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Use of an Unmanned Aerial Vehicle — Mounted Video Camera to Assess Feeding Behavior of Raramuri Criollo Cows☆

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ABSTRACT

We determined the feasibility of using unmanned aerial vehicle (UAV) video monitoring to predict intake of discrete food items of rangeland-raised Raramuri Criollo non-nursing beef cows. Thirty-five cows were released into a 405-m^2 rectangular dry lot, either in pairs (pilot tests) or individually (experiment tests), that contained 12 food bowls arranged in an open semicircle and placed approximately 1 m apart. Four bowls containing either long alfalfa hay (AH, 200 g), long Sudangrass hay (SH, 200 g), or cottonseed cake (CC, 50 g) were alternated (CC, AH, SH) using the same sequence in all tests. Video footage of all arena tests was acquired with a three-dimensional Robotics Y6 Multi-copter fitted with a two-axis brushless gimbal and a GoPro Hero 3 Silver Digital Camera. Video files were processed to extract a total of 4 893 two-second-interval still images that were viewed to determine cow feeding activity. Cows that were naïve to the sound of the UAV fed as frequently ($P > 0.05$) as their adapted counterparts during 12-min pilot tests. Significant positive correlations ($r = 0.68 - 0.91$; $P < 0.05$) between video-derived feeding frequency estimates and amount of AH, SH, and CC consumed per bowl were observed during the individual 4-min experiment tests. Our results suggest that UAV video monitoring could be a useful tool to monitor feeding behavior of rangeland cows.

Introduction

The use of unmanned aerial vehicles (UAVs or drones) in science and engineering has increased dramatically in recent years (Harris, 2013) and is revolutionizing landscape-scale monitoring of ecological phenomena (Anderson and Gaston, 2013). Drones are being used to assess rangeland ecohydrology dynamics (Vivoni et al., 2014), monitor vegetation cover (Laliberte et al., 2011a) and phenology (Browning et al., 2015), and track wildlife populations (Jones et al., 2006) including birds (Ratcliffe et al., 2015; Vas et al., 2015), elephants (Vermeulen et al., 2013), rhinoceros (Mulero-Pázmány et al., 2014), and other species of conservation interest (Barasona et al., 2014). Although US government regulations currently constrain the use of this tool for research (Vincent et al., 2015), it is highly likely that in the near future UAVs will become the preferred remote sensing platform for applications that inform sustainable rangeland management (Laliberte et al., 2011b; Rango et al., 2011).

In confined livestock systems, video technology has largely replaced more invasive traditional research techniques of direct observation of animal behavior (e.g., Morrow-Tesch et al., 1998; Mitlohner et al., 2001; Mendes et al., 2011). Conversely, remote monitoring of feeding behavior of livestock on rangelands continues to pose significant logistical challenges despite remarkable advances in acoustic telemetry systems (Clapham et al., 2011; Navon et al., 2013 and references therein) and recent availability of GPS collars with video capabilities (www.lotek.com). UAV-mounted video cameras could provide new opportunities to overcome these challenges using relatively inexpensive off-the-shelf remotely controlled small aircrafts. No studies to date have tested the efficacy of this tool to describe feeding habits of livestock. The objective of this study was to determine whether UAV video monitoring could be used to predict intake of discrete food items of rangeland beef cows in a controlled foraging environment.

Methods

We conducted a series of arena tests with 35 nonlactating adult rangeland-raised Raramuri Criollo cows weighing approximately 360

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kg. All tests were conducted at the central livestock handling facilities of the US Department of Agriculture — Agricultural Research Service Jornada Experiment Range (JER HQ), near Las Cruces, New Mexico, United States. Animal handling protocols were approved by the New Mexico State University (NMSU) Institutional Animal Care and Use Committee (Protocol 2015–012). Video footage of all arena tests was acquired with a 3D Robotics Y6 Multi-copter (3D Robotics, Berkeley, CA) fitted with a two-axis brushless gimbal with a BaseCam open source controller and a GoPro Hero 3 Silver Digital Camera (GoPro, San Mateo, CA) shooting 30 FPS at 1080i. All flights were piloted by a US Department of Transportation, Federal Aviation Administration (FAA)-certified commercial/IFR pilot under the NMSU Unmanned Aircraft System Flight Test Center (UASFTC) Certificate of Authorization (COA). This insured that all FAA regulations regarding UAS flights were followed throughout the experiment.

Pilot tests were conducted on April 24, 2015 to determine whether the sound of the UAV altered the feeding behavior of cows. Four days before conducting these tests, 20 adult non-nursing cows were randomly assigned to either the UAV-naïve or UAV-adapted treatment groups. Cows in the UAV-adapted group ($n = 10$) were held in a pen adjacent to the experiment arena and were exposed to an intermittent recording of the sound of the Y6-Multi-copter engines. A sound file was extracted from an MP4 video file recorded during a previous UAV flight and was played on a laptop computer connected to a pair of desktop computer speakers placed near the holding pen. The speaker volume was set to approximate the sound level of the UAV, and the recording was clearly audible in the holding pen. A timer was used to switch the speakers on for intermittent 1-hr periods throughout daytime hours for 3 consecutive days before the tests. Twenty rubber bowls (20-cm diameter × 8-cm depth) containing cottonseed cake were placed in the holding pen to allow cows to become acquainted with feeding bowls and cottonseed cake. Animals in the holding pen were fed triticale hay ad libitum and had free access to water. Animals in the UAV-naïve group were released into a small holding pasture with a single water source approximately 3.2 km from the JER HQ. The sound of the UAV recording was not audible from the pasture. Again, 20 rubber bowls containing cottonseed cake were placed near the drinker to allow all cows to become familiar with the containers and cottonseed cake. All bowls in the holding pen and pasture were replenished with 450 g of cottonseed daily.

On April 24, 2015, pairs of either UAV-adapted or UAV-naïve cows were exposed to the experiment arena for 12 min. Twelve feed containers (described earlier) were arranged in an open semicircle in a 405-m^2 rectangular arena (15 × 27 m) devoid of vegetation. Bowls were numbered and placed approximately 1 m apart in the area of the arena farthest from the entry gate. Each bowl contained either long alfalfa hay (AH, 200 g), long Sudangrass hay (SH, 200 g) hand cut into segments ≤ 20 cm, or cottonseed cake (CC, 50 g, 20% CP range cubes, ≈19 mm diameter). All feed weights are expressed on an as-fed basis. Four bowls of each food type were alternated (CC, AH, SH) using the same sequence in all tests allowing us to unambiguously pair a food type with each numbered bowl in the analysis of video footage. All cows were familiar with the feeding arena and three foods offered and had been fasted overnight to ensure adequate motivation to seek food during the arena tests. Before and after testing, cows were held and/or released in pens adjacent to the arena with access to fresh drinking water. A technician recorded ear tag numbers as animals entered the arena and operated a stopwatch to time each test. The first five tests were conducted beginning at 0800 h with pairs of UAV-naïve cows to minimize the likelihood of them becoming familiar with the UAV sound. The last five tests were conducted with UAV-adapted pairs of animals. The UAV flight crew was located approximately 10 m from the arena and deployed the UAV immediately after a pair of cows entered the arena. In all tests, the UAV was flown at an altitude of 25 ± 2 m above ground level and typically hovered over the arena. It was returned to home base as soon as cows were removed from the arena. Immediately after each trial, food orts from each bowl were collected and bagged separately and each bowl was replenished with the appropriate type and amount of food. All orts were weighed later that day.

On 26 June, 2015, we conducted the experiment tests with a different group of 15 adult nonlactating cows to determine whether UAV video monitoring could be used to predict intake of known amounts of discrete food items. Four days before the tests, cows were moved to the holding pen where they were held until testing. While in the pen, cows had free access to water and were offered triticale hay ad libitum. Again, they were offered CC in the rubber bowls described earlier (450 g * bowl^{-1}). Given the results obtained during pilot tests (see later), no adaptation to the UAV sound was conducted before experiment tests. Arena layout and amount and types of food offered were identical to those used in the pilot tests. Once again, cows were fasted overnight and held in the same pen adjacent to the arena before tests. Cows were led into the arena individually in random order and were allowed to feed from bowls for approximately 4 min. Test length was determined by UAV battery life, which typically supplied power for 5- to 6-min flights. A technician recorded ear tag numbers as animals entered the arena and operated a stopwatch to time each test. Thus, 15 four-min individual tests were conducted, each of which was filmed with the UAV deployed from a nearby location, again at an altitude of 25 ± 2 m. Food orts from each bowl were collected and bagged separately immediately after each trial, and each bowl was replenished with the appropriate type and amount of food. Again, all orts were weighed later the same day.

The UAV camera was configured to store video footage for each flight (arena test) in a separate digital high-definition (HD) MP4 file (see Supplementary Material Video File Clip). Therefore, after concluding each set of arena tests, all video files were downloaded and renamed to reflect the experiment phase (pilot or experiment test) and test number. Each video file was then processed with the freeware version of FrameShots 3.1 (EOF Productions, www.frame-shots.com) to extract 2-sec-interval still images. Averages of 350 and 100 images were extracted for each pilot and experiment test, respectively. The UAV camera was incorrectly configured in one of the 26 June experiment tests; therefore, video footage was obtained for 14 of the 15 arena tests conducted on that day. Overall, a total of 4 893 images were inspected to determine cow feeding activity. For image analysis, a cow was assumed to be feeding if its muzzle was in a bowl, in which case the bowl number was recorded. Numbers of visits to bowls with AH, SH, and CC during each arena test were added and expressed as a frequency (%) by dividing the number of visits to bowls containing a given food item by the total number of still images extracted from the video footage of a given test.

Frequency data gathered in the pilot tests conducted on 24 April were analyzed with a Student's *t* test to determine if UAV-naïve and UAV-adapted animals exhibited different feeding frequencies. Each 12-min arena test was treated as the experimental unit ($n = 5$ per treatment). All analyses including tests to determine possible violations of normality (Shapiro-Wilk) and homogeneity of variance (Folded F) assumptions were conducted using PROC UNIVARIATE and PROC TTEST in SAS 9.3 (SAS Institute, Cary, NC). Frequency data from the experiment tests conducted on 26 June were subjected to Linear and Spearman Rank Correlation analyses to determine the relationship between video-derived feeding frequency of individual cows and amount of food consumed per bowl (g * bowl visited^{-1} or rank). Individual 4-min tests were again treated as the experimental unit ($n = 14$). All analyses were conducted using PROC UNIVARIATE and PROC CORR in SAS 9.3 (SAS Institute, Cary, NC). Differences between means or relationships between variables were considered statistically detectable at $P \leq 0.05$.

Results

During pilot tests, pairs of cows fed out of 11 ± 0.8 bowls and consumed on average 79 ± 5% of all food offered in the arena (1200 g). Although UAV-naïve pairs tended ($P = 0.07$) to feed from CC bowls less frequently than their UAV-adapted counterparts, no differences in

Table 1
Mean feeding frequency (%) ± SE derived from 2-s interval stills extracted from a UAV-mounted video camera of non-nursing Criollo cows (naïve or adapted) in an arena with 12 bowls containing cottonseed cake, alfalfa hay, or Sudangrass hay (four of each).

Food	Treatment		DF[2]	*t* Value	*P*
	UAV[1] Naïve (%)	UAV Adapted (%)			
Cottonseed cake	17.64 ± 3.51	26.74 ± 2.61	8	2.08	0.07
Alfalfa hay	18.76 ± 5.30	18.39 ± 1.62	4.74[3]	−0.07	0.95
Sudangrass hay	21.64 ± 5.57	19.45 ± 2.55	8	−0.36	0.73
All foods	58.04 ± 13.81	64.59 ± 5.15	8	0.44	0.67

[1] UAV indicates unmanned aerial vehicle.
[2] DF is degrees of freedom.
[3] Satterthwaite unequal variance degrees of freedom.

feeding frequency of UAV-adapted and UAV-naïve groups were detected in the pilot arena tests (Table 1). Therefore, we did not adapt the second group of cows to the UAV sound before the experiment tests conducted on 26 June.

During experiment tests, individual cows fed out of 4 ± 0.3 bowls and consumed on average 22 ± 6% of all food offered in the arena (1200 g). We found strong positive correlations between feeding frequency observations obtained from UAV video footage analysis and the amount of food consumed per bowl, as well as food preference or rank (Figure 1). This relationship was strongest for Sudangrass hay ($r = 0.91$ and 0.88; $P < 0.01$, Pearson and Spearman rank correlation coefficients, respectively) and weakest for cottonseed cake ($r = 0.68$ and 0.74; $P < 0.01$, Pearson and Spearman rank correlation coefficients, respectively).

Discussion

Our pilot tests showed no differences in feeding behavior between UAV-naïve and UAV-adapted cows, suggesting that this monitoring technique could provide an acceptable noninvasive means of describing behavior of nonadapted rangeland beef cows. A recent study conducted with bears in the wild reported no changes in animal behavior

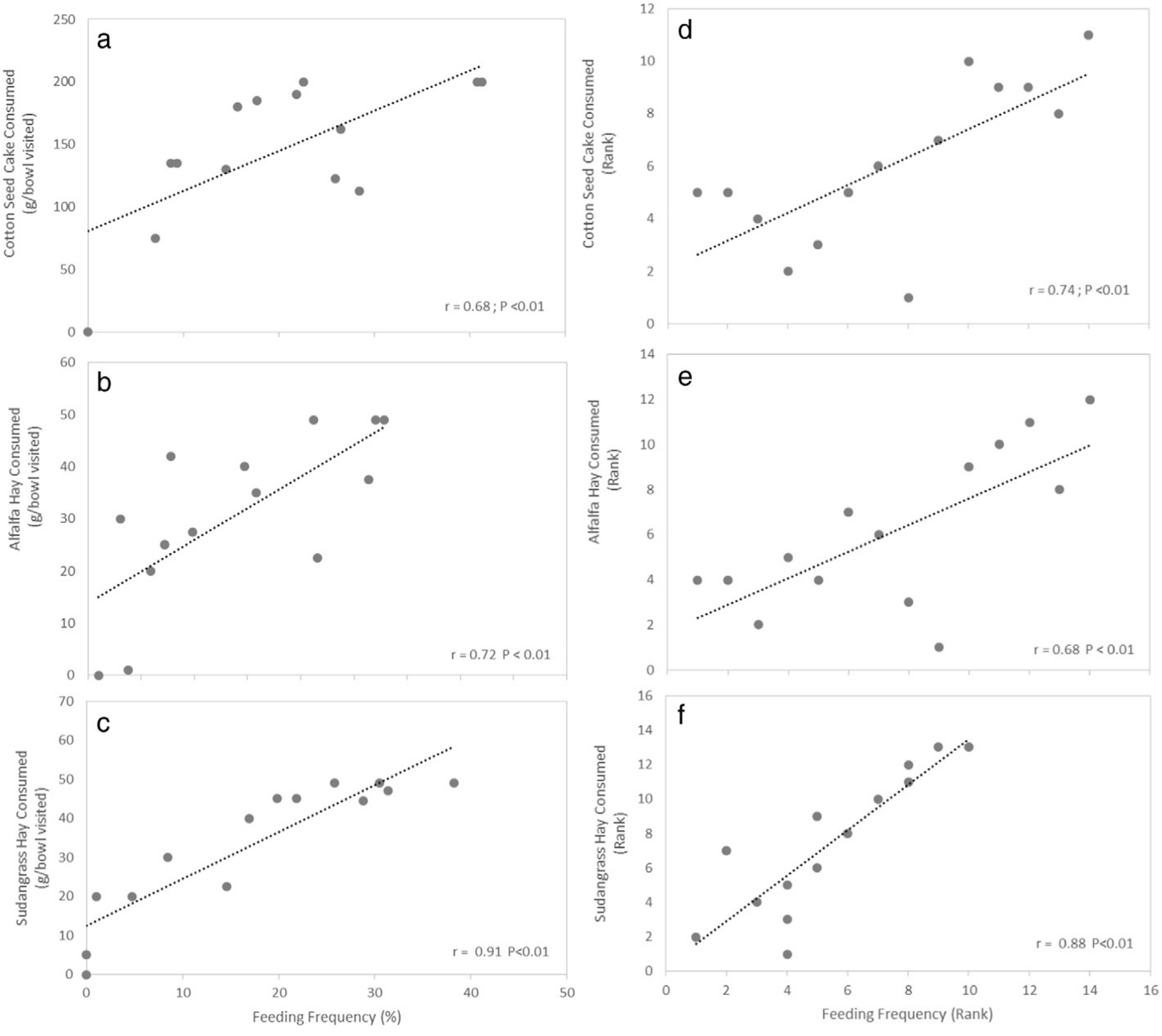

Figure 1. Relationships between feeding frequency (% or rank) of 14 individual cows obtained via an unmanned aerial vehicle—mounted video camera and 1) (left panel) grams of cottonseed cake (*a*), alfalfa hay (*b*), and Sudangrass hay (*c*) consumed per bowl visited (Pearson correlation coefficients shown); and 2) (right panel) overall consumption rank for cottonseed cake (*d*), alfalfa (*e*), and Sudangrass hay (*f*) (Spearman rank correlation coefficients shown) during 4-min arena tests with non-nursing mature Criollo cows.

(movement rates) in response to drone flights, as in our study, but detected increased heart rates, particularly in mothers with offspring (Ditmer et al., 2015). Although not part of the study, our UAV flew over a group of cows with newly born calves in a pen near our experiment arena and we observed moderate levels of alertness in the dams. Further research is necessary to determine state-dependent (nursing vs. non-nursing) influence on UAV monitoring and its effects on indicators of free-ranging cow behavior and welfare.

The tendency of naïve cows to feed less often from CC bowls compared with their adapted counterparts may have been the result of less familiarity with CC. Raramuri Criollo cows at the JER are rarely provided winter feed supplement, which, if fed, usually consists of alfalfa or grass hay. Thus, UAV-naïve cows adapted to CC in a pasture may have had fewer opportunities to feed from the bowls during the adaptation period than their penned UAV-adapted counterparts. The clear lack of differences in the frequency with which cows in both groups fed from bowls with hay (AH or SH) supports this explanation.

Feeding frequency estimates derived from the analysis of UAV video footage collected during our experiment tests were positively and significantly correlated with the amount of food consumed. Our results are comparable with those of Bingham et al. (2009), who found significant relationships between video-derived measurements of feeding behaviors and daily feed intake of feedlot heifers. Interestingly, our analysis yielded tighter relationships for the AH and SH, both of which are fibrous feeds with presumed higher processing time (sensu Searle et al., 2005). It is possible that feeding frequency of concentrates with lower processing times (such as CC) may be better captured with more frequent video sampling (e.g., 1-s vs. 2-s still images) or by analyzing cumulative time spent feeding from continuous video footage (as in Bingham et al., 2009) rather than subsampling and tallying discrete video stills as in this study. Although our study demonstrates the feasibility of using UAV-derived video footage to describe relative differences in intake of discrete dietary items (e.g., shrubs vs. grasses on rangeland), technical constraints such as short UAV battery life (≤15 min) must be overcome for this tool to become useful in extensive rangeland pasture situations.

Implications

To our knowledge, this is the first study to demonstrate the feasibility of using a UAV to monitor cattle feeding behavior. Further development of UAV power sources to provide greater flight autonomy will be required to use this tool in rangeland environments. Because UAV image acquisition is spatially explicit (video can be linked to a GPS and time stamp), the integration of video from improved UAVs coupled with wireless transmission of acoustic signals from microphones fitted on grazing animals could provide unprecedented opportunities for integrating the study of diet and habitat selection of free-ranging livestock.

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