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A pilot study into the use of global navigation satellite system technology to quantify the behavioural responses of sheep during simulated dog predation events

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Abstract. The predation of sheep (*Ovis aries*) by wild and domestic dogs (*Canis lupis*) is a major issue in Australia, causing serious welfare issues to inflicted animals. The estimated cost of sheep and cattle production losses caused by wild dogs when combined with an extensive range of control measures, costs the Australian economy AU$66 million annually. Spatio-temporal data derived from global navigation satellite system (GNSS) devices were used to quantify the behavioural responses of two flocks of 15 Merino ewes ranging from 2 to 8 years old (average 4.5 years) during simulated dog predation events. Each sheep was fitted with a GNSS collar, and the behavioural responses of the sheep were video recorded during six trials (three per flock). The behavioural data collated from video recordings were then compared with the movement metrics derived from the GNSS collars. Derived metrics include the spatial distribution of flock members, speed of animal movement and specific behavioural changes including centripetal rotation (circling behaviour of the flock, with individual sheep seeking the centre). While the spatial distribution data did not appear to be specific enough to enable identification of a predation event, the velocity of sheep was higher ($P < 0.001$) during compared with before and after a simulated dog predation event. Centripetal rotation occurred in 80% of the simulated predation events during this study, and may provide a means for identifying predation. The spatio-temporal data from GNSS devices have potential as a research tool to assist in understanding sheep movement patterns during a dog attack. While further research and mathematical modelling of predation events is clearly required, the application of remote sensing technology has the potential to improve future livestock monitoring.

Additional keywords: behaviour, dog attack, global positioning system, remote monitoring.

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Introduction

The declining availability of rural labour and increased labour costs are considered two major limiting factors for the sustainability of the Australian sheep and wool industry (Morris *et al*. 2011). In addition, over the past decade Australian sheep numbers have declined due to drought, low wool prices and animal welfare concerns associated with practices like mulesing, live sheep export and an inability to supply adequate monitoring to extensive systems. In addition, another important issue faced by sheep producers in some regions of Australia is the loss of sheep due to predation. Of the livestock systems in Australia, the sheep industry experiences one of the highest production and economic losses from predation (Fleming and Korn 1989; Allen and Fleming 2004). These losses are most evident in rangeland Australia, with Allen and West (2013) predicting wool and sheep production will disappear in some regions over the next 30 years if livestock losses from predation are not reduced. McLeod and Norris (2004) estimated sheep production losses from predation in Australia to be AU$16 million annually. The recent development of a National Wild Dog Action Plan, an Australia-wide coordinated program to determine the best control methods, highlights the seriousness of the issue (Wool Producers Australia 2013). The main canine predators in Australia are dingoes (*Canis lupis dingo*), wild (feral) dogs including dingo-crosses (*Canis lupis*) and free-roaming urban domestic dogs (*Canis lupis familiaris*) (Fleming *et al*. 2006). Predators attack all forms of sheep, including juveniles, ewes with lambs and sick or injured individuals (Gluesing *et al*. 1980). The wounds inflicted during a predation event are commonly found around the neck, body or hind limb region of the sheep and vary from superficial wounds (Schaefer *et al*. 1981), severe lacerations to mutilation (Jennens 1998). This becomes a serious welfare concern, as injured individuals that survive an attack may remain undetected for an extended period of time, especially in extensive production systems where the frequency of monitoring might be low.

The present experiment investigated the application of new technologies to improve our understanding of sheep behavioural responses during a (simulated) predation event. Theoretically, such an approach may inform how remote sensing technology could be developed to detect the onset of a predation event on a commercial farm, thus enabling an alert to be broadcast, followed by a response procedure to protect the flock. From a research perspective, global navigation satellite systems (GNSS) devices have the potential to facilitate continuous animal monitoring for a range of scenarios. Therefore, the objective of this study was to identify if spatio-temporal data derived from GNSS technology can identify a (simulated) dog predation event. We hypothesised that during simulated dog predation events sheep will flock together and increase their speed of movement.

Materials and methods

Location

The experiment was conducted at the University of Sydney sheep reproduction unit in Cobbitty, NSW (34.02°S, 150.65°E) over 5 days (18–22 April 2013), under approval of the University of Sydney Animal Ethics Committee (Protocol N00/3-2013/3/5963). Two paddocks measuring 1.0 and 1.1 ha, with similar obstructions (a live and a dead tree, respectively), were utilised during this research.

GNSS collar configuration and deployment

UNEtracker II GNSS collars (Trotter *et al*. 2010) costing AU$1000 each were configured to receive a positional fix every 5 s using the Navstar global positioning system. The GNSS collars were deployed on 30 Merino ewes of mixed ages (mean 4.5 years; range 2–8 years), run as two flocks of 15 ewes. The ewes were weighed (mean 45.7 kg; range 35.1–62.5 kg) and randomly allotted to the flocks before attachment of the GNSS collars. Each collar weighed ~0.3 kg, which was less than 1% of the bodyweight and thus was unlikely to have influenced the sheep's behaviour (Hulbert *et al*. 1998). Each collar was buckled around the animal's neck and an identification bib was attached by elastic under the ewe's abdomen. All ewes were monitored for 30 min after attachment of the GNSS collars to ensure that the collar and identification bib caused no discomfort; no signs of distress were observed. Ewes were randomly assigned to one of the two paddocks and left undisturbed for at least 22 h (the minimum habituation period is 16 h; Hulbert *et al*. 1998), allowing the sheep to become accustomed to their new environment and wearing of the GNSS collars and identification bibs.

Simulated dog predation events

The simulated dog predation events took place on the second day following collar deployment. Three trained and muzzled Kelpie sheep dogs ranging in age and sheep work experience were used and included a 1-year old with minimal sheep herding experience, a 5-year-old experienced dog and a 13-year-old retired dog. Coloured fabric was attached to each dog for identification and video cameras (Samsung Digital Camcorder, model SMX-F30BP/XSA, Samsung Electronics Australia, Sydney, NSW, Australia) were set up mid-way along the paddock fence on two adjacent sides, ~1 m outside the paddock to record sheep behaviour. Sheep at this property were experienced and familiar with the dogs used, stockperson, human contact and the surrounding environment. The stockperson instructed the three dogs to carry out the same command simultaneously, with the order and frequency of each command dependent on sheep responses during each trial. The stockperson's commands, associated dog behaviours and sheep responses included:

- 'round up the flock': this was the first instructed behaviour and involved the dogs travelling fast to gather and retrieve the flock to the stockperson. These sheep were accustomed to this command, the sheep moved as a group to the opposite end of the paddock.
- 'run around the periphery of the flock': a dog behaviour designed to elicit a panicked response by the sheep that might be seen during a predation event. It resulted in sheep exhibiting individual behavioural responses such as breaking free from the flock (defined as 'flee'; see Table 1).
- 'walk towards the flock': instruction to change the dogs' behaviour from travelling fast to a walk, which was assumed to be less threatening to the sheep.
- 'stand still': involved the dogs' standing stationary. The dogs were positioned around the flock and/or an individual sheep depending upon the response initiated by the flock/sheep, to halt the movement of the sheep.

The same procedure was then repeated with the second flock. The duration of trials was controlled by the stockperson, who closely monitored the sheep and ended the trial before any sheep showed signs of overt distress. Thus, the trials were time limited to 5–12 min, with a minimum recovery period of 90 min between trials.

GNSS analyses

The sheep were left undisturbed for a further 2 days after the simulated dog predation events before the GNSS collars and identification bibs were removed. GNSS data were then downloaded using Microsoft Hyperterminal. UNEtracker II GNSS collar performance statistics have previously been discussed by Trotter *et al*. (2010), with a mean Horizontal Dilution of Precision (HDOP) of 1.4 m recorded for both Flocks 1 and 2 in this study. Displacement records were derived using an add-in for ArcGIS 10.1 (Beyer 2012) and speed was calculated in Microsoft Excel by dividing the distance between consecutive GNSS points by the time interval between the points. Spatial distribution is the dispersal of individual sheep across the paddock at a particular point in time. The spatial distribution at known times of grazing and camping were visually determined and compared in ArcGIS 10.1 across 2 consecutive days, when the dogs were present (first day) and absent (second day).

Behaviour analyses

Individual ewe and flock behaviours were recorded and collated from the video records using continuous *ad libitum* sampling (Martin and Bateson 2007) during 49 min of video recordings from six trials (three from each flock). The occurrence of these *a priori* behaviours was also determined in conjunction with any interactions with the dog/s. Centripetal rotation was identified

Table 1. Sheep and flock behavioural responses to dog presence during simulated predation events in descending frequency of occurrence
Also listed is a description of dog behaviour that typically induced the sheep or flock behaviour

Sheep response to dog presence	Description	Typical dog behaviour	Frequency
Flee	Individual sheep breaks away and is isolated from its flock or group	Dog(s) at a distance or standing in close proximity. However, the dog(s) only targeted the individual sheep after it had fled	55
Sheep pursued by dog(s)	An individual sheep that is situated away from the flock (as they are on the periphery, have initiated the flee response, have fallen over or are faster/slower than the flock) and is pursued by at least one dog	Dog 'targeting' the individual	38
Flock retreats	The flock moves to the opposite end or corner of the paddock, away from the dog(s)	Dog(s) enter the paddock	37
Stands still	Individual sheep looks in the direction of the dog(s) while standing stationary	Dog(s) at a distance or standing in close proximity	26
Centripetal rotation by flock	The flock appears to rotate, as the individual sheep perform a 'centre-seeking' behaviour in which they move forwards in a curved, circular path of movement, pressing against each other, apparently attempting to move into the middle and away from the periphery of the flock	Multiple dogs, positioned around the flock, which may be against a fence	16
Flock fans out	Individual sheep change from a flock formation to dispersing and spreading out in a curved line	Dogs rounding up or running around the flock	13
Collide	A panicked sheep, which is isolated from the flock collides with a barrier (fence/gate, dog or other sheep)	Dog(s) at a distance or standing in close proximity	11
Fall over	Individual sheep apparently startled by the dog flees and falls to the ground. The sheep usually stood up soon afterwards	Dog 'targeting' the individual	8
Challenge dog	Individual sheep looks towards dog and stamps foot; may step towards the dog, lower head and butt the dog	Dog 'targeting' the individual	7
Lie down	Individual sheep that retreats from dog(s) lies on the ground, usually in close proximity of a fence or tree. Sheep in this state were seen to stand when the dog sniffed at or walked past, or when the main flock moved close to the individual sheep	Dog(s) at a distance or standing in close proximity, in which resulted in the sheep standing upright	7
Startle	Individual sheep appears to be startled by the dog and panics, resulting in erratic behaviour before another behaviour is quickly initiated	Dogs rounding up or running around the flock	5
Sub-flocking	The main flock splits up into two or more smaller sub-flocks/groups containing more than three sheep each	Dogs rounding up or running around the flock	4
Individual sheep retreats	Individual sheep moves to the opposite end, or corner of the paddock straight away	Dog(s) at a distance or standing in close proximity	4
Jumps over dog	Individual sheep appears to be startled by the dog and jumps over the dog	Dog 'targeting' the individual	2

from the video recordings *a priori* as a behaviour of interest and matched to the corresponding GNSS data for visual depiction in ArcGIS 10.1. The list of observed sheep behaviours is presented in Table 1.

Statistical analyses

Speed of movement was analysed using a REML linear mixed model (LMM) in Genstat 15.2 (VSN International 2013). The data were transformed to adjust for normality, with the response equalling log(speed + 0.01). Time was a fixed effect (before, during and after the simulated dog predation event) and flock/trial was a random effect. Summary statistics were used to create box plots in Microsoft Excel. Centripetal rotation was analysed using a generalised LMM (GLMM) to determine the significance of this behaviour occurring between trials, in conjunction with whether it occurred during the first or second half of the trial. Trial was a fixed effect, with flock being a random effect. A *P*-value of <0.05 indicated a significant response. A model-based probability to determine the probability of centripetal rotation occurring was also undertaken using a GLMM, with no fixed effects.

Results

Spatial distribution

The spatial distribution of sheep was visually compared at 0924 hours (Flock 2) and 0953 hours (Flock 1) on consecutive days, when dogs were present (first day) and absent (second day). There was little apparent difference in the spatial distribution of the flock between the 2 days. Further, the spatial distribution of the flock was also similar on occasions when the animals were resting (camping).

Speed of movement

The difference in average speed measured at three points in time (before, during and after a simulated predation event) was statistically different ($P < 0.001$), with average speed greater during, than before or after, the simulated dog attack. Fig. 1 highlights the average speed of movement during simulated dog predation events across three trials for both flocks, in conjunction with the speed before the simulated predation event. The time period depicted 'prior' was 10 min before Trial 1 where no dogs were present. The average speeds of Flocks 1 and 2 were always higher in the presence of dogs than before the first trial. The highest maximum speeds were recorded during the simulated predation event across all trials, with a maximum speed of 11.1 m/s documented during Trial 1 in Flock 1 (data not shown).

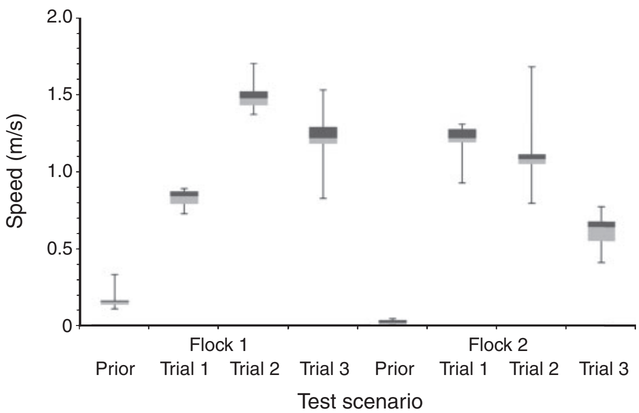

Fig. 1. Speed of movement (m/s) of sheep wearing global navigation satellite system collars before and during simulated dog predation events, in two small flocks. The data for speed of movement are presented as box and whisker plots, and thus show the quartile spread of speed by sheep within each flock in each trial. The duration of individual trials varied from 12, 10 and 8 min for Flock 1, respectively, and 7, 7 and 5 min for Flock 2, respectively. The end of each trial was determined by the experienced stockperson, who ended the trials before the sheep showed signs of overt distress.

Behaviour

Fourteen different sheep and flock behaviours were recognised during simulated dog predation events (Table 1). However, the five most common behaviours were: (i) flee, (ii) sheep pursued by dog(s), (iii) flock retreats, (iv) individual sheep stands still and (v) centripetal rotation by flock (Table 1). Three examples using sequential GNSS data point locations of sheep performing the behavioural response of centripetal rotation are shown in Fig. 2, highlighting individual variability between trials. A model-based probability, from a GLMM in GENSTAT, determined the probability of centripetal rotation occurring was 80% during simulated dog predation events. There was no significant difference in the probability that this behaviour occurred between trials ($P = 0.998$), or in the first compared with second half of the trial ($P = 1.00$).

Discussion

The ability to rapidly and remotely detect the onset of predation events in real time is the first step in being able to prevent sheep losses due to a dog attack. While an alert could inform graziers of the presence of predatory dogs among their sheep, enabling rapid action to assist injured sheep, an alert could also facilitate wider, immediate reporting to pest control officers in the locale tasked with the elimination of the dogs. Thus, such technology has enormous potential for improving animal welfare and the frequency of livestock monitoring in extensive systems. The present experiment recorded higher speeds of movement by sheep during a simulated dog predation event, supporting the hypothesis. When considered in combination with behavioural changes such as centripetal rotation of the flock, remote sensing technologies might be capable of identifying dog attacks on sheep. Unexpectedly however, the change in spatial distribution of the flock during a simulated dog predation event compared with a normal grazing situation did not differ greatly.

Speed of movement

Speed of movement varied between trials, with Flock 1 having a greater median average speed of movement in Trial 2 than Trial 1

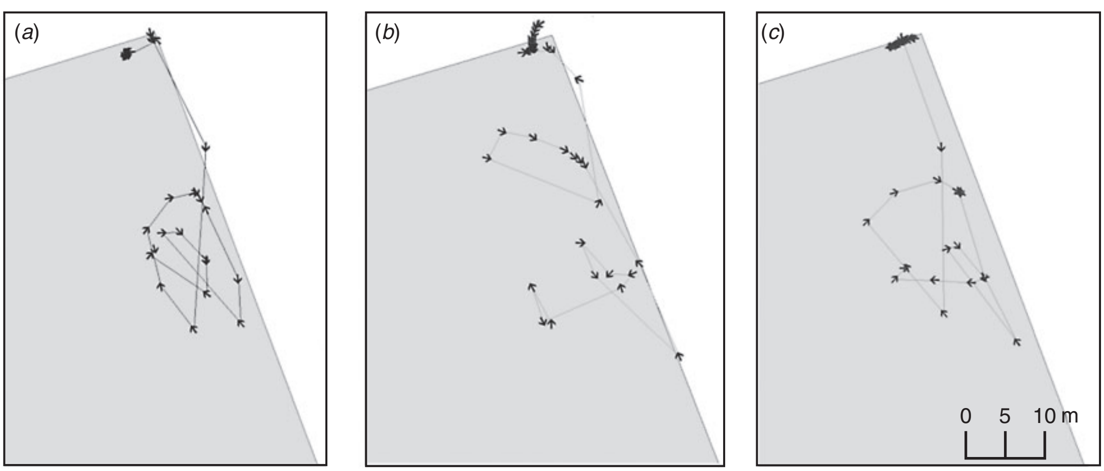

Fig. 2. Global navigation satellite system locations in 5-s intervals, showing concurrent centripetal rotation movements of three individual sheep (*a–c*) illustrating one flock behaviour in the presence of dogs. Each arrow represents the sheep's direction of movement at each sequential point in time.

(Fig. 1), perhaps reflecting normal variability between simulated dog predation events. Despite this variability, the average speed of movement during a simulated predation event was significantly higher than before or after the predation event. Isolated sheep have faster movements compared with flocks containing 5–10 individuals (González *et al*. 2013); and could contribute to an overall increase in the average speed. The majority of documented accounts have reported predation events as crepuscular, coinciding with dawn and dusk (Jennens 1998). Hence, the average speed of movement could be higher if the event occurred during these times, with Bighorn sheep fleeing faster if approached at night (Woolf *et al*. 1970).

Sheep tolerance of dogs varies between different breeds, with Merino sheep ranked as one of the fastest moving breeds in yard tests during routine farming procedures (Whateley *et al*. 1974). Consequently, the high maximum speeds recorded for sheep in the present study may not be representative of other breeds, and athletic characteristics need to be considered if a remote, automatic alerting system is developed for commercial sheep production systems. It is conceivable for example, that in automatic alerting systems false positives may occur due to a lag in response time and an increase in speed following an attack. Therefore, speed of movement needs to be used in conjunction with another form of analysis in order for an alerting system to be effective in the future.

Centripetal rotation by flock

Centripetal rotation occurs when a tightly packed flock is formed (defined as flocking; Vine 1971), with animals on the periphery of the group performing a centre-seeking behaviour. King *et al*. (2012) documented sheep moving closer to the flock centroid when a trained dog approached. In the present study, this was the fifth most recorded behaviour (Table 1). Individuals on the periphery of the flock are the most vulnerable to predators (Dwyer 2004), and hence animals seek the centre of the flock during this formation (Gluesing *et al*. 1980). This behavioural response occurred 80% of the time during simulated dog predation events and highlights a potential indicator to detect the occurrence of a predation event. In order for this flock behaviour to occur, pressure was required on at least two sides, by either dogs or a barrier (fence/gate). This pressure resulted in the circling motion of the flock, and varied between different individuals depending upon their location in relation to the rest of the flock (Fig. 2). In addition, the level of predatory experience may vary between animals (Laporte *et al*. 2010), with different flocks initiating different behavioural responses and/or occurrences depending upon the level of predatory exposure. This consideration needs to be further analysed, in conjunction with any age variables that may predispose this behavioural response.

Spatial distribution

Spatial behaviour represents the results of counteracting motivations to disperse, for example to access resources such as pasture, water and shade away from flock mates, while needing to maintain visual contact and vigilance behaviour with flock mates in order to remain safe (King *et al*. 2012). Responses to predation were thought to alter the spatial distribution between individual sheep. Gluesing *et al*. (1980) suggested that an increased distance between two individuals increases the chance of being predated, as sheep that are segregated from the main flock are more vulnerable to predator attack. However, no change in spatial distribution in response to a predatory event was evident in the present study, with the spatial distribution apparently similar among the three scenarios investigated: grazing, camping and during a simulated dog predation event. While this emphasises how this variable may not be informative for detecting a predation event, the small flock size may be a potential reason why no changes were detected during the present study. Michelena *et al*. (2009) noted that changes in spatial distribution became more evident as flock size increased. Conversely, the average area per ewe decreased when flock numbers increased (from 5 to 10) (Averós *et al*. 2014), reducing the spatial distribution between individual sheep. In addition, due to the relatively small flock size used in the present experiment ($n = 15$), sub-flocking of sheep may not have been as evident as would normally be expected. Therefore, in a commercial setting where larger flocks are common, the spatial distribution may vary as more sub-flocks form. Finally, sheep breed has also been reported to alter spatial distribution, with Suffolks ('lowland' breed) more likely to stay in close proximity with one another than Scottish blackface sheep ('hill' breed) (4.4–11.4-m ewe–ewe distance, respectively) (Dwyer and Lawrence 1999; Ekesbo 2011). Australian Merino sheep under normal grazing conditions have a relatively small social distance between individuals (3.1 m) compared with British hill breeds (8.6 m) (Arnold and Dudzinski 1978), thus reinforcing the variation between breeds. In conclusion, there are several potential reasons why spatial distribution did not vary in the present study. Further research perhaps needs to incorporate observations of wild dogs in paddocks representative of commercial sheep production and/or where sheep have been previously traumatised by wild dog attacks, although this would raise serious ethical concerns. Nevertheless, a precedent was set by Thomson (1992), who used radio-tracking devices to monitor hunting by wild dingoes in Western Australia. Thomson (1992) observed and reported several instances of dingoes attacking sheep.

The welfare concerns, production losses and economic impact of an attack by a predatory animal have led to extensive wild dog control programs being implemented, many of which fail to reduce livestock losses. In addition, a rise in farm labour shortages has resulted in the overall monitoring of sheep being reduced (Australian Wool Innovation 2010). Therefore, in the future, the application of new remote monitoring technologies may improve livestock monitoring and welfare, and offer a potential method to automatically detect a predation event. The combination of the high speed of sheep movement during a simulated predation event, and the behaviour of sheep, in particular centripetal rotation, has the potential to be detected when this event occurs. Further work is needed to develop an algorithm of these two variables in order for remote sensing technology to be developed, trialled and employed on a commercial setting.

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