (Rushen *et al* 1999). Anxiety may be experienced, particularly with production or companion animals, due to a poor relationship with a stocksperson or owner (Hemsworth 2003; Boissy *et al* 2005) or sub-optimal housing conditions (Carter *et al* 2011).

The typical behavioural response to fear for most mammals is either to flee (Stankowich & Blumstein 2005), to avoid the fearful stimulus, or to freeze (Davis *et al* 2010), to avoid detection. Behavioural testing of fear often involves subjecting the animal to a short, aversive event, such as a foot shock, and recording the presence or absence of a startle or freezing response (Davis *et al* 2010; Daldrup *et al* 2015). Interestingly, freezing in dogs and pigs can also mean that they want to play (Norman *et al* 2015; Pellis & Pellis 2016) but obviously the nature of a 'play freeze' and a fearful freeze differ qualitatively. A frozen posture in rodents and dogs, for example, has been described (but not characterised biomechanically) as tension in the body (Hagenaars *et al* 2014) where the tail may be tucked and ears lying flat (Tami & Gallagher 2009). Fearful cows also lay their ears flat on their head, clamp their tail between their hind legs and have their eyes open more widely than non-fearful ones (Kutzer *et al* 2015). The fear characteristics identified could aid in the detection, and mitigation, of fear in animals, either visually or through an automated system. Practically, for example, fear detection systems could be installed in live animal transport vehicles, in housing enclosures for production, zoo or laboratory animals, or in the home when a companion animal owner is at work. Automated detection would also aid in research by mitigating biases from the experimenter being present during fear (or any affective state) testing and observation (Tuyttens *et al* 2014). Practically, automated detection could alert a person that an animal is in a fearful state, allowing the person to intervene. Such technology could be of benefit on-farm, in veterinary clinics or shelters or as part of a research environment.

Behavioural assessment of anxiety in animals typically involves tests of open-field activity (Aykac *et al* 2015; Pichova *et al* 2016), movements in an elevated plus maze (Korte & De Boer 2003; Hunter *et al* 2015) or approach or avoidance behaviour (Luerzel *et al* 2016; Powell *et al* 2016). Elevated maze tests measure the time taken for an animal (mostly rodents) to enter, as well as time spent exploring, the open (threatening) area of a maze. Researchers may also record the frequency of a behaviour known as the stretch-attend posture, which involves the rodent dipping its head, lowering its back and elongating its body, either while stationary or moving forward slowly in a maze (Grant & Mackintosh 1963; Molewijk *et al* 1995). One study has attempted to roughly characterise and automate the detection of this posture by fitting an ellipse to the image of a mouse (Holly *et al* 2016). A more elongated ellipse denotes the stretch-attend posture (Holly *et al* 2016). However, this system was still only designed to count the frequency of the behaviour. Elevated maze tests are generally robust but have been shown to be inconsistent or even contradictory at times, with the frequency of stretch-attend postures not corresponding with inferred anxiety (Hogg 1996; Ennaceur 2014). Furthermore, trepidation to enter the open areas of a maze may not actually be reflective of anxiety but rather a natural preference by the animal to avoid a threatening stimulus (Ennaceur 2014). It has been difficult to determine whether rodents still experience anxiety in the protected areas of the maze due to the uncertainty and the motivational conflict between avoiding and exploring the open areas (Ennaceur 2014). Therefore, kinematics could provide extra information about the specifics of how rodents, or other species, move to potentially remedy these inconsistencies. It may be that the nature, for example, the angle of the rodent's head relative to its back or the length by which the spine elongates, rather than the frequency, of the stretch-attend posture better reflects the strength of the anxiety experience.

Similarly, approach/avoidance tests ultimately rely on whether the animal approaches a stimulus or not, but researchers have had difficulty interpreting circumstances where the animal does approach but only tentatively, taking longer to do so. There may be subtle behavioural clues in how the animal moves, in terms of gait, as it approaches a stimulus that could be elucidated by kinematic assessment. In other words, kinematics could characterise the apprehension in an animal's gait. In human cases, for example, anxious individuals walk more slowly (Martens *et al* 2015; Cleworth *et al* 2016) and take shorter strides (Martens *et al* 2015) than non-anxious ones.

As a final note, due to the issues surrounding standard tests of anxiety, and their predominant use only with rodent species, it may be useful to consider other instances where anxiety may occur and characterise the behaviour of an animal in those circumstances. For example, separation anxiety is a common issue with dogs (Storengen *et al* 2014). The behavioural quality of the dog prior to separation could be described using kinematics in a controlled setting. This could have welfare implications for better recognising anxious individuals in, for example, a shelter setting.

Joy and curiosity

As well as negative affective states, there is growing neurobiological and behavioural evidence that mammals experience positive affective states, such as joy or curiosity (Panksepp 2011a, 2016). Unlike negative affects, such as fear, it has so far been difficult to determine a physiological marker, in terms of hormones or a change in heart rate, associated with positive affects (Yeates & Main 2008). Predominantly, this is due to positive emotional states not usually being characterised by high levels of arousal, making them difficult to differentiate from one another (Fredrickson 1998). Therefore, use of behavioural assessment is even more crucial to measures of positive states.

Positive welfare states are characterised by an animal engaging actively and energetically with things that are intrinsically rewarding (Yeates & Main 2008; Mellor 2015a; Mellor & Beausoleil 2015). Curiosity can be defined as an animal's agency or how motivated it is to engage with a particular environment or stimulus (Byrne 2013). Joy, therefore, is the accompanying, or following, emotional experience fulfilling that motivation (Berridge & Robinson 2003). Animals may experience curiosity and joy during exploration of their environment, food-seeking, bonding with offspring, during play with conspecifics or during sexual behaviour (Mellor 2015b).

The display of play behaviour (Sarti Oliveira *et al* 2010; Sutherland *et al* 2014; Anderson *et al* 2015; Jensen *et al* 2015; Vicino & Marcacci 2015), anticipation behaviour (Vinke *et al* 2004; Hansen & Jeppesen 2006; Peters *et al* 2012) and cognitive/judgement bias tests (Bethell & Koyama 2015; Baciadonna *et al* 2016; Deakin *et al* 2016; Graulich *et al* 2016; Schino *et al* 2016) are the main behavioural assessment methods that have been explored as a way to assess positive affect, potentially indicative of joy. The approach/avoidance paradigm has been indicated as a potential way to assess curiosity (Yeates & Main 2008; Byrne 2013).

Kinematics may be a useful tool to supplement other behavioural assessment methods, like cognitive bias tests or measures of anticipation behaviour, and potentially differentiate between different positive affective states. Anticipation behaviour has mostly been defined as an increase in activity, however, one study described (but did not quantify the quality of) anticipation joy in dogs as their heads held high, wide open and 'bright' eyes, ears upright, tail wagging and mouth open. To help identify anticipation postures, it is possible to shift the timing of known events, such as feeding in a zoo environment, which may 'leave behind' anticipatory cues as distinct from other behaviours which may occur due to time of day (Watters 2014). As these cues may be subtle, the animal could be recorded, using kinematics, and their behaviour and posture from their usual time compared to the new time (Watters 2014).

The approach/avoidance paradigm is used both for testing anxiety and curiosity and, as noted previously, relies on a binary measurement of 'go/no go' (approach or not) which can be ambiguous and difficult to interpret (Carreras *et al* 2015). Again, the way an animal approaches or avoids a

https://doi.org/10.7120/09627286.26.4.383 Published online by Cambridge University Press

stimulus is crucial. It may be the case that positively valanced animals not only approach more quickly but also take longer, more relaxed strides (Venture *et al* 2014) or have a more relaxed spinal posture.

Some studies have tried, experimentally, to elicit positive emotions through positive tactile contact like stroking of anxious shelter cats (Gourkow *et al* 2014) or tickling of rats (Ishiyama & Brecht 2016). One of the major issues with studying joy experimentally is that it is difficult to determine which stimuli an individual finds rewarding (de Vere & Kuczaj 2016). In addition, the administration of a rewarding stimulus (such as grooming) often requires human presence which can counteract some of the reward if the animal is timid or fearful (Tuyttens *et al* 2014).

Instead of trying to induce a positive state in an animal, another approach may be to characterise an animal's movement or posture as they engage naturally, in their own time, and through their own motivation with different aspects of their home environment. Examples include mechanical brushes in a dairy environment or toys in a zoo or laboratory enclosure. Furthermore, cattle, goats, horses and sheep have strong motivation to graze and forage (Mellor 2015a). Research could therefore compare the posture of a cow while actively engaging in grazing on pasture to a cow kept in an indoor intensive system that is simply presented with its food.

Finally, it has been suggested that animals display facial expressions indicative of positive emotion (Yeates & Main 2008; Montag & Panksepp 2016). To date, only one study has described and characterised a joyful facial expression in rats, using kinematic-like techniques. Finlayson *et al* (2016) found that rats' ear colour was scored as significantly pinker by observers after the rat had received a positive tickling treatment than after a somewhat aversive white noise treatment. The authors also measured quantitative changes in ear angle, with a positive treatment being associated with the ears held more forward and outward (wider ear angle) (Finlayson *et al* 2016). However, the study was unable to identify any other facial features indicative of positive emotion in rats. This may be because images used in analyses were taken after the tickling treatment had occurred, rather than during, due to the difficulty associated with taking quality facial images of a moving animal. In contrast, studies investigating grimacing due to pain take images during the painful experience. An improvement may be to utilise the novel tickling treatment described in Finlayson *et al* (2016) and hold the rat up near a high-speed video camera during the positive treatment. A higher frame capture rate of 80 to 100 fps may be able to compensate for the movement of the animal. In addition, by marking specific points on the face, kinematics could be used to detect subtle facial feature changes better than later trying to superimpose markings on the captured images. The alternative, as mentioned previously, could be to develop a head-mounted camera system to stabilise the face relative to any body movement, however this may be better suited to larger species. Other studies allude to the possibility of joyful facial expressions in other species. Cows in a positive emotional state, as elicited by being brushed, showed less eye white (Proctor & Carder 2015) than when they were not being brushed. Similarly, in horses, the angle between a line drawn through the eyeball and the highest wrinkle above the eye (as perceived by visual observation alone) decreased during grooming (Hintze *et al* 2016). Several studies have also noted that sheep, cows and horses in a low arousal or positive state spend more time with their ears in a forward or relaxed position instead of an upright one (Reefmann *et al* 2009; Stubsjoen *et al* 2009; Veissier *et al* 2009; Boissy *et al* 2011; Vögeli *et al* 2014; Guesgen *et al* 2016b).

General discussion: Kinematics for basic science research and the possibility of automation

There is increasing acceptance and uptake of integrating sensors or technologies into farming systems to measure and alert producers of changes in the health status of individuals (Rutten *et al* 2013; Dela Rue *et al* 2014; Diosdado *et al* 2015; Gaspardy *et al* 2015). In the future, it may become possible to automate the process of detecting affective states for research purposes or allow producers, animal handlers or veterinarians to get alerts related to the emotion of their animals (be it discomfort, anxiousness, boredom, depression or joy) and make adjustments to their management accordingly. However, using kinematic technology to supplement existing tests of affective states in animals is likely the best use of kinematic technology at the current time for two reasons: i) a lack of baseline information regarding a variety of affective states in animals; and ii) practical considerations when using the technology and feasibility (or lack thereof) of automation.

Few studies exist which attempt to address the experience and expression of boredom, depression, frustration, joy or curiosity in mammals. In particular, there is little information on livestock species which may experience a range of affective states weekly or even daily as a result of housing or handling. Additionally, literature precisely describing and quantifying the nature of affective behavioural expressions is scarce. Therefore, it is vital to gather quality, descriptive, quantitative baseline data regarding affective states in a controlled, experimental environment. To do so, however, first requires defining each affective state in a testable, non-species-specific manner, through frameworks such as the Five Domains (Mellor & Beausoleil 2015; Mellor 2016).

Previous studies have provided 'clues' as to the behaviours or postures which may be associated with particular affective states, such as a hunched posture for depression (Fureix *et al* 2012) or a relaxed facial expression for joy (Finlayson *et al* 2016). The next step in understanding, and differentiating between, affective states is to deconstruct these overt, or 'macro' behaviours, into their more subtle ('micro' behavioural) components. This approach is particularly useful in livestock species or other prey animals which may not display overt behavioural indicators of emotion (Williams 2002). Doing so not only informs our understanding of affective states but could also provide insight, from an animal communication perspective, into the cues or signals animals employ to convey their experience to other conspecifics (Mateo 1996; Craig 2009).

As with any study of affective state, researchers need to have a way to ensure that the behaviour (be it macro- or micro-) that they are seeing can be confidently related to a particular affect. Ultimately, the subjective ('feeling') aspects of affective states can only be inferred by measuring other, observable, components, such as behaviour, physiology or neuro-images (Beausoleil *et al* 2016). This method relies on the educated assumption, based on evolutionary history, shared anatomy and similar responses to particular situations, that animals feel affective states (Beausoleil *et al* 2016). While animals cannot verbally self-report the subjective ('feeling') aspect of emotions they can, to some extent, self-report through behaviour. In a very basic sense, animals will continue to engage or seek out activities which give them pleasure and avoid or try to alleviate situations which cause them to experience negative emotion (Green & Mellor 2011; Hemsworth *et al* 2014). Pharmacological agents could be used to elucidate these motivations, for example, by providing drinkers for animals to self-administer NSAIDs to alleviate pain (Caplen *et al* 2013). Another approach is to validate new postures or behaviours against ones which have been previously identified as indicating an affective state, such the ultrasonic vocalisations produced by joyful rats (Finlayson *et al* 2016; Ishiyama & Brecht 2016). It may also be possible to elicit affective behavioural responses through deep brain stimulation, if the areas associated with a particular emotion are known (Panksepp 2005; Ishiyama & Brecht 2016).

The possibility of automation

Automated optical systems are being currently developed and tested for the detection of lameness pain. Attempts to create a lameness detection system for dairy cows have been fairly effective with detection rates reaching 94.8% using the kinematic gait parameter of trackway overlap (Song *et al* 2008); up to 90% using a combination of ten gait variables, such as stride length or stance time (Maertens *et al* 2011); 88% when taking individual gait inconsistencies into account alongside these ten gait variables (Van Nuffel *et al* 2015b); and between 83 (Viazzi *et al* 2013) and 90.9% (Van Hertem *et al* 2014) using back posture.

Practically, however, kinematic technology is still labour intensive, costly and complex. A more in-depth review about the practicalities of automated dairy cow lameness detection can be found in Van Nuffel *et al* (2015c), however, the key issues, as they pertain to kinematics, are outlined here. Most cow lameness detection systems which are highly sensitive and accurate still require manual extraction or labelling of still images collected from video footage (Song *et al* 2008; Maertens *et al* 2011), or require manual identification of individuals (Van Hertem *et al* 2014) and therefore cannot be considered fully automated at this stage. In cases where detection is nearly, or fully, automated, it is still difficult for most systems to distinguish between non-lame and mildly lame individuals (Van Nuffel *et al* 2015b). Detecting early signs of lameness pain is crucial in order to minimise welfare compromise. Several authors also acknowledge that environmental variables (flooring type or lighting), physiological (udder fill) or reproductive variables (gestation stage and lactation stage) influence gait characteristics and therefore lameness (due to pain) detection validity (Maertens *et al* 2011). It may be possible to integrate these variables into kinematic algorithms to increase the sensitivity of cow lameness detection (Van Nuffel *et al* 2016), but this first requires a detailed understanding, and investigation of, how other parameters affect gait. In terms of set-up in the barn environment, using floor plates or 3D cameras mounted overhead is practically feasible as such systems can be integrated above runways leading to an automatic milking system or feed area. However, the quality of information gained from such systems can be easily compromised by excessive cow traffic, animals getting scared or distracted and stopping (Maertens *et al* 2011; Mohling *et al* 2014), low lighting situations, or a small field of camera view (Viazzi *et al* 2014). Finally, the majority of research around automation of kinematics has focused on dairy cows and a few on sows (Mohling *et al* 2014; Stavrakakis *et al* 2015b). Automation of pain or discomfort measurement in sick rats is limited to general activity monitoring through automated individual positioning systems (Richardson 2015).

Therefore, we are currently lacking even the most baseline information needed to create any kind of automated system for pain detection in species other than dairy cows or sows, or detection systems for any other affective state described previously in this review. The only way for automated affective state detection to come to fruition is to develop basic kinematic methodologies better, to continue to utilise kinematics to better our understanding of animal affective states under controlled laboratory conditions, and simultaneously improve, and learn from, an automated dairy cow lameness pain detection system.

Animal welfare implications

There is a shift in animal welfare science towards defining, developing tests for, and assessing positive welfare states in mammals. In addition, little is known about an animal's subjective experience of boredom or frustration. Kinematic assessment is a tool which could be used in conjunction with tests of preference or motivation, or to precisely deconstruct subtle behaviours, such as facial expressions or postures. In this way, it provides an avenue to gather much-needed baseline information about the expression of affective states. Since an animal's subjective experience of its environment is intrinsic to its welfare, we cannot begin to get a full picture of animal welfare without exploring the breadth of emotions animals can experience. Once it is possible to accurately recognise an animal's affective state, it will allow researchers to identify and modify aspects of the animal's environment to not only create a state of neutral, but one of positive, welfare.

Conclusion

The information gained from using a kinematic approach to assess animal affect through behaviour could be valuable in three key ways. Firstly, it offers a way to measure, in a more precise way, subtleties in behaviour which other methods may overlook or offer supplementary information where these methods provide inconsistent or ambiguous answers. Secondly, kinematics may be better suited to detecting 'low' affective states. Finally, such information could be eventually collected remotely, following the development of an automated welfare detection system both for research and for animal care on-farm or in-lab. This requires engagement from many areas of science outside of animal welfare, such as sport and movement science, computer science, engineering and psychology. We, therefore, encourage the active discussion and utilisation of kinematic assessment.

Acknowledgements

We would like to thank the Natural Sciences and Engineering Research Council of Canada (NSERC) for providing Discovery funding to evaluate the use of micro-behaviour biometrics and kinematics as part of automated technology platforms in livestock.

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