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Automated monitoring of behavioural-based animal welfare indicators

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Abstract

On-farm scoring of behavioural indicators of animal welfare is challenging but the increasing availability of low cost technology now makes automated monitoring of animal behaviour feasible. We discuss some of the issues with using automated methods to measure animal behaviour within the context of assessing animal welfare. Automated feeders (eg for dairy calves) can help measure the degree that animals are hungry and have potential to identify sick animals even in group housing. Such equipment is best used for longitudinal studies of individual animals rather than making comparisons between farms. Devices attached to animals (eg accelerometers or GPS devices) can help measure the activity levels of animals with a high degree of accuracy and can easily be transported between farms, making them best suited for welfare assessment at the group level. Automated image analysis has great potential to assess movement within groups of animals, but following individual animals can be difficult. The techniques have been validated against traditional methods (eg direct observation). The accuracy of measures taken automatically varies between methods but can be increased by combining measures. Technological developments have provided us with a variety of tools that can be used to monitor behaviour automatically, and these have great potential to improve our ability to monitor animal welfare indicators on-farm. However, it is important that methods be developed to measure a wider range of behaviour patterns. Animal welfare assessment schemes should not place undue emphasis on behavioural indicators solely on the basis that they can be monitored automatically.

Keywords: *animal behaviour, animal welfare, automated monitoring, behavioural indicators, farm animals, on-farm assessment*

Introduction

An article search, using the words 'automation' or 'automatic' and 'animal welfare' reveals that the number of scientific articles using these words increased from 5 in 1997 to 80 in 2010. It is clear that the implications of farm automation for animal welfare are being recognised, including the potential of automation to monitor animal welfare. At its simplest, automated assessment of animal welfare involves using automation to take measures on some aspect of an animal, which a human then interprets in terms relevant to animal welfare; for example, using machines to measure the activity of an animal, which a person then uses to decide whether the animal is lame. In addition, computer algorithms are being developed to make higher order inferences from data collected automatically, eg judging whether an animal is lame or not. In this paper, we focus on using automated methods of measuring animal behaviour. We do not deal intensively with the technical aspects of the equipment available, nor do we attempt a comprehensive review of all of the uses to which automation has been put. Instead, we focus upon some of the issues in using automation to increase the use of on-farm behavioural recording in the context of assessing animal welfare at both the level of the individual animals and at the farm and group level. We include self-assessments of animal welfare carried out by farmers themselves as well as third-party audits.

Why automate? Most recent analyses of the concept of animal welfare accept that behavioural issues are a key aspect. This is apparent in the Five Freedoms (www.fawc.org.uk/freedoms.htm), which include the 'freedom' to perform most normal patterns of behaviour. Furthermore, behavioural measures, such as the occurrence of aggression or stereotypic behaviour, are important indicators of welfare problems. Including behavioural-based welfare criteria is, therefore, essential for an overall welfare assessment (Blokhuis *et al* 2010). Despite this, current on-farm welfare assessment schemes often focus heavily on health issues and include few behavioural measures. We suggest that this is due mainly to the difficulty, time involved and cost in taking behavioural measures during farm visits (Edwards 2007; Sørensen *et al* 2007); the occurrence of behaviour patterns is often erratic over time or else their recording requires long periods of observation, while on-farm assessments need to be done in a short period of time (Edwards 2007; Webster 2009). These problems are likely to increase as farm size increases. The availability of equipment which can measure the behaviour of animals automatically may help resolve this problem (Blokhuis *et al* 2010).

Another reason is that automation may prove superior to people at measuring some behaviours. On-farm welfare assessment requires that we minimise differences between observers (Edwards 2007; Webster 2009) but behavioural measures can be challenging to take reliably and this requires considerable training of observers. This is evident, for example, with gait scoring of animals to detect lameness (Butterworth *et al* 2007; Flower & Weary 2009). While observers can see some gait changes associated with lameness, other changes, which can be detected with the appropriate equipment, are much harder to observe (eg van Nuffel *et al* 2009). The practical difficulties in detecting lameness in cattle on-farm are well known, with farmers repeatedly being shown to substantially underestimate the number of lame cows on their farms (eg Espejo *et al* 2006). Hopefully, increased use of automation to record behaviour patterns will result in more reliable measures being taken. Finally, assessments done by people tend to provide only a snapshot of the state of welfare on the farm at a particular time-point (Webster 2009). Use of automation may allow longer term monitoring of the animals' behaviour.

The main types of automation that we consider are the use of equipment that is installed on farms, devices that can be attached temporarily to animals, and the use of computer vision and computer 'hearing'.

On-farm automation

Computer-controlled feeders, which recognise individual animals, usually by means of radio frequency identification (RFID), are increasingly being used in the dairy, beef and swine industries and can automatically record aspects of feeding behaviour. Data from such feeders can help identify problems associated with hunger and may help detect animals that are sick.

The absence of hunger is one of the least controversial of the 'Five Freedoms' as an aspect of good animal welfare. Nevertheless, some commonly used management practices do result in farm animals being hungry for varying periods of time (D'Eath *et al* 2009), and some method of assessing the degree of hunger felt by animals would be valuable. For example, a controversial issue in the raising of dairy calves involves how much milk to feed unweaned calves and the best age to wean them off milk. It is common for calves to be fed milk or milk replacer in quantities which are substantially lower than the amount they drink when allowed free access (Khan *et al* 2011). In addition, calves may be weaned off milk at an early age and have difficulty adapting to solid feed. Calves fed these low amounts of milk visit automated milk feeders far more often, and these are usually unrewarded visits during which milk is not available (eg Jensen & Holm 2003; De Paula Vieira *et al* 2008; Borderas *et al* 2009a). Unrewarded visits also increase when animals are being weaned and there is a negative correlation between energy intake and the frequency of visits to the milk feeders (de Passillé *et al* 2011) (Figure 1). Thus, automatic monitoring of the frequency of unrewarded visits to milk feeders that calves make can detect periods when the calves are hungry due to inadequate feeding and can identify individual animals that are having difficulty adapting to post-weaning diets.

Farm animals are increasingly being housed in groups but a potential disadvantage of group housing is that illness is harder to detect. Changes in feeding behaviour of animals can be used to identify animals that are sick (Millman 2007; Weary *et al* 2009) and these can be detected automatically. Early research with beef cattle feeding from specialised feeders showed that drops in feed intake or time spent feeding could accurately identify steers suffering from respiratory disease substantially earlier than the normal inspections (Quimby 2000). Automatically recorded changes in feeding behaviour can also help identify dairy cows suffering from peri-parturient diseases such as metritis, ketosis or lameness (Huzzey *et al* 2007; Gonzalez *et al* 2008; Proudfoot *et al* 2010) (Figure 2) and dairy calves suffering from a variety of illnesses (Svensson & Jensen 2007; Borderas *et al* 2009b). Electronic sow feeders also have the potential to be used this way (Cornou *et al* 2008). In addition, changes in drinking behaviour and water intake, monitored automatically, may also be useful to identify sick animals (Madsen & Kristensen 2005; Lukas *et al* 2008; Kruse *et al* 2011).

Automated feeders are not the only on-farm equipment that can be used in this way. Automated milking systems for dairy cattle automatically collect data on the milking of dairy cows and have potential for monitoring poor health. For example, lameness in dairy cows is apparent in a reduced frequency of visits to the robot (Bach *et al* 2007; Borderas *et al* 2008), although this appears to have low specificity as many other low attending cows are not lame (Borderas *et al* 2008).

Use of force plates to measure the weight animals place on their feet when walking can detect gait abnormalities in poultry (Corr *et al* 2007; Sandilands *et al* 2011). A force-plate system for measuring the force that cows exert when walking is commercially available (Rajkondawar *et al* 2006) and been installed in some dairies but the sensitivity of the measure for detecting lameness is low (Bicalho *et al* 2007) perhaps because the time when the force is exerted is very short. Measuring weight distribution when the animals are standing still is easier and can detect lame cows (Rushen *et al* 2007; Chapinal *et al* 2010; Pastell *et al* 2010). Research with weigh scales installed in automated milking systems showed that automated measures of weight distribution could identify lame cows significantly faster than was achieved through routine veterinary inspection (Pastell & Kujala 2007). Furthermore, these measures of weight distribution are sensitive to the degree of pain associated with the lameness (Rushen *et al* 2007; Chapinal *et al* 2010).

Advantages and disadvantages

Using data from equipment that is already installed on the farm is relatively cheap since the only costs for using these in welfare assessment are those associated with data extraction and manipulation. A disadvantage is that the data most likely belong to the farmer and so there may be issues in

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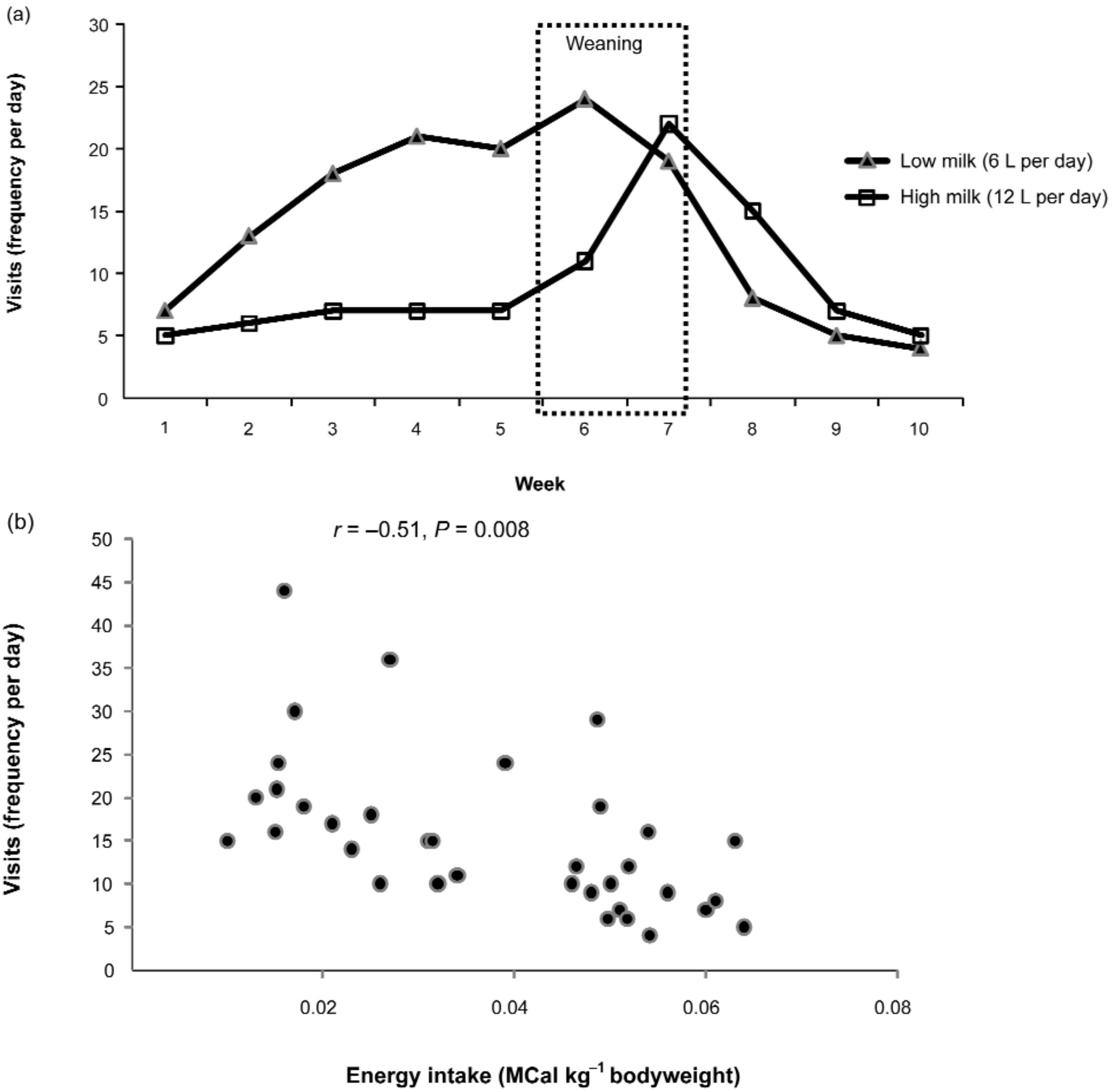
Figure 1



The (a) mean daily frequency of visits to the milk feeder of dairy calves fed either 6 L per day of milk (black triangles) or 12 L per day of milk (open squares) at each week of age, including during the 10-day weaning period and b) mean daily frequency of visits to the milk feeder and the man daily intake of digestible energy of dairy calves during the weaning period. Figures redrawn from data presented in de Passillé *et al* (2011).

using these data for third-party audits. However, the information is very useful for farmers who wish to improve the welfare of animals on their farms. An important disadvantage is that, at present, most automated equipment involves feeders, so there is less opportunity to record other forms of behaviour in this way.

With RFID, this type of equipment can recognise individual animals, and is most suited for longitudinal monitoring of individuals, in real time if necessary, where data on each animal can be accumulated over relatively long periods of time (eg Pastell & Kujala 2007). Although force-plates could, in principle, be transported between farms, most such equipment cannot be. Since not all farms would have the same equipment, and those that do may not manage it in the same way, there are limits on our ability to make comparisons between farms. Thus, the equipment is less useful for animal welfare assessment at the group level than at the individual level.

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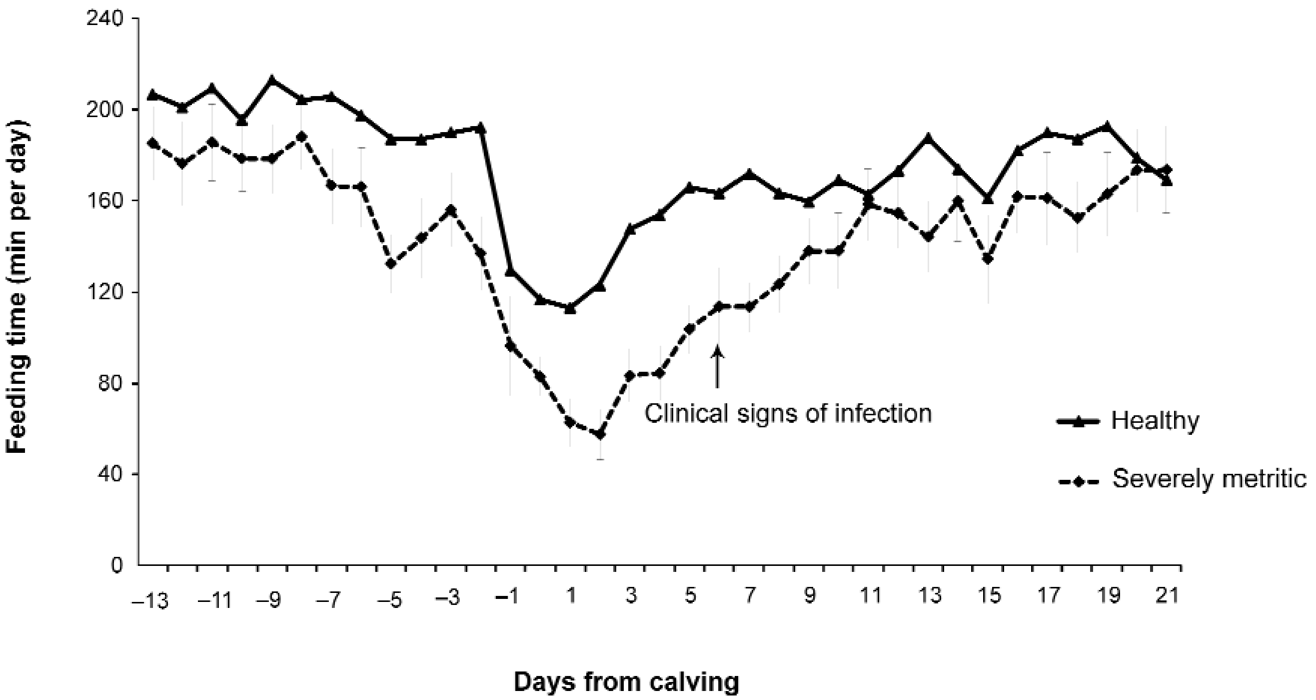
Figure 2



Mean daily time spent feeding at each day before and after calving (day 0) of dairy cows that were detected as suffering from severe metritis or which remained free of metritis after calving. The vertical arrow shows the average time at which clinical signs of metritis were present. Figure redrawn from data presented in Huzzey *et al* (2007).

Devices attached to the animals

The second category of automation consists of devices that can be attached temporarily to the animals specifically for monitoring their behaviour. These are most commonly accelerometers, but other devices such as pedometers, simple tilt switch devices or GPS devices have also been used.

The amount of time that dairy cows spend standing up or lying down each day is an important measure of their welfare, since short lying times are a reflection of inadequate stalls and can lead to increased risk of lameness (Rushen *et al* 2008). The time that cows spend lying down can be measured by watching video, but obtaining a reliable estimate in this way requires a considerable amount of labour, and is quite impractical for on-farm visits. A number of relatively cheap, small and accurate electronic devices are now available that can be used to measure time spent standing and lying (Ledgerwood *et al* 2010).

Accelerometers or tilt switch activated devices can be attached to the legs of cattle and can measure the orientation of the leg, with the assumption that when the leg is horizontal, the animal is most likely lying down. Such devices have recently been shown to be useful for on-farm measurements. For example, Ito *et al* (2009, 2010) attached accelerometers to over 2,000 cows on 43 Canadian dairy farms and measured the time the cows lay down over five days. The results showed variation between and within farms in the average time that the cows lay down each day (Figure 3). The average lying time was longer for lame cows, suggesting that unusually long average lying times on a farm may be indicative of a high prevalence of lameness.

Accelerometers attached to the legs can also measure the pattern of acceleration associated with stepping (de Passillé *et al* 2010; Ringgenberg *et al* 2010; Tanida *et al* 2011; Figure 4). At the simplest level, this provides a measure of the number of steps taken by an animal, and commercial devices (eg IceTag® from Ice Robotics Inc, Edinburgh, UK) are now available to do this. Step counting has been used to detect lameness in dairy cows (Chapinal *et al* 2010), to assess the adequacy of different flooring surfaces (Ouweltjes *et al* 2011) and to assess the effects of changing flooring in barns (Platz *et al* 2008). Accelerometers may also allow automated gait scoring: one of the most obvious signs of lameness is asymmetric stepping (Flower & Weary 2009) where there is a difference within a pair of legs in the speed or duration of a stride. Accelerometers attached to two legs can measure differences between the legs in the variance of acceleration and this is correlated with subjective assessment of asymmetric stepping (Chapinal *et al* 2011). Accelerometers attached to any part of a cow's body can estimate walking speed (Chapinal *et al* 2011). Measures of acceleration can distinguish different gait types in dairy calves and can help detect play running (de Passille *et al* 2010; Figure 4).

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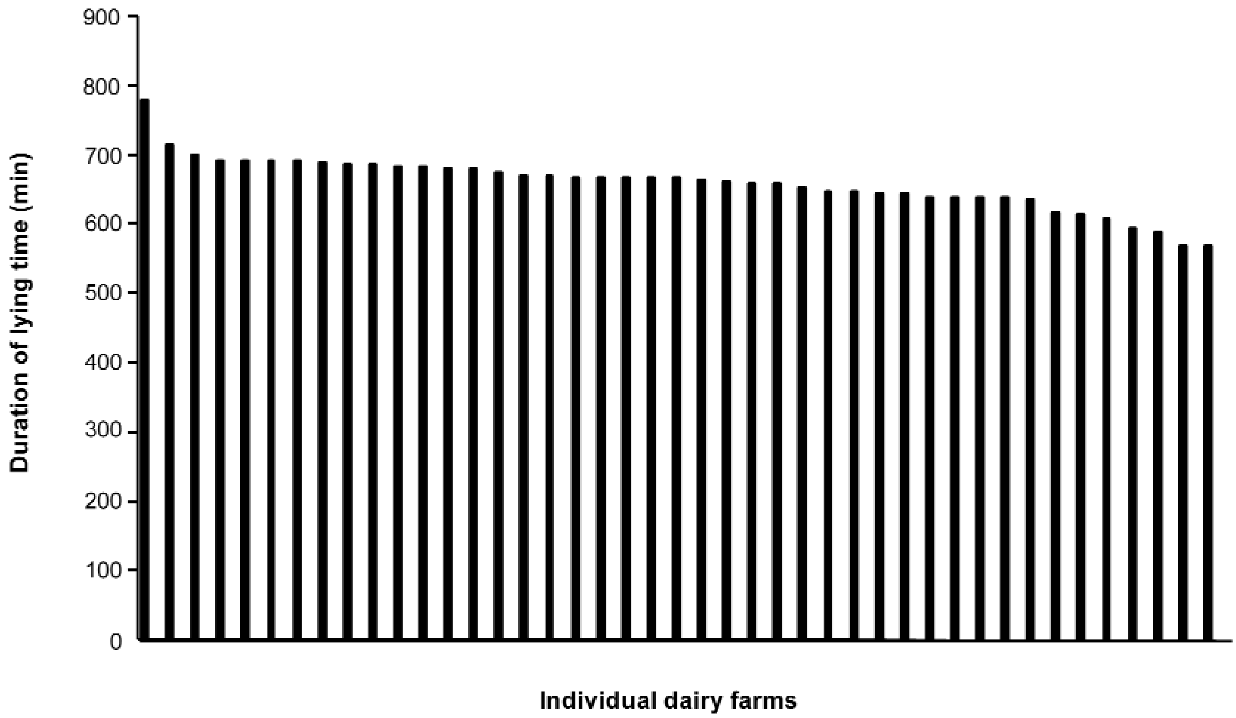
Figure 3



Mean daily duration of time spent lying down, as measured by accelerometers, of lactating dairy cows on individual Canadian dairy farms. Figure redrawn from data presented in Ito *et al* (2009).

Figure 4

Measure of acceleration in vertical direction of dairy calves' legs when calves were walking (upper panel) or galloping (lower panel). Individual steps can clearly be seen. Figure redrawn from data presented in de Passillé *et al* (2010).

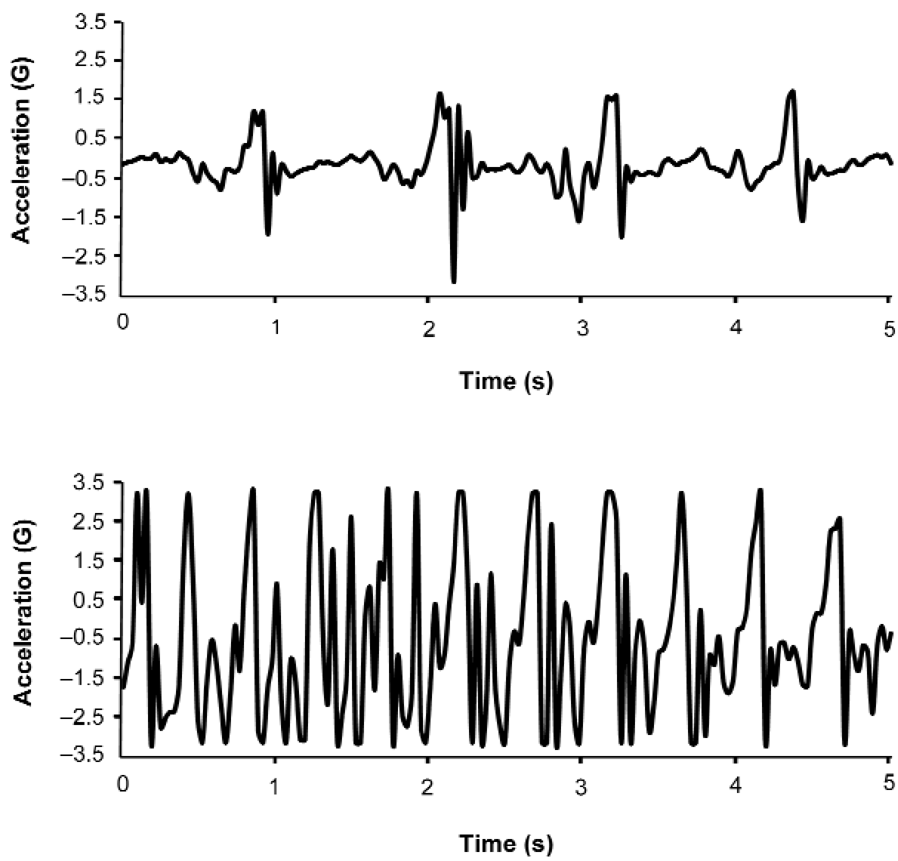


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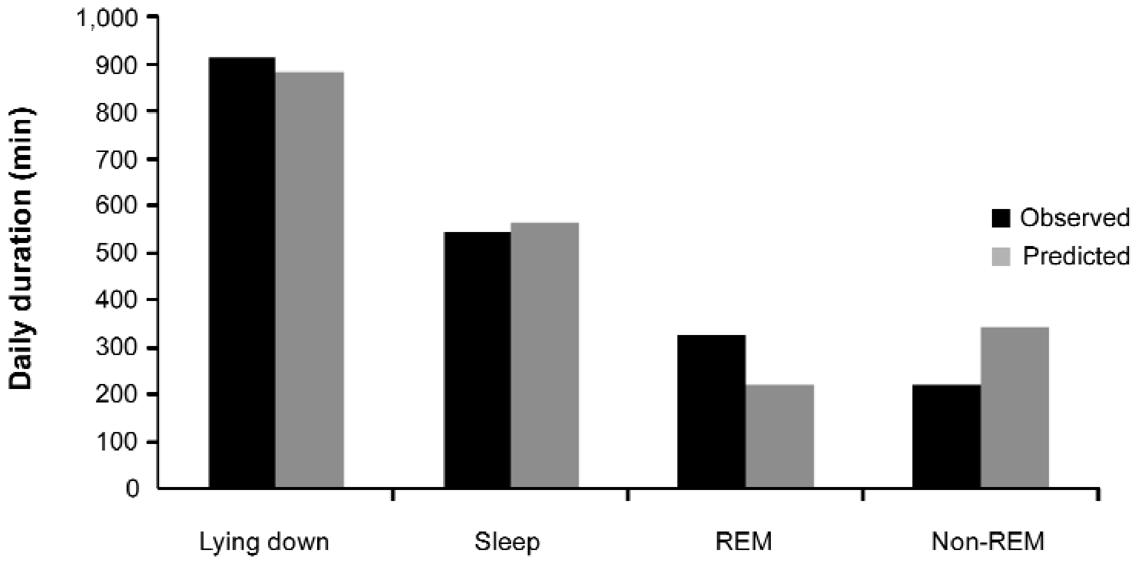
Figure 5



Amount of time that calves spent lying down, sleeping, in rapid eye movement sleep (REM) or non-rapid eye movement sleep (non-REM) based on observations from video or predicted from the data from accelerometers attached to the calves' necks. Redrawn from data presented in Hokkanen *et al* (2011).

Accelerometers attached to various body parts have been used to automatically detect the occurrence of other behaviour patterns such as sleep patterns in dairy calves (Hokkanen *et al* 2011) (Figure 5), activity around parturition for sows (Cornou *et al* 2011) and feeding behaviour in goats (Moreau *et al* 2009). Finally, measures of acceleration over time can be used as a proxy measure for energy expenditure (Gleiss *et al* 2011), and can be used to distinguish different forms of locomotion in calves (de Passillé *et al* 2010).

Other devices have also been used to automatically record animals' locations, for example, local positioning has been used to locate dairy cattle within a barn (Gygax *et al* 2007), and GPS has helped assess the extent that zoo elephants visit various parts of their enclosures (Leighty *et al* 2010).

Advantages and disadvantages

The main advantage of these devices for animal welfare assessment at the farm or group level is that they can be transported easily between farms or zoos, thus facilitating comparisons. Many of the devices are self-contained with their own power supply and memory storage, which means that they can be used on free-roaming animals, such as beef cattle on the range (Robert *et al* 2009) for which other methods of data collection may be impractical.

These devices can be quite inexpensive, although this depends upon the particular device being used. Since at least one device is needed per animal, the total cost can be high when there is a large number of animals, which will place a pressure on reducing sample sizes during a welfare assessment.

One of the biggest disadvantages is the trade-off between cost and the size of memory storage and power options. The cheaper the device the less power can be carried and the smaller the memory. The limit on memory means that sampling frequency must be limited, which reduces the ability of these devices to record the occurrence of short duration behaviours over long periods of time. If the data are recorded on the device itself, this reduces the chance of doing real-time monitoring. The limits on memory can be overcome by wireless collection of the data, which does allow for real-time monitoring, but this increases the price and restricts the area over which the animals can move, since they must be in continuous or regular contact with the receiver.

Another disadvantage is that such devices, since they are attached to the animals, are potentially invasive and may influence the animals' behaviour, or possibly cause wounding, although this is rarely reported. The size of the devices necessary to have a decent memory or power supply will limit the extent that they can be used on smaller animals such as poultry. Furthermore, some labour is needed to attach and remove the devices from the animals, which can increase the labour requirements of an animal welfare inspection. Finally, the animals' ability to remove the devices must be considered: this can be particularly challenging in the case of inquisitive animals, such as group-housed pigs, or elephants, for example (Leighty *et al* 2010). Together, these problems place limits on the duration of time that the devices can stay attached to the animals meaning that they are less valuable for longitudinal studies where animals are followed for a long period of time.

Perhaps one of the biggest disadvantages with these devices, however, is the limited number of behaviour patterns for which we have adequate tests of reliability and accuracy.

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Time spent lying and standing, general activity, and aspects of gait can be reliably recorded in this way, and are clearly important measures for animal welfare assessment. Although there have been attempts to use accelerometers to measure other behaviour patterns, we still lack sufficient demonstrations of their ability to reliably and accurately measure, for example, different forms of social behaviour (eg Gygax *et al* 2007) or stereotyped behaviour etc.

Image and sound analysis

The ready availability of digital imagery along with the development of computer programmes that can 'read' such images, has resulted in the possibility of using automated image analysis ('computer vision') to take measures of animal behaviour. In addition, the ability of automation to identify different sounds is also being explored.

A number of computer-assisted image analysis applications are being developed, such as for measuring space use by cattle when getting up or lying down in order to assess recommendations on stall size (Ceballos *et al* 2004), tracking the activity levels of individual chickens and relating this to the degree of lameness (Aydin *et al* 2010), and tracking the movements of individual pigs in group-housing systems (Ahrendt *et al* 2011). Experimental studies of automated image analysis have been done most often to aid in detecting lameness in dairy cows. Two behavioural indicators of lameness in cows are walking with an arched back, and poor tracking up, where the back hoof is placed somewhat behind the front hoof (Flower & Weary 2009). Computer programmes have been used to detect both behaviour patterns (Flower *et al* 2005; Pluk *et al* 2010; Poursaberi *et al* 2010).

On-farm application of these approaches appears limited by the difficulty in recognising a large number of individuals. Image analysis has also been used to measure the thermoregulatory 'clumping' of pigs to assess the adequacy of the pen temperature (Shao & Xin 2008), which does not require the identification of individual animals but can be used at the group level.

A promising and practical on-farm use of automated image analysis comes from work using measures of 'optical flow' to examine movement patterns of broiler chickens. Measures of optical flow are based on the changes in the location of pixels in consecutive frames of a video, which can be used to estimate the velocity of movement. Dawkins *et al* (2009) placed webcams in ten commercial broiler houses with flock size ranging from 3,000 to 40,000 birds, and where traditional gait scoring on a sample of birds had been used to estimate the prevalence of lameness within the groups. The measures of optical flow were highly correlated with the measures of gait scores. A major advantage of this technique is that it does not require the identification of individual animals but involves assessing movements of the whole group of chickens. A subsequent study found that measures of optical flow could identify periods of disturbance within flocks of laying hens, which would help predict outbreaks of feather pecking (Lee *et al* 2011).

Finally, the development of computer programmes that can identify and classify sounds is proving to be an interesting development. This is particularly suitable for pigs which are very vocal in expressing their emotional states: simple measures of the amplitude of the sound produced by pigs can give some information on the pigs' responses to the relative temperature and humidity within a barn (Borges *et al* 2010) and computer programmes have been developed to recognise pig vocalisations and separate these from background noise (Schön *et al* 2004). Exadaktylos *et al* (2008) were able to develop a sound recognition programme that could detect coughs by piglets. Preliminary results showed that 82% of the sick cough sounds could be correctly identified. They concluded that the application could be used to monitor the welfare in a pig house, and provide early identification of sick animals. Such an approach is also being tested for dairy calves (Ferrari *et al* 2010).

Advantages and disadvantages

A major advantage of this type of automation is that it is non-invasive. This is particularly important when considering smaller animals, such as poultry, where it would be difficult to attach devices such as accelerometers. A second important advantage is that the equipment is relatively cheap, eg relatively simple webcams have been used successfully (eg Dawkins *et al* 2009). Some forms of image analysis do, however, require specialised cameras, and the programmes for analysing the information can be expensive to develop or buy.

The non-invasive nature of the equipment means that it can be used for long-term monitoring of groups of animals, and is also suitable for making comparisons between farms. However, the difficulty in recognising a large number of individual animals means that the approach is probably less useful for long-term monitoring of individual animals than for welfare assessment at the group level. Again, a major limitation arises from the small number of behaviour patterns that can be identified by computer vision. Measuring general activity within groups appears relatively simple with overhead cameras. For recording other forms of behaviour, eg identification of lame cows through changes in gait, it may be difficult to find a suitable location for the camera.

General issues with using automation to measure behaviour

Validity and accuracy of automated measures

As with any scientific measurement, it is necessary to establish the validity (ie are we measuring what we are supposed to be measuring?) as well as the accuracy of the measures (ie what is their sensitivity and specificity?).

The most common method of judging the validity of measures collected automatically is by comparing them with observations made by people, which can be either direct or from video. DeVries *et al* (2003b) validated the data generated by one automated system for recording feeding behaviour (the GrowSafe monitoring system) and compared this with measures taken from time-lapse video.

The GrowSafe measure of the daily frequency of meals showed perfect agreement with the result from the video recordings. The duration of these meals was also highly correlated with that estimated from the video. Comparison with observations has also been used to validate automated image analysis (Dawkins *et al* 2009) and devices such as accelerometers (Ledgerwood *et al* 2010), although cross-comparison with different types of loggers has also been used (Ito *et al* 2009). However, in some cases it may be difficult to validate automated measures since these are effectively the only way of collecting data from, for example, free-ranging animals.

It is also important to determine the accuracy (sensitivity and specificity) with which the equipment can measure behaviour. Automation is often assumed to be more accurate than human observers, but, unfortunately, machines do make mistakes, and while the electronics may be very accurate in detecting the electronic signals, events can occur which reduce the accuracy by which the electronic signals match the behaviour of interest. For example, in their test of the accuracy with which automated feeders detect feeding behaviour, DeVries *et al* (2003b) found some instances in which the video showed that a cow was present at the feed alley which was not recorded by GrowSafe (12.6% of observations) and a few instances in which the reverse was true (3.5% of observations). Sometimes, however, automated feeding equipment can be superior to human observation: Chapinal *et al* (2007) reported that discrepancies between automated feeders and human observers in measuring feeding behaviour of cattle was due to the difficulties of seeing some aspects of feeding from video recordings. Nevertheless, despite these positive results it is important to stress that some estimate of the likelihood of errors be determined.

Studies of accelerometers (Robert *et al* 2009; Ledgerwood *et al* 2010; Ringgenberg *et al* 2010) generally report that they measure standing and lying down with a high degree of accuracy, especially when attached to the leg. The ability of accelerometers to detect other behaviour patterns varies according to the degree of fine discrimination between similar behaviour patterns required. For example, Hokkanen *et al* (2011) were able to identify 90% of the total sleeping time of calves, with accelerometers attached to the neck but were not as accurate in distinguishing the total time the calves slept in either non-rapid eye movement sleep or rapid eye movement sleep (Figure 5), although the level of accuracy they report is still impressive.

However, the degree of accuracy of measures collected automatically will depend upon the sampling schedule and the method of 'cleaning' the data. For example, accelerometers do not take measures continuously but instead take samples. In many cases, the sampling rate is many times a second, which can be considered essentially continuous. However, since most devices in use are small and store the data onboard, the limits on memory size mean that a longer sampling interval (eg of several minutes) may be chosen when recording over a long period of time. In these cases, a sampling interval must be chosen which accurately measures the behaviour in question but allows the device to store the information for the period of time required. This needs prior knowledge of the normal frequency and duration with which the behaviour is performed.

Some editing of the data is also usually needed. For example, automated measures of feeding behaviour often show that the most common inter-visit intervals are very small, often only a few minutes, and are unlikely to represent real inter-meal intervals (DeVries *et al* 2003a). These brief intervals can most easily be explained by temporary loss of contact between the radio transmitter and the receiver, for example, when the calf turns or lowers its head. These are usually dealt with by removing very short inter-meal intervals. A similar situation exists with devices such as accelerometers. These effectively measure the orientation of the leg, and the measures are based on the assumption that the animal is lying down whenever the leg is horizontal. However, a horizontal leg position can also occur briefly when the animal is grooming, for example, and the most accepted method is to remove very short occurrences on the assumption that large animals are unlikely to lie down and then stand up again within a short period of time. Ledgerwood *et al* (2010) found that removal of very short bouts of lying down from the data increased the accuracy of the measures, while Cornou *et al* (2011) claimed that many misclassifications of sleeping sows as 'active' could result from small movements that the sow may make while sleeping. Of course, it may be that in some circumstances cows do lie down for short periods of time; for example, Ledgerwood *et al* (2010) suggested that this occurs more often when cows are uncomfortable. Hence, some care needs to be taken in ensuring the real and meaningful behavioural events are not removed during the data-cleaning process.

For other automated recording systems, the results of tests of accuracy are less encouraging. For example, measures of ground reaction force while cows are walking were shown to have low sensitivity at detecting lameness in cows and were inferior to subjective gait scoring (Bicalho *et al* 2007), although recent developments have improved the ability of pressure-sensitive walkways to detect lameness (Maertens *et al* 2011). The accuracy of measures of weight distribution or weight shifting while cows are standing are better, but still relatively low. For example, Chapinal *et al* (2010) found that the optimal result was a sensitivity of nearly 60% and specificity of around 80% for detecting lame cows. Tests of the ability of electronic sow feeders to detect illness also report relatively low degrees of sensitivity (eg Cornou *et al* 2008). Force plates have been shown to have low accuracy in detecting leg problems in broilers, although they are somewhat better than visual gait scores (Sandilands *et al* 2011). Such low levels of accuracy mean that a large number of animals would need to be tested in order to obtain an accurate estimate of the farm prevalence (eg Sandilands *et al* 2011), which does limit their value for on-farm testing. It is likely that accuracy will be improved by combining data from different sources: for example, Chapinal *et al* (2010) found that by combining measures of weight distribution with measures of walking speed and

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lying time, the sensitivity of detecting cows with sole ulcers increased from nearly 60 to nearly 80%. Furthermore, the accuracy can be improved by accounting for extraneous factors that can systematically affect automated equipment. For example, measures of how cattle distribute their weight are affected by the time since milking (Chapinal *et al* 2009).

In general, the measure of accuracy or validity is valid only for the conditions under which the test was done. For example, IceTag accelerometers come with an algorithm for calculating the number of steps taken by a dairy cow, which appears quite accurate in doing this (Robert *et al* 2009; Nielsen *et al* 2010). However, the measure is not accurate for smaller dairy calves (Trénel *et al* 2009), probably because the pattern of acceleration for the smaller animals is very different from that of adults and a higher sampling frequency is needed (de Passillé *et al* 2010).

Bias towards measures that can be automated

A real danger is that the enthusiasm for automated recording will mean that more emphasis will be given to certain behaviours in welfare assessment solely on the basis that their measurement can be automated. For example, it is relatively easy to automatically measure how much time cows or pigs spend standing up, but an increased time spent standing could occur because the animals are exploring more or because they are fighting more, which have very different implications for animal welfare. We need to choose behavioural measures according to their relevance to animal welfare and then develop methods of recording these automatically, rather than choosing measures for their ability to be recorded automatically.

Effects on relationship between people and animals

A valid concern in the use of any automation in animal production is the effect on the relationship between people and the animals, since automation generally reduces the necessity for direct contact between them (Cornou 2009). This is also true for the use of automation to assess the welfare of animals, particularly welfare assessments done by farmers, since the risk is that automation will reduce the time that farmers spend watching their animals. On the other hand, automation can give the farmers information about the animals that they would not otherwise have, for example, feed intakes of individual animals housed in groups (Cornou 2009). Automated feeders can also help detect sick animals within groups, which is difficult by direct observation. Finally, farms are likely to continue increasing in size for economic reasons, and farmers will have less free time to observe their animals. Finding automated methods of replacing human observers is a necessary result of this rather than a contributing cause.

This is less of an issue in using automated recording in third-party assessments, except that using automation may reduce an assessor's opportunities to make qualitative judgements based on their direct observations. However, most often automation is used not as a substitute for human observers but to obtain data that would otherwise be prohibitively expensive to obtain.

Conclusion

To be useable for on-farm animal welfare assessment, behavioural measures need to be valid, reliable and feasible to take; the latter requirement usually means that recording behaviour be cheap, not too time consuming, and not interfere with the animals or the farm routines (Edwards 2007; Webster 2009). Our review leads us to conclude that automatic measurement of animal behaviour has the potential to meet all of these criteria. Most tests have been able to establish validity and reliability, which is at least as good as found between human observers. Feasibility has yet to be fully established but while most examples of using automation to record welfare-relevant behaviours come from small-scale experimental studies, there have been some real on-farm applications in welfare assessment (Dawkins *et al* 2009; Ito *et al* 2009). However, the different forms of automation have advantages and disadvantages; with some being most useful for longitudinal monitoring of individual animals, while others are best used for 'cross-sectional' studies of group behaviours. Furthermore, the claims for 'objectivity' need to be taken with a pinch of salt; the need to clean data and the choice of sampling strategies means that there is still an element of human judgement involved in these measures. Perhaps the biggest problem so far is the limited range of behaviours that have been measured automatically, but technological developments, especially in computer-vision will undoubtedly expand the range; greater collaboration between ethologists and engineers would certainly help. Behavioural measures need to be chosen according to their relevance to animal welfare rather than solely on their ability to be recorded automatically. In general, however, we feel very positive about the potential of automation to greatly extend the range of behavioural measures that can be incorporated into on-farm animal welfare assessment.

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References

Ahrendt P, Gregersen T and Karstoft H 2011 Development of a real-time computer vision system for tracking loose-housed pigs. *Computers and Electronics in Agriculture 76*: 169-174. http://dx.doi.org/10.1016/j.compag.2011.01.011

Aydin A, Cangar O, Ozcan SE, Bahr C and Berckmans D 2010 Application of a fully automatic analysis tool to assess the activity of broiler chickens with different gait scores. *Computers and Electronics in Agriculture 73*: 194-199. http://dx.doi.org/10.1016/j.compag.2010.05.004

Bach A, Dinarés M, Devant M and Carré X 2007 Associations between lameness and production, feeding and milking attendance of Holstein cows milked with an automatic milking system. *Journal of Dairy Research 74*: 40-46. http://dx.doi.org/10.1017/S0022029906002184

Bicalho RC, Cheong SH, Cramer G and Guard CL 2007 Association between a visual and an automated locomotion score in lactating Holstein cows. *Journal of Dairy Science 90*: 3294-3300. http://dx.doi.org/10.3168/jds.2007-0076

Blokhuis HJ, Veissier I, Miele M and Jones B 2010 The Welfare Quality® project and beyond: safeguarding farm animal well-being. *Acta Agriculturae Scandinavica A: Animal Sciences 60*: 129-140

Borderas TF, Fournier A, Rushen J and de Passillé AM 2008 Effect of lameness on dairy cows' visits to automatic milking systems. *Canadian Journal of Animal Science 88*: 1-8. http://dx.doi.org/10.4141/CJAS07014

Borderas TF, de Passillé AM and Rushen J 2009a Feeding behavior of calves fed small or large amounts of milk. *Journal of Dairy Science 92*: 2843-2852. http://dx.doi.org/10.3168/jds.2008-1886

Borderas TF, Rushen J, von Keyserlingk MAG and de Passillé AM 2009b Automated measurement of changes in feeding behavior of milk-fed calves associated with illness. *Journal of Dairy Science 92*: 4549-4554. http://dx.doi.org/10.3168/jds.2009-2109

Borges G, Da Silva Miranda KO, Gates RS and Sales GT 2010 Environmental conditions effects in noise emission by piglets in an intensive production farm. *Proceedings of the American Society of Agricultural and Biological Engineers Annual International Meeting* pp 5251-5257. 2010, Pittsburgh, PA, USA

Butterworth A, Knowles TG, Whittington P, Matthews L, Rogers A and Bagshaw CS 2007 Validation of broiler chicken gait scoring training in Thailand, Brazil and New Zealand. *Animal Welfare 16*: 177-179

Ceballos A, Sanderson D, Rushen J and Weary DM 2004 Improving stall design: Use of 3-d kinematics to measure space use by dairy cows when lying down. *Journal of Dairy Science 87*: 2042-2050. http://dx.doi.org/10.3168/jds.S0022-0302(04)70022-3

Chapinal N, de Passillé AM and Rushen J 2009 Weight distribution and gait in dairy cattle are affected by milking and late pregnancy. *Journal of Dairy Science 92*: 581-588. http://dx.doi.org/10.3168/jds.2008-1533

Chapinal N, de Passillé AM, Rushen J and Wagner S 2010 Automated methods for detecting lameness and measuring analgesia in dairy cattle. *Journal of Dairy Science 93*: 2007-2013. http://dx.doi.org/10.3168/jds.2009-2803

Chapinal N, de Passillé AM, Pastell M, Hänninen L, Munksgaard L and Rushen J 2011 Measurement of acceleration while walking as an automated method for gait assessment in dairy cattle. *Journal of Dairy Science 94*: 2895-2901. http://dx.doi.org/10.3168/jds.2010-3882

Chapinal N, Veira DM, Weary DM and von Keyserlingk MAG 2007 Technical note: Validation of a system for monitoring individual feeding and drinking behavior and intake in group-housed cattle. *Journal of Dairy Science 90*: 5732-5736. http://dx.doi.org/10.3168/jds.2007-0331

Cornou C 2009 Automation systems for farm animals: potential impacts on the human-animal relationship and on animal welfare. *Anthrozoös 22*: 213-220. http://dx.doi.org/10.2752/175303709X457568

Cornou C, Vinther J and Kristensen AR 2008 Automatic detection of oestrus and health disorders using data from electronic sow feeders. *Livestock Science 118*: 262-271. http://dx.doi.org/10.1016/j.livsci.2008.02.004

Cornou C, Lundbye-Christensen S and Kristensen AR 2011 Modelling and monitoring sows' activity types in farrowing house using acceleration data. *Computers and Electronics in Agriculture 76*: 316-324. http://dx.doi.org/10.1016/j.compag.2011.02.010

Corr SA, McCorquodale C, McDonald J, Gentle M and McGovern R 2007 A force plate study of avian gait. *Journal of Biomechanics 40*: 2037-2043. http://dx.doi.org/10.1016/j.jbiomech.2006.09.014

Dawkins MS, Lee H, Waitt CD and Roberts SJ 2009 Optical flow patterns in broiler chicken flocks as automated measures of behaviour and gait. *Applied Animal Behaviour Science 119*: 203-209. http://dx.doi.org/10.1016/j.applanim.2009.04.009

D'Eath RB, Tolkamp BJ, Kyriazakis I and Lawrence AB 2009 'Freedom from hunger' and preventing obesity: the animal welfare implications of reducing food quantity or quality. *Animal Behaviour 77*: 275-288. http://dx.doi.org/10.1016/j.anbehav.2008.10.028

de Passillé AM, Borderas TF and Rushen J 2011 Weaning age of calves fed a high milk allowance by automated feeders: Effects on feed, water, and energy intake, behavioral signs of hunger, and weight gains. *Journal of Dairy Science 94*: 1401-1408. http://dx.doi.org/10.3168/jds.2010-3441

de Passillé AM, Jensen MB, Chapinal N and Rushen J 2010 Technical note: use of accelerometers to describe gait patterns in dairy calves. *Journal of Dairy Science 93*: 3287-3293. http://dx.doi.org/10.3168/jds.2009-2758

De Paula Vieira A, Guesdon V, de Passillé AM, von Keyserlingk MAG and Weary DM 2008 Behavioural indicators of hunger in dairy calves. *Applied Animal Behaviour Science 109*: 180-189. http://dx.doi.org/10.1016/j.applanim.2007.03.006

DeVries TJ, von Keyserlingk MAG, Weary DM and Beauchemin KA 2003a Measuring the feeding behavior of lactating dairy cows in early to peak lactation. *Journal of Dairy Science 86*: 3354-3361. http://dx.doi.org/10.3168/jds.S0022-0302(03)73938-1

DeVries TJ, von Keyserlingk MAG, Weary DM and Beauchemin KA 2003b Technical note: validation of a system for monitoring feeding behaviour of dairy cows. *Journal of Dairy Science 86*: 3571-3574. http://dx.doi.org/10.3168/jds.S0022-0302(03)73962-9

Edwards SA 2007 Experimental welfare assessment and on-farm application. *Animal Welfare 16*: 111-115

Espejo LA, Endres MI and Salfer JA 2006 Prevalence of lameness in high-producing Holstein cows housed in freestall barns in Minnesota. *Journal of Dairy Science 89*: 3052-3058. http://dx.doi.org/10.3168/jds.S0022-0302(06)72579-6

Exadaktylos V, Silva M, Aerts JM, Taylor CJ and Berckmans D 2008 Real-time recognition of sick pig cough sounds. *Computers and Electronics in Agriculture 63*: 207-214. http://dx.doi.org/10.1016/j.compag.2008.02.010

Ferrari S, Piccinini R, Silva M, Exadaktylos V, Berckmans D and Guarino M 2010 Cough sound description in relation to respiratory diseases in dairy calves. *Preventive Veterinary Medicine 96*: 276-280. http://dx.doi.org/10.1016/j.prevetmed.2010.06.013

https://doi.org/10.7120/09627286.21.3.339 Published online by Cambridge University Press

Flower FC, Sanderson DJ and Weary DM 2005 Hoof pathologies influence kinematic measures of dairy cow gait. *Journal of Dairy Science 88*: 3166-3173. http://dx.doi.org/10.3168/jds.S0022-0302(05)73000-9

Flower FC and Weary DM 2009 Gait assessment in dairy cattle. *Animal 3*: 87-95. http://dx.doi.org/10.1017/S1751731108003194

Gleiss AC, Wilson RP and Shepard ELC 2011 Making overall dynamic body acceleration work: on the theory of acceleration as a proxy for energy expenditure. *Methods in Ecology and Evolution 2*: 23-33. http://dx.doi.org/10.1111/j.2041-210X.2010.00057.x

González LA, Tolkamp BJ, Coffey MP, Ferret A and Kyriazakis I 2008 Changes in feeding behavior as possible indicators for the automatic monitoring of health disorders in dairy cows. *Journal of Dairy Science 91*: 1017-1028. http://dx.doi.org/10.3168/jds.2007-0530

Gygax L, Neisen G and Bollhalder H 2007 Accuracy and validation of a radar-based automatic local position measurement system for tracking dairy cows in free-stall barns. *Computers and Electronics in Agriculture 56*: 23-33. http://dx.doi.org/10.1016/j.compag.2006.12.004

Hokkanen AH, Hänninen L, Tiusanen J and Pastell M 2011 Predicting sleep and lying time of calves with a support vector machine classifier using accelerometer data. *Applied Animal Behaviour Science 134*: 10-15. http://dx.doi.org/10.1016/j.applanim.2011.06.016

Huzzey JM, Veira DM, Weary DM and Von Keyserlingk MAG 2007 Prepartum behavior and dry matter intake identify dairy cows at risk for metritis. *Journal of Dairy Science 90*: 3220-3233. http://dx.doi.org/10.3168/jds.2006-807

Ito K, Weary DM and von Keyserlingk MAG 2009 Lying behavior: Assessing within- and between-herd variation in free-stall-housed dairy cows. *Journal of Dairy Science 92*: 4412-4420. http://dx.doi.org/10.3168/jds.2009-2235

Ito K, von Keyserlingk MAG, LeBlanc SJ and Weary DM 2010 Lying behavior as an indicator of lameness in dairy cows. *Journal of Dairy Science 93*: 3553-3560. http://dx.doi.org/10.3168/jds.2009-2951

Jensen MB and Holm L 2003 The effect of milk flow rate and milk allowance on feeding related behaviour in dairy calves fed by computer controlled milk feeders. *Applied Animal Behaviour Science 82*: 87-100. http://dx.doi.org/10.1016/S0168-1591(03)00054-6

Khan MA, Weary DM and von Keyserlingk MAG 2011 Invited review: effects of milk ration on solid feed intake, weaning and performance in dairy heifers. *Journal of Dairy Science 94*: 1071-1081. http://dx.doi.org/10.3168/jds.2010-3733

Kruse S, Traulsen I, Salau J and Krieter J 2011 A note on using wavelet analysis for disease detection in lactating sows. *Computers and Electronics in Agriculture 77*: 105-109. http://dx.doi.org/10.1016/j.compag.2011.04.002

Ledgerwood DN, Winckler C and Tucker CB 2010 Evaluation of data loggers, sampling intervals, and editing techniques for measuring the lying behavior of dairy cattle. *Journal of Dairy Science 93*: 5129-5139. http://dx.doi.org/10.3168/jds.2009-2945

Lee HJ, Roberts SJ, Drake KA and Dawkins MS 2011 Prediction of feather damage in laying hens using optical flows and Markov models. *Journal of the Royal Society Interface 8*: 489-499. http://dx.doi.org/10.1098/rsif.2010.0268

Leighty KA, Soltis J and Savage A 2010 GPS assessment of the use of exhibit space and resources by African elephants (*Loxodonta africana*). *Zoo Biology 29*: 210-220

Lukas JM, Reneau JK and Linn JG 2008 Water intake and dry matter intake changes as a feeding management tool and indicator of health and estrus status in dairy cows. *Journal of Dairy Science 91*: 3385-3394. http://dx.doi.org/10.3168/jds.2007-0926

Madsen TN and Kristensen AR 2005 A model for monitoring the condition of young pigs by their drinking behaviour. *Computers and Electronics in Agriculture 48*: 138-154. http://dx.doi.org/10.1016/j.compag.2005.02.014

Maertens W, Vangeyte J, Baert J, Jantuan A, Mertens KC, De Campeneere S, Pluk A, Opsomer G, Van Weyenberg S and Van Nuffel A 2011 Development of a real time cow gait tracking and analysing tool to assess lameness using a pressure sensitive walkway: The GAITWISE system. *Biosystems Engineering 110*: 29-39. http://dx.doi.org/10.1016/j.biosystemseng.2011.06.003

Millman ST 2007 Sickness behaviour and its relevance to animal welfare assessment at the group level. *Animal Welfare 16*: 123-125

Moreau M, Siebert S, Buerkert A and Schlecht E 2009 Use of a tri-axial accelerometer for automated recording and classification of goats' grazing behaviour. *Applied Animal Behaviour Science 119*: 158-170. http://dx.doi.org/10.1016/j.applanim.2009.04.008

Nielsen LR, Pedersen AR, Herskin MS and Munksgaard L 2010 Quantifying walking and standing behaviour of dairy cows using a moving average based on output from an accelerometer. *Applied Animal Behaviour Science 127*: 12-19. http://dx.doi.org/10.1016/j.applanim.2010.08.004

Ouweltjes W, van der Werf JTN, Frankena K and van Leeuwen JL 2011 Effects of flooring and restricted freestall access on behavior and claw health of dairy heifers. *Journal of Dairy Science 94*: 705-715. http://dx.doi.org/10.3168/jds.2010-3208

Pastell ME and Kujala M 2007 A probabilistic neural network model for lameness detection. *Journal of Dairy Science 90*: 2283-2292. http://dx.doi.org/10.3168/jds.2006-267

Pastell ME, Hänninen L, de Passillé AM and Rushen J 2010 Measures of weight distribution of dairy cows to detect lameness and the presence of hoof lesions. *Journal of Dairy Science 93*: 954-960. http://dx.doi.org/10.3168/jds.2009-2385

Platz S, Ahrens F, Bendel J, Meyer HHD and Erhard MH 2008 What happens with cow behavior when replacing concrete slatted floor by rubber coating: a case study. *Journal of Dairy Science 91*: 999-1004. http://dx.doi.org/10.3168/jds.2007-0584

Pluk A, Bahr C, Leroy T, Poursaberi A, Song X, Vranken E, Maertens W, Van Nuffel A and Berckmans D 2010 Evaluation of step overlap as an automatic measure in dairy cow locomotion. *Transactions of the ASABE 53*: 1305-1312

Poursaberi A, Bahr C, Pluk A, Van Nuffel A and Berckmans D 2010 Real-time automatic lameness detection based on back posture extraction in dairy cattle: Shape analysis of cow with image processing techniques. *Computers and Electronics in Agriculture 74*: 110-119. http://dx.doi.org/10.1016/j.compag.2010.07.004

Proudfoot KL, Weary DM and von Keyserlingk MAG 2010 Behavior during transition differs for cows diagnosed with claw horn lesions in mid lactation. *Journal of Dairy Science 93*: 3970-3978. http://dx.doi.org/10.3168/jds.2009-2767

Quimby W 2000 Application of feeding behaviour to predict morbidity of newly received calves in a commercial feedlot. *Canadian Journal of Animal Science 81*: 315-320. http://dx.doi.org/10.4141/A00-098

Rajkondawar PG, Liu M, Dyer RM, Neerchal NK, Tasch U, Lefcourt AM, Erez B and Varner MA 2006 Comparison of models to identify lame cows based on gait and lesion scores, and limb movement variables. *Journal of Dairy Science 89*: 4267-4275. http://dx.doi.org/10.3168/jds.S0022-0302(06)72473-0

Ringgenberg N, Bergeron R and Devillers N 2010 Validation of accelerometers to automatically record sow postures and stepping behaviour. *Applied Animal Behaviour Science 128*: 37-44. http://dx.doi.org/10.1016/j.applanim.2010.09.018

Robert B, White BJ, Renter DG and Larson RL 2009 Evaluation of three-dimensional accelerometers to monitor and classify behavior patterns in cattle. *Computers and Electronics in Agriculture 67*: 80-84. http://dx.doi.org/10.1016/j.compag.2009.03.002

Rushen J, Pombourcq E and de Passillé AM 2007 Validation of two measures of lameness in dairy cows. *Applied Animal Behaviour Science 106*: 173-177. http://dx.doi.org/10.1016/j.applanim.2006.07.001

Rushen J, de Passillé AM, von Keyserlingk MAG and Weary DM 2008 *The Welfare of Cattle*. Springer: Dordrecht, The Netherlands. http://dx.doi.org/10.1007/978-1-4020-6558-3

Sandilands V, Brocklehurst S, Sparks N, Baker L, McGovern R, Thorp B and Pearson D 2011 Assessing leg health in chickens using a force plate and gait scoring: how many birds is enough? *Veterinary Record 168*: 77. http://dx.doi.org/10.1136/vr.c5978

Schön PC, Puppe B and Manteuffel G 2004 Automated recording of stress vocalisations as a tool to document impaired welfare in pigs. *Animal Welfare 13*: 105-110

Shao B and Xin H 2008 A real-time computer vision assessment and control of thermal comfort for group-housed pigs. *Computers and Electronics in Agriculture 62*: 15-21. http://dx.doi.org/10.1016/j.compag.2007.09.006

Sørensen JT, Rousing T, Møller SH, Bonde M and Hegelund L 2007 On-farm welfare assessment systems: What are the recording costs? *Animal Welfare 16*: 237-239

Svensson C and Jensen MB 2007 Short communication: Identification of diseased calves by use of data from automatic milk feeders. *Journal of Dairy Science 90*: 994-997. http://dx.doi.org/10.3168/jds.S0022-0302(07)71584-9

Tanida H, Koba Y, Rushen J and de Passillé AM 2011 Use of three-dimensional acceleration sensing to assess dairy cow gait and the effects of hoof trimming. *Animal Science Journal 82*: 792-800. http://dx.doi.org/10.1111/j.1740-0929.2011.00903.x

Trénel P, Jensen MB, Decker EL and Skjøth F 2009 Technical note: quantifying and characterizing behavior in dairy calves using the IceTag automatic recording device. *Journal of Dairy Science 92*: 3397-3401. http://dx.doi.org/10.3168/jds.2009-2040

van Nuffel A, Sprenger M, Tuyttens FAM and Maertens W 2009 Cow gait scores and kinematic gait data: can people see gait irregularities? *Animal Welfare 18*: 433-439

Weary DM, Huzzey JM and Von Keyserlingk MAG 2009 Board-invited Review: Using behavior to predict and identify ill health in animals. *Journal of Animal Science 87*: 770-777. http://dx.doi.org/10.2527/jas.2008-1297

Webster AJF 2009 The Virtuous Bicycle: a delivery vehicle for improved farm animal welfare. *Animal Welfare 18*: 141-147

https://doi.org/10.7120/09627286.21.3.339 Published online by Cambridge University Press