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Corresponding Author: Dr. Nicholas James Bell, MA VetMB PhD

Corresponding Author's Institution: Royal Veterinary College

First Author: Nicholas J Bell, MA VetMB PhD

Order of Authors: Nicholas J Bell, MA VetMB PhD; Hanna Miedema; Ioana Blajan; Toby Mottram

Abstract: The aim of this study was to determine if there was a difference in automatically recorded walking speed between cows with different visually assessed mobility scores. Mobility scores range from 0 (no impairment of mobility, perfect locomotion) to 3 (severe impairment of mobility) with 1 (imperfect mobility) and 2 (impaired mobility) as the intermediate scores. Walking speed was recorded using time of passage (TOP) between two automatic radio frequency identification (RFID) scanning points. Mobility scores (n >50) were matched to TOPs on four dates over a period of three months. Comparisons were made between the mean value of the minimum TOP for five days where the middle day was when the mobility score was recorded for lame and non-lame cows. Lame cows were generally slower than non-lame cows in walking a distance of 5 metres. The method provides a potential means of screening for lame cows and a proxy for mobility score, available on a daily and automated basis that compares well with veterinary inspection.

Royal Veterinary College (South of England)
Stinsford Business Centre
Kingston Maurward College
Dorchester
Dorset DT2 8PY
M +44 (0)7870619211
E njbell@rvc.ac.uk

Dr John Schueller

Editor-in-chief

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Dear Dr Schueller,

Short communication: Automatic measurement of mobility score in dairy cows using walking speed

Thank you for your email with comments from reviewers and thank you for your continued patience in waiting for our responses. The academic financial situation is just as challenging in other parts of the world as it is in the UK I'm sure.

We would like to take the opportunity to thank the reviewers for their comments which has helped strengthen this paper. This work shows good potential when combined with some of the advances in parlour software and RFID reader technology.

Yours sincerely,

Nick J. Bell MA VetMB PhD MRCVS

Lecturer in livestock veterinary extension services

On-behalf of the co-authors

Short communication: automatic measurement of walking speed to determine mobility score of dairy cows

Nick J. Bell[1], Hanna Miedema[2], Ioana Blajan[3] and Toby Mottram[2]

- Walking speed, recorded as time of passage (TOP), was measured between points.
- Two automatic radio frequency identification (RFID) scanning points were used.
- Mobility scores were matched to TOPs on four dates (n >50) over three months.
- Lame cows were consistently slower than non-lame cows.
- The method provides a simple way of compiling mobility scores.

Reviewer 1:

Title This paper does not cover automatic measurement of mobility scores but automatic measurement of walking speed. Please change the title.

Response/Action: agreed and changed

Introduction

Line 40-43: the mobility scoring mentioned here is not the typical approach in Europe as it seems to be based on this text. I guess that this scoring methods is commonly used in England. If so, please state this in the text or point out that this is one of the frequently used scoring methods.

Response/Action: line 43-45 altered to inform the reader that this has become the industry standard method throughout the UK

Line 61-66: Suggestion to move this section after the sentence on line 53 to make a smoother transition from mobility scoring to automatic measuring TOP.

Response/Action: agreed and moved.

Line 68-69: Not clear yet what mobility score 2 and 3 represent: change to 'longer in cows with high mobility scores indicating lameness'.

Response/Action: agreed and changed

Materials and Methods

Line 83: Where is the sorting gate located? At the beginning of the raceway?

Response/Action: clarification added

Line 90-91: Move this line between line 87 and line 88.

Response/Action: moved

There seem to be several criteria to discard data from the dataset: slow cows that caused a traffic jam (line 101-104), cows returning or recorded twice (how is this possible in the raceway?), longer than 20 sec (line 108-110). Please put this criteria together in the text.

Response/Action: moved together and double recordings explained in more detail

Also, it would be interesting to know how many measurements (%) were omitted from the study due to these reasons.

Response/Action: quite a number discarded (31.7%) to ensure we had complete datasets aligned with each mobility score. This has been added.

Line 107-108: It is not clear what is meant by this sentence. However, the discussion adds more information on why you used the min/max TOP during at least 2 days around the mobility scoring (line …). It would clarify the M&M section if you bring this part of the discussion to the M&M section.

Response/Action: M&M section reworded rather than sentence moved from discussion.

Statistical analysis:

Do I understand correctly that you linked the mobility score only to the Min TOP of that cow for the 5 days (day of mobility scoring + 2 days before and 2 days after mobility scoring) for every cow in the study? Why not Mean TOP and Max TOP?

Response/Action: correct. We have added further explanation in the first paragraph of the discussion. A maximum potential speed (min TOP) tells you more that average or bottom speed, much like assessing a sports car performance. A sentence added to M&M and discussion clarified.

If all measurements (n>50) on the 4 days (table 1) were done on the same farm, did you take into account that some cows might be present in the lame or non lame group on different measurement days? Or were all cows in the lame and non lame group different?

Response/Action: we assumed the mobility score for cows remained constant during the five days that TOP data was collected. Cows did change scores between mobility score dates but there were too few that changed to do any meaningful stats on these.

Results

Line 120: Change to: There were four days during which mobility scores were assigned, TOPs were recorded on the day of mobility scoring and on two days on either side of this day.

Response/Action: changed

Line 121-122: Is not clear → For every mobility score per cow, the minimum and maximum TOP of these 5 days was calculated per cow.

Response/Action: sentence removed as as covered in M&M

Line 125: … (Figure 1). → Please state here why you only use the minimum TOP in the T-test (is mentioned in discussion at line 138-140). Else, give also the results of the T-test for maximum TOP. Also, to my opinion, the mean TOP on these 5 days would be interesting. Did you look at this?

Response/Action: we did calculate mean TOP but we were very unclear how to interpret this as it gave us no indication if cows were capable of speed or were consistently slow unlike min and maxTOP. We dropped it quite early on as it confused the paper. We almost dropped maxTOP but most people would intuitively go for that figure because it should show slow cows when minTOP is actually best in practice. This is very interesting to us! Reasoning added to M&M and explained in discussion.

Discussion

Line 142: Which days (or %)? Is this also a reason why you didn't taken max TOP into account?

Response/Action: not days falling in the dataset. Clarified. Not reason for avoiding maxTOP although it might be.

Line 148-151: Does this mean that TOP might not be useful at herd level (as lots of automatic measured lameness indicators are) but might have potential in time series analysis on individual level?

Response/Action: we would not discount it, but the potential looks greatest for individual discrimination rather than generalisation at herd level without individual profiling. A statement indicating further work is necessary has been added as we feel we can't draw these conclusion just yet from this dataset.

Line 153 + line 163-165: If so, would you suggest to only take the min TOP of the 5 last days into account as 'indicator' or also the mean of TOP over the last 5 days?

Response/Action: clarified so it reads mean minimum TOP

Reviewer #3: M&M

It is enough 5 meters to assess speed?

Our response: A longer passage would increase the range of passage times and would only add to the discriminating power of the approach. In this instance 5 meters is all that was practically possible within the confines of the yard. None-the-less, the results proved positive and this represents a useful next stage to the research.

Action: comment added to discussion (line 71-2 on page 7).

What happens with dominant cows? Was this taken into consideration?

Our response: The animals entered a loafing/dispersal area immediately after leaving the parlour and before entering the monitoring passageway, which allowed dominant animals to change position within the line. We would largely expect cows first into the parlour to be the first cows through the monitoring passageway as most reordering due to social rank would probably have occurred prior to this point, in the collecting yard.

Action: the loafing area is described in line 78 on page 4. Clarification has been added to discussion about how we handled artefacts due to queuing cows.

The fact that cows were walking to a feeding area, was considered as a positive stimulus for walking faster?

Our response: Yes, we considered this to be an important factor for ensuring cows that could move quickly did so more consistently, while cows with impaired mobility could not.

Action: Comment added lines 48-51 page 6.

Why correlations were not calculated?

Our response: While time of passage was a continuous variable with considerable variation, mobility score was essentially a binary state as most cows were mobility score 1 or 2 in this population. With a larger sample then more cows at the extremes of the mobility score would be seen and a correlation would be an appropriate statistical test.

Action: none unless the reviewers insist we add correlations.

Results
Figure 1. Could be a Table

Our response: this was a table in an initial draft but we felt a graphical representation was clearer.

Action: none unless reviewers insist on a change.

Discussion
In order to obtain the present results the authors had to remove from the analysis "cows that had a time of passage greater than the mean TOP of all the cows plus one standard deviation. They also used the data just when the gap between cows was greater than 30 seconds".
Also they removed data when "times of less than 5s (due to a cow returning and being recorded twice) and longer than 20s (when a cow may have been impeded by traffic at the end of the exit race) were removed from the data set."
So it would be nice to have a bit of discussion of how these problems could be solved if this device is going to be used reliably by farmers.

Our response: Apart from a few occasions there was little external interference in the movement of cows but some artefacts occurred due to cow queuing. The effect of cows being prevented from passing through by a slow moving or bully cow were removed and this can be easily filtered by software. Similarly, unfeasibly short passage times are due to cows standing close to the exit gate being repeatedly registered by the software was addressed so only the first passageway on any given milking session was registered. Again, this is simple to address in future by the use of a filter in the algorithm.

The most important feature of the mobility score by this method is that it can be repeated at every milking and so data can be removed from the analysis without loss of precision. There are many ways in which a cow can be delayed but the most important single data point is the minimum time it takes a cow to walk through the passageway. The mean value is used to establish a reasonable estimate of the time a cow should pass through a minimum value for a cow above the mean is an indicator of an impaired mobility.

Action: Comment added to discussion lines 58-63, page 7.

Short communication: automatic measurement of walking speed to determine mobility score of dairy cows

Nick J. Bell[1], Hanna Miedema[2], Ioana Blajan[3] and Toby Mottram[2]

[1] The Royal Veterinary College, Hawkshead Lane, North Mymms, Hatfield, Hertfordshire, UK AL9 7TA

[2] eCow Ltd, Design Hub, Port Dundas Business Centre, 100 Borron St, Glasgow, Scotland G4 9XG.

[3] School of Veterinary Sciences, University of Bristol, Langford House, Langford, Bristol, UK BS40 5DU

Corresponding author: Dr Nick Bell, The Royal Veterinary College, Stinsford Business Centre, Kingston Maurward College, Dorchester, Dorset, UK DT2 8PY Telephone: +447870 619211. No fax. Email: njbell@rvc.ac.uk

Abstract

The aim of this study was to determine if there was a difference in automatically recorded walking speed between cows with different visually assessed mobility scores. Mobility scores range from 0 (no impairment of mobility, perfect locomotion) to 3 (severe impairment of mobility) with 1 (imperfect mobility) and 2 (impaired mobility) as the intermediate scores. Walking speed was recorded using time of passage (TOP) between two automatic radio frequency identification (RFID) scanning points. Mobility scores (n >50) were matched to TOPs on four dates over a period of three months. Comparisons were made between the mean value of the minimum TOP for five days where the middle day was when the mobility score was recorded for lame and non-lame cows. Lame cows were

generally slower than non-lame cows in walking a distance of 5 metres. The method provides a potential means of screening for lame cows and a proxy for mobility score, available on a daily and automated basis that compares well with veterinary inspection.

Key words: automatic lameness detection, mobility score, dairy cow

Abbreviations:

Time of passage=TOP

Radio frequency identification=RFID

1 Introduction

Lameness is a major problem for modern dairy herds. To help manage the problem and identify techniques that reduce lameness to a minimum, some farmers are required by their milk buyers to provide frequent reports on the mobility scores of their milking animals (Archer et al., 2010).

The typical approach to screening for lameness involves watching every cow take at least three purposeful, unimpeded strides and a turn. Cows are then allocated a score based on the observation of a set of five key behaviours associated with lameness; namely even weight bearing on all four limbs, even rhythm of walking, stride length, posture and speed of locomotion. DairyCo have published guidance for farmers looking to score their herds for mobility (Anon, 2011a; Anon 2011b) which has become the industry standard approach in the UK. The recommendation is that farmers should screen their herds regularly, ideally scoring at least monthly. However, the quality of this screening remains questionable given there are variations in the environment in which cows are scored; a clear view of each cow is not always achieved when groups are being moved; there are difficulties with identifying

cows; intervals between scoring is longer than ideal for managing lameness and the intra- and inter-observer repeatability are a concern. The relatively insensitive and intermittent nature of the scoring also means trends in lameness are difficult to confidently identify at the individual and herd level.

O'Callaghan *et al.* (2003) showed walking speed was a useful predictor or the presence of foot lesions, although fast walking animals did not guarantee absence of lesions. Similarly, Flower *et al.* (2006) showed that cows with ulcers walked more slowly than those without ulcers. However, another study that investigated the relationship between hoof lesions and behavioural signs of lameness found no differences in walking speed between cows with or without lesions, although there were negative correlations between walking speed and all gait attributes (Chapinal *et al.*, 2009).

Time consuming manual techniques for mobility scoring could potentially be enhanced by automation. Mottram and Bell (2010) reported that the time of passage of a cow walking under her own volition between two points could indicate with 70% accuracy the mobility score of dairy cows. That study was conducted at a veterinary school farm on two occasions using a stopwatch and had limited statistical strength. The potential for using radio frequency identification (RFID) ear tags and static portal antennas for measuring time of passage on a larger scale over an extended period of time was investigated in this study.

The hypothesis to be tested was that the time of passage would be longer in cows with mobility scores of 2 and 3 which are indicators of cows likely to benefit from treatment (lameness).

2. Materials and Methods

A commercial farm with cows in groups of up to eighty was recruited. The farm had cows marked with

freeze brands and RFID ear tags (Allflex, UK using Tiris RFID). The cows exited the milking parlour through a raceway in which two portal antennas (ATL Agricultural Technology Limited, UK) were placed five metres apart. Only one cow could pass through at a time. The milking parlour was a 12-24 Herringbone system which meant cows left in batches of 12 when released by the milker. A dispersal and loafing area between the parlour and the raceway permitted some overtaking of slow cows by the faster cows. The work was conducted during the summer of 2010 when cows were leaving the parlour to take supplementary forage at a feeding station about 30 metres beyond the second portal antenna.

The herd was scored for mobility as cows exited the sorting gate located adjacent to the RFID antennas. All scoring was done by one veterinary surgeon (IB) trained by NJB. Video clips were used for training to minimize observer drift and to ensure scoring was consistent with a panel of international experts. The DairyCo mobility scoring system was used (Anon, 2011a; Anon 2011b). The scores are: 0 = no impairment of mobility, perfect locomotion; 1 = imperfect mobility; 2 = impaired mobility; 3 = severe impairment of mobility. Cows that were score 2 and 3 were classed as lame. Scoring took place on seven occasions over the three months of the study. Freeze brand numbers were used to identify animals and scores were entered onto a centralized database to ensure cows were correctly matched to their electronic identity (Mobility monitor; National Milk Records, UK).

When a cow was within ± 200 mm of either of the antennas her identity was transmitted to a computer which logged her time passing under each antenna, from which the time of passage was computed. The data file created was transmitted by internet every night to the experimenters so that no visits to the farm were necessary except for maintenance and mobility scoring. A web cam was installed to enable the passage of the cows to be monitored without interference.

Only the first appearance of a cow during the milking session was used for analysis. Subsequent

appearances at the antenna were due to supervised cow movements for artificial insemination, veterinary treatments etc and so were not made at the cows' natural speed. It was observed that some slow cows held up cows behind her. Therefore, when a cow had a time of passage greater than the mean TOP of all the cows plus one standard deviation, the data for the cows following her were discarded until the gap between cows was greater than 30 seconds. Times of less than 5s (due to a cow returning to the yard adjacent to the raceway and being recorded twice) and longer than 20s (when a cow may have been impeded by traffic at the end of the exit race) were removed from the data set.

To account for variations in TOP due to cows queuing, TOP data were collected over five days centred over a mobility scoring session on the middle day. It was important to match these two sets of data in this way as mobility scores can change over time with the onset and recovery of lameness. Any cows with only one TOP recording were removed from the data set. The 5-day period means of the minimum and maximum TOPs for each cow were calculated, and minimum TOP compared between lame (mobility scores of 2-3) and not lame cows (mobility scores of 0-1).

Minimum TOP was considered the preferred way to discriminate between lame and sound cows as sound cows may walk slowly due to curiosity or due to cows in front of them impeding progress; however, lame cows would not be capable of achieving the equivalent high speeds through the passage regardless of circumstances. T-tests were used to investigate if there was a significant difference between these two groups. Sensitivity and specificity for lameness detection was calculated using three thresholds: less than 8 seconds, less than 10 seconds and less than 12 seconds.

3. Results

There were four days during which mobility scores were assigned and TOPs were recorded on two days on either side of this date. Discarded TOP recordings resulted in 31.7% of mobility scores being removed from the dataset in total over the four dates. Of the remaining scores there were 44 lame cows, of which only one cow was a score 3 (on September 10th). At the individual level there was considerable overlap in the mean minimum and maximum TOP (Figure 1). The mean minimum TOPs for the groups of lame and non-lame cows are shown in Table 1. Groups of non-lame cows walked significantly faster ($p \leq 0.05$) around three of the four dates (Table 1). A plot of sensitivity versus sensitivity (Figure 2) revealed the optimal threshold for sensitivity and specificity of detection using mean minimum TOP was about 10s which had a sensitivity of 70.5% and specificity of 63.3%.

4. Discussion

Slow walking speed is one behavioural indicator of lameness (O'Callaghan *et al.*, 2003; Flower *et al.*, 2006) and is one of the signs of severe lameness used to assign cows to score 3 on the DairyCo mobility score (Anon, 2011a). In instances when lameness scoring has been difficult to perform, speed of locomotion has been used as a proxy measure to lameness in one study (Berry *et al.*, 2008). Furthermore, walking speed is potentially easy to record automatically using existing technology (Mottram and Bell, 2010). Therefore, the aim of this study was to investigate the relationship between measured walking speed and mobility score, with minimum TOP (maximum recorded speed) showing greater discrimination than maximum TOP (slowest recorded speed; Figure 1).

Occasional days falling between the four blocks of data collection periods had extended times of passage and on inspection these were found to be days when a feed delivery or other farm operation

interrupted the flow of animals. In any commercial system these could be identified by detecting occasions when the mean TOP was higher than average by a margin determined over time. Rules could be established to filter times of passage that are longer due to congestion.

TOPs over time were not solely correlated to mobility score. Some animals walk faster or slower and this may be related to age, temperament or other factors not explored in this study. Cows were motivated to walk through the shedding gate as feed was present beyond the monitoring area and this was considered important for reducing variation due to anything other than appetite (a behaviour which would apply to all lactating dairy cows) and lameness. Consequently, it would appear there is no fixed value that could be used to distinguish between cows with different mobility scores at an individual cow level. Furthermore, congestion in cow flow as cows passed through the shedding gate and social interactions add variation to TOPs. Therefore, the minimum TOP value over a period of five days was used to assess mobility. By comparing a cow to her baseline data built up over time it may be possible to improve the correlation between mobility score and minimum time of passage using rolling means from the preceding days. Further work is needed to investigate whether mean minimum TOP over five days is optimal and assess whether this approach applies across different types of farm and breed of cow.

Apart from a few occasions, there was little external interference in the movement of cows but some artifacts occurred due to cow queuing. The effect of cows being prevented from passing through by a slow moving or dominant cow was removed and this can be easily filtered by software. Similarly, unfeasibly short passage times due to cows standing close to the exit gate and being repeatedly registered by the RFID antenna was addressed, so only the first passageway on any given milking session was recorded. Again, this is simple to account for using a software filter.

The technology for measuring TOP is relatively simple. The passage of the cows past two fixed markers must be recorded accurately. In this study we used two RFID portal antennas which only recorded the cows when they passed within 200 mm of the vertical part of the antenna. As the cow walks 5 m in approximately 10 s we can assume that her velocity is approximately 0.5 m/s. Thus she can pass through the 500mm deep field of the antenna within 1 s. The two antennas can be linked to a computer that ensures clocks are synchronised and the time between the two points is accurate. Increased variation and precision of score allocation could be achieved with a passageway longer that 5m, although this was not practically feasible on the farm used in this study.

The conclusion of this study is that mobility scores can be compared reliably with minimum time of passage measured between pairs of portal antennas that can detect an individual animal within a consistent and limited range.

5. Acknowledgements

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Referees:

1. Professor Matti Pastell PO. Box 28, FI-00014 University of Helsinki, Finland email:

   matti.pastell@helsinki.fi

2. Dr Nicola Blackie, Writtle College, Chelmsford, Essex CM1 3RR email: Nicola.blackie@writtle.ac.uk
3. Dr Bart Sonck, ILVO, Scheldeweg 68, 9090 Melle, België email:bart.sonck@somewhereintime.com ilvo.vlaanderen.be
4. Dr Alistair McRae, Dairy Herd Health and Productivity Service (DHHPS), Division of Veterinary Clinical Sciences, Royal (Dick) School of Veterinary Studies, University of Edinburgh, Easter Bush, Roslin, Midlothian EH25 9RG Email A.I.Macrae@ed.ac.uk

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Table 1. Results from t-tests testing the difference in minimum TOPs between lame and non-lame cows.

Date	n lame	Mean minimum TOP (SD) for lame cows (s)	n not lame	Mean minimum TOP (SD) for non lame cows (s)	t	p
June 16th	12	10.4 (2.1)	53	8.9 (1.7)	-2.30	0.037
June 30th	9	13.5 (3.2)	56	10.5 (1.7)	-2.72	0.026
August 17th	14	10.6 (2.5)	51	9.4 (1.5)	-1.83	0.088
Sept 10th	9	11.1 (1.6)	50	9.8 (1.8)	-2.20	0.050

Figures 1 & 2.docx
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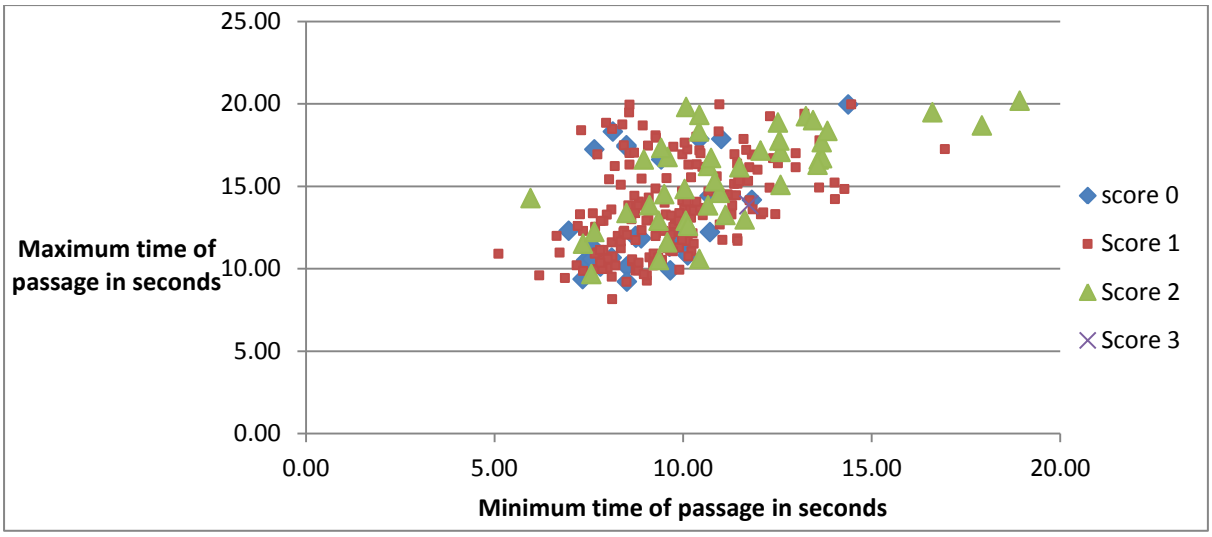

Figure 1 A scatterplot of maximum time of passage versus minimum time of passage for cows of various mobility scores

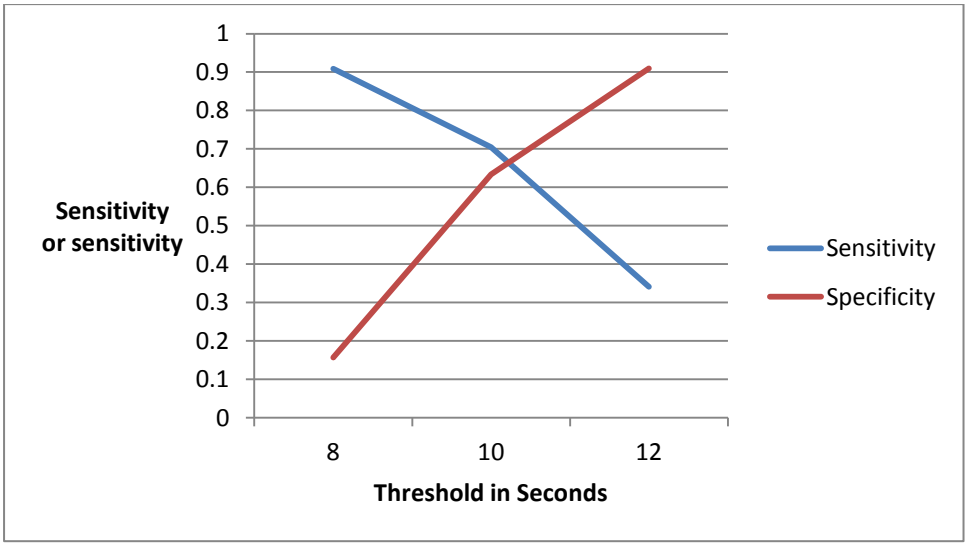

Figure 2 A plot of sensitivity against specificity using five-day mean minimum time of passage as a predictor of lameness (mobility score 2 or 3) using three thresholds (less than 8 seconds; less than 10 seconds; less than 12 seconds)