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Evaluation of the impacts of radio-marking devices on feral horses and burros in a captive setting

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Abstract: Radio-collars and other radio-marking devices have been invaluable tools for wildlife managers for >40 years. These marking devices have improved our understanding of wildlife spatial ecology and demographic parameters and provided new data facilitating model development for species conservation and management. Although these tools have been used on virtually all North American ungulates, their deployment on feral horses (*Equus ferus caballus*) or burros (*E. asinus*) has been limited. To determine if radio-collars and radio-tags could be safely deployed on feral equids, we conducted a 1-year observational study in 2015 to investigate fit and wear of radio-collars on feral horses and burros kept in pastures/pens at the Bureau of Land Management contracted adoption facility in Pauls Valley, Oklahoma, USA. We assessed the impact of radio-collars and transmitter tags on individual behavior, body condition, and evaluated neck surface for effects. We tested 2 radio-collar shapes (teardrop and oval) and a radio-tag (i.e., avian backpack) braided into the mane and tail of horses. Behavior of mares did not differ between radio-collared (n = 12) and control (uncollared; n = 12) individuals. Despite the small sample size, collared burro jennies (n = 4) spent more time standing than controls (n = 4). Stallions wearing radio-collars (n = 9) fed less, moved less, and stood more than controls (n = 8). During the study, we did not detect injuries to the necks of mares or burro jennies, but stallions developed small sores (that healed while still wearing radio-collars and re-haired within 3 months). Two radio-collars occasionally flipped forward over the ears onto the foreheads of stallions. Although our study confirmed that radio-collars could be safely deployed on captive mares and jennies, stallions proved challenging for a variety of reasons. While our conclusions were optimistic, longer studies will be required to ensure radio-collar safety on free-ranging feral horses and burros.

Key words: equid, *Equus asinus*, *Equus ferus caballus*, feral burro, feral horse, Oklahoma, radio-collar, radio-tag, telemetry, ungulate

Radio-collars (collars) using very-high frequency (VHF) transmissions are an essential tool for wildlife biologists studying virtually all ungulate species. The development of collars and other animal tags with global positioning system (GPS) devices have enabled biologists to gather detailed data from animals without having to directly observe them. More recently, satellite connectivity has enabled nearly real-time tracking of animals with GPS collars or tags. Radio-collars (VHF or VHF plus GPS) have been deployed on all North American ungulate species, providing vital information on their movements, habitat use, and demography (White and Garrott 1990, Millspaugh and Marzluff 2001, Manly et al. 2002). They have been used to "mark" individuals for use in aerial surveys, improving the precision and accuracy of population estimates (White 1996). Data from collars have informed ungulate ecology studies examining effects of predation on habitat use (Creel and Winnie 2005, Creel et al. 2005, Creel and Christianson 2009, Fortin et al. 2009), foraging-vigilance tradeoffs (Robinson and Merrill 2013), interspecies competition (Stewart et al. 2002), and mating behavior (Whiting et al. 2008). Collars have also been crucial for collecting data on the range and habitat use of ungulates that could not be collected by visual observation or any other means (Buuveibaatar et al. 2013, Owen-Smith et al. 2013).

In Africa and Asia, collars have been deployed on equid species such as Asiatic wild asses (*Equus hemionus*; Goyal et al. 1999, Kaczensky et al. 2008), plains zebra (*E. quagga*; Fischhoff et al. 2007, Brooks and Harris 2008, Bartlam-Brooks et al. 2011, Owen-Smith 2013, Cain et al. 2011), and Grevy's zebra (*E. grevyi*; Sundaresan et al. 2007, Low et al. 2009, Zero et al. 2013). However, the number of these studies is small compared to the volume of published research using collars conducted on other wild ungulates on those continents. Collars have rarely been used for the study of feral horses (*E. ferus caballus*) or burros (*E. asinus*). Of the 9 peer-reviewed research papers published on feral horses equipped with collars (Ganskopp and Vavra 1986; Asa 1999; Goodloe et al. 2000; Hampson et al. 2010*a*, *b*; Girard et al. 2013; Collins et al. 2014; Hennig et al. 2018; Leverkus et al. 2018), less than half were conducted in the United States. Most published equid studies also do not mention the type of collar used. Only 1 study commented on collar fit and evaluated behavioral effects between 2 different collar types (Brooks et al. 2008). These authors highlighted the need for the lightest possible collar to minimize impact on equid foraging behavior.

In the United States, management of feral horses and burros is highly contentious and accompanied with high public interest and visibility. Public resistance to managing feral horses stems from emotional connections with horses and their role in human cultural evolution as well as their status as icons of the West (Scasta 2018, Scasta et al. 2018). Currently, feral horse populations exceed management objectives in almost all areas of their range in the United States (Bureau of Land Management [BLM] 2019*a*, *b*).

A major reason why collars have not been used more frequently on feral horses and burros in the United States is because of a study conducted in the mid-1980s that went awry (National Research Council [NRC] 1991). Although researchers were experienced with deploying collars, use of telemetry, and fieldwork, they did not anticipate possible complications. They deployed a similar collar design previously used on wild ungulates, yet some horses suffered large wounds. Twenty-three collared horses were recaptured to have their collars removed, 2 horses died during recapture, and 1 horse died because of wearing the collar (NRC 1991). The problems were attributed to collar design, including material and construction of collars (stiff and inflexible), irritation caused by the radio units, difficulty in making fine adjustments on collars at first fitting, natural growth of young horses, rapid weight gain of horses because of abundant forage (the study was initiated in the second year of a drought, followed by 2 years of heavy precipitation), and abnormal weight gain as a result of hormone implants (the treatment in the study). Most neck injuries were attributed to the large radio battery units used. In addition, animals were anesthetized, and some were lying down when their collars were fitted, potentially leading to improper adjustment. Because of this study, BLM managers were averse to any further use of collars on feral horses.

Since this study, there have been many improvements in collar design, technology, and safety. New flexible materials are now available, and collars are lighter with smaller battery components. The technical attributes of VHF and GPS transmission and recording systems are well understood and have been used for many years on other species (Tomkiewicz et al. 2010). Because better information is needed regarding the movements of feral equids for management, the safety and utility of new collar technology for application to these species require further testing.

Our goal was to test the fit and wear (safety) of collars and transmitter tags on feral horses and burros in a controlled setting where individuals could be closely monitored. Before implementing our research, we contacted international and local researchers that had worked or were working with collars on equid species to incorporate their input. Specifically, we tested for any difference in collar shape (oval and teardrop) on neck effects or wear, for behavioral differences in equids wearing a collar, and lastly examined if there were any effect of wearing a collar on animal body condition. We evaluated persistence (longevity) and potential behavior effects of radio-tags (tags) braided into the mane and tail of feral horses.

Table 1. Sample size by sex and species of radio-collared and radio-tagged horses (*Equus ferus caballus*) and burros (*E. asinus*) for study testing fit and wear, Pauls Valley, Oklahoma, USA, 2015–2016. Each collared individual received either an oval- or teardrop-shaped at random; controls were not fitted with a radio-collar.

Species (sex)	Collar	Mane and tail tag	Control
Horse (mare)	12	2	14
Burro (jenny)	4	n/a	4
Horse (stallion)	9	3	5
Total	25	5	22

Study area

All test equids were maintained at a BLM adoption facility in Pauls Valley, Oklahoma, USA. Average annual precipitation in Pauls Valley is 98 cm. Summers are hot and humid, and winters are cold and windy. Average annual ambient temperature is 16 °C, and maximum high and low temperatures are 39 °C and -7 °C, respectively. All study mares (female horses) and jennies (female burros) were kept together in a 40-ha grass pasture that allowed individuals to move and interact naturally. No other horses or burros were in the same pasture.

The large size of this pasture also allowed individuals to avoid each other if desired. Stallions (male horses) were randomly assigned to each of 3 27 x 27-m enclosures/pens with ≤8 stallions per enclosure. These pens did not simulate conditions of free-roaming horses like the mare/jenny pasture but did promote frequent interaction between stallions. In other studies, levels of social interaction were inversely correlated with enclosure size of captive equids (Hogan et al. 1988, Andersen 1992); thus, we viewed this as a test of whether collars and tags could withstand stallion interactions. The horses and burros in our study were all born in the wild and maintained at the facility with minimal human contact. None were approachable or accustomed to humans or "tamed" in any way.

Methods

Collar deployment and monitoring fit and wear

We tested oval- and teardrop-shaped collars that are considered suitable for the necks of equid species. These shapes had either been used on equids previously or were designed by authors of this study with a cooperating vendor. Vendors that provided equipment (radio-collars or transmitter tags for mane/tail application) included Telonics (Mesa, Arizona, USA), Biotrack Ltd. (Wareham, Dorset, United Kingdom), Titley Scientific (Columbia, Missouri, USA), Vectronic Aerospace GmbH (Berlin, Germany), Advanced Telemetry Systems (Isanti, Minnesota, USA), and Lotek Wireless (Newmarket, Ontario, Canada). Collars weighed between 658 g and 1,145 g depending on model. Each collar had a timed-release drop-off programmed to disengage after 1 year, and all collars were removed at the end of the study.

Sample sizes were based on how many individuals were available at the facility to participate in the study as well as a minimum sample size needed for behavior research. Collared individuals were randomly selected from the pool of study individuals, but all were adults (≥4 years). Six mares, 6 stallions, and 2 jennies were equipped with teardrop-shaped collars, and 6 mares, 3 stallions, and 2 jennies were fitted with oval-shaped collars (Table 1). We did not test 1 oval-shaped collar on stallions because it had been shown in a previous study to not fit well on geldings (Collins et al. 2014). Twelve mares, 5 stallions, and 4 jennies were uncollared controls (Table 1). Control stallions were identified by their pre-existing freeze mark or individual markings. Control mares and jennies were initially marked with identification neck straps (Bocks IdentiCompany, Mattoon, Illinois, USA), but these came off within a few weeks, and thereafter, controls were identified from individual markings. No burro jacks were included in our study because they were not present at the facility.

For collar fitting, we moved treatment individuals through a corral system ending in a hydraulic padded squeeze chute, where horses stood while we affixed radio-collars. Applying the squeeze changed their stance and neck shape, so very minimal restraint was applied during collar fitting. Control animals were moved through corrals and padded squeeze chute and exposed to the same handling as treatment individuals. Collars were fitted high on the neck, directly behind the ears, and adjusted to be snug when the head was

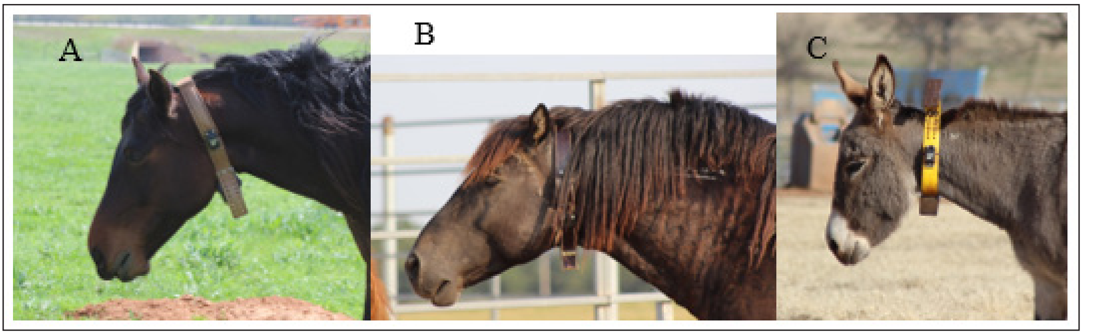

Figure 1. Correct placement of collars on (A) mare, (B) stallion, and (C) jenny in a study testing collar fit and wear on feral horses (*Equus ferus caballus*) and burros (*E. asinus*) in a captive setting, Pauls Valley, Oklahoma, USA, 2015–2016.

Figure 2. Placement of (A) tail tags and (B) mane tags for a study of radio-marking feral horses (*Equus ferus caballus*) and burros (*E. asinus*) in a captive setting, Pauls Valley, Oklahoma, USA, 2015–2016.

held high. In a previous test in July 2014, the necks of domestic horses were measured, and circumference with head-up (alert) position was up to 15 cm larger than when in head-down (grazing) position (U.S. Geological Survey [USGS] 2014, unpublished data). Maintaining snug fit in the head-up position was important so collars would not be too loose during grazing. Burros did not have a large neck circumference difference with head position, so collars were fastened less snugly.

We photographed both sides of the head, under the chin, and the poll (top of the head) before and after collars were placed on animals. Controls were also photographed. We did not trim the mane before collar deployment. We observed collared horses and burros in pens for 2 hours directly after collar deployment to make sure all individuals were feeding and moving normally. Only experienced biologists fitted collars, and all handling procedures were approved by USGS Animal Care and Use Committee (FORT-IACUC Approval 2014-07).

We monitored collars for 1 year. We assumed any effect of collars on necks, body condition, or behavior would be evident and measurable within 3 months, as shown in Stabach et al. (2020). For the first 3 months after deployment, collared and control animals were moved through a chute or into a holding pen to be checked closely for collar effects once a week; photographs were taken of the head and

neck of each individual, and detailed notes of any effects were recorded (Figure 1). For the remaining 9 months of the study, animals were moved through a chute or into a holding pen monthly and photographed, and notes were taken to record evidence of longer-term neck wear or effects.

During collar checks, we recorded all effects regardless of magnitude. On a scale from the most minor effects, we recorded indented fur, hair loss or matting, evidence of chafing (fur rubbed away but no broken skin), presence of a callous (hardened skin), presence of a scab (redness and relatively fresh), presence of a healed scab (darker scab), or healing skin (regrowing fur). We also recorded whether the collar was in the correct position on the neck or upside down (spun).

GPS tags

We obtained small GPS tags (commonly used as avian backpacks; ~75 g) to braid and epoxy into the mane and tail of 2 mares and 3 stallions (each treatment individual received both mane and tail tag; Table 1). The morphology of burro manes and tails did not allow for tags to be affixed, so only horses were evaluated. On the tail, we placed tags halfway down the tail bone to prevent horses from rubbing or crushing them (Figure 2A). On the mane, tags were placed high on the neck, just below the ears, to avoid being crushed during rolling (Figure 2B). For both mane and tail, we fitted a cord through holes at the top of the tag and braided the cord into hair. We used a low temperature curing epoxy to secure tags to hair (Field et al. 2012) and used cable ties to hold them in place while epoxy cured. Care was taken to attach tags to hair rather than skin or fur. We monitored tags to determine how long they were maintained on horses, and fall-off date was recorded. Each tagged animal and control were examined closely every week for the first 14 weeks, then monthly for 9 months. All individuals wearing tags were handled the same number of times as collared individuals.

Behavioral observations

We collected behavioral data weekly for the first 14 weeks of collar deployment (February 26 to May 29, 2015). Behavioral observations consisted of instantaneous scan sampling of each individual (collar, tagged, and control) every 1 minute for 40 minutes in both a morning and afternoon session. Mares and jennies were randomly assigned to observation groups of 7–10 animals within the pasture for data recording, as it was not possible to scan sample more individuals at once with 1 observer. For logistical reasons, stallions in each pen were observed in consecutive observation sessions, but mare/jenny observation groups were observed in random order. All individuals were observed for 1 observation session in the morning and 1 session in the afternoon each week.

At the beginning of each observation session, we recorded weather conditions and body condition of focal animals. All behavioral observations were conducted by the same observer. We recorded behaviors in the following categories:

1. Feeding – grazing, eating hay, moving while chewing
2. Moving – any ambulatory behavior
3. Lying down – sternally or laterally recumbent
4. Standing – either stand resting or standing active
5. Grooming – this included: mutual grooming (2 individuals grooming each other), self-grooming with teeth or hoof, rubbing a body party against a solid object or other individual, and rolling the body on the ground
6. Other – any behavior not included in the other categories (e.g., agonistic interactions, play, etc.)

Body condition

We followed the Henneke score (Henneke et al. 1983) to record body condition for each individual at the beginning of weekly observation sessions for the first 3 months of the study. The same observer classified body condition score for all observations.

Data analyses

For collar fit and wear, we described collar impacts and neck wear from observations and documented the description with photographs. Necks of control animals were also photographed and described. Given the qualitative nature of effects on animals wearing collars, we did not use statistical analyses to

Table 2. Effects of collars on burro (*Equus asinus*) necks during monthly monitoring in a study of fit and wear of collars on feral horses (*E. ferus caballus*) in a captive setting, Pauls Valley Adoption Facility, Oklahoma, USA, 2015–2016. An empty cell indicates no effects were observed that month; nd = no data. Collar A was oval shaped, B and D were teardrop shaped. Collar C was not maintained on burros (fell off after 1 month).

Month	Control	Collar A	Collar B	Collar D
Duration worn (months)		12	12	12
Apr 2015				
May		Small scab		
Jun		Small scab	Rubbed fur	Small scab
Jul	Callous	Callous	Matted fur	Callous
Aug	nd	nd	nd	nd
Sep		Small scab		
Oct		Rubbed fur		Rubbed fur
Nov		Rubbed fur		Small scab
Dec				
Jan 2016			Small scab	
Feb				
Mar				Indented fur

Table 3. Effects of radio-collars on mare necks during monthly monitoring in a study of fit and wear of radio-collars on feral horses (*Equus ferus caballus*) and burros (*E. asinus*) in a captive setting, Pauls Valley Adoption Facility, Oklahoma, USA, 2015–2016. An empty cell indicates no effects were observed that month; nd = no data. Number in parentheses is number of animals showing the effect. Collar A was oval shaped, B and D were teardrop shaped. Collar C was not maintained on mares (fell off within 2 months).

Month	Control	Collar A	Collar B	Collar D
Duration worn (months)		12	12[1]	12[1]
Apr 2015				
May		Indented fur (1), rubbed fur (1)		
Jun				
Jul		Hair loss, callous (1)	Hair loss at poll (1)	Callous (1)
Aug	nd	nd	nd	nd
Sep[1]	Indented fur (1), rubbed fur (2)	Rubbed fur (1)	Small scab (1)	Matted hair at poll (1), small scab (1)
Oct	Indented fur (1)		Rubbed fur (1)	Hair loss at poll (1)
Nov		Small scab (1)	Rubbed fur (1)	
Dec		Matted hair at poll (1)		
Jan 2016		Matted hair at poll (2)		Matted hair at poll (1), hair loss at poll (1)
Feb		Matted hair at poll (1)	Matted hair at poll (1)	Matted hair at poll (1)
Mar	Indented fur (1)	Matted hair at poll (2), hair loss at poll (1)		Hair loss at poll (1)

[1]Three control mares and 2 collared mares (1 mare wearing collar B and 1 mare wearing collar D) died at the facility in September 2015 due to a power outage causing a pasture water drinker malfunction that went undetected by the weekend maintenance worker. No burros died. This reduced our mare sample size halfway through the study.

Table 4. Effects of collars on stallion necks during monthly monitoring in a study of fit and wear of collars on feral horses (*Equus ferus caballus*) and burros (*E. asinus*) in a captive setting, Pauls Valley, Oklahoma, USA, 2015–2016. An empty cell indicates no effects were observed; nd = no data. Number in parentheses is number of animals showing the effect. Scabbing refers to jaw/gullet only. Collar A was oval shaped, B and D were teardrop shaped. Collar A was previously tested on geldings (Collins et al. 2014) with negative results, thus not tested in this study. Collar C was not maintained on stallions (fell off within 2 months).

Month	Control	Collar B	Collar D
Mean duration worn (months)		10.3	12
Apr 2015			
May		Hair loss at poll (1), indented fur (1)	Hair loss at poll (2), small scab (1)
Jun		Small scab (2)	Small wound, scab (1)
Jul		Hair loss, callous, open sores (2)	Scab, callous mandible (2)
Aug		nd	nd
Sep[1]		Hair loss at poll, rubbed fur (1), small scab (1)	Collar over ears (1), Small scab (3)
Oct		Hair loss, scarring (1)	Healed scab (1), small scab (1), indented fur (2), matted hair at poll (1)
Nov		Collar over ears (1), small scab (1), hair loss/regrowth (1)	Small scab, matted hair at poll (1)
Dec		Small scab (1)	Indented fur (2)
Jan 2016		Small scab (1)	Healed scab (1), small scab (1), matted hair at poll (2)
Feb		Indented fur (1)	Healed scab (1)
Mar		Matting at poll, healed scab/hair regrowth (1)	Small scab, matted hair at poll (1)

[1]Collar B was found off one of the stallions after 6 months (September). Thus, subsequent results for collar B are based on 2 stallions.

report effects, but rubbed hair, for example, constituted a minimum effect that we report descriptively in results.

For behavioral analyses, we calculated the rate of each behavior per minute by dividing the count of each behavior with the number of minutes each individual was observed (for controls and animals that were present or wearing a collar in every behavioral observation) or the number of minutes the individual was wearing the collar (for individuals where the collar fell off). For study jennies and mares, there was an equal number of treatment and control individuals for comparison. For stallions, individuals fitted with tags were used as controls for radio-collars due to not having enough stallions at the facility. Our primary goal for tags was to determine longevity on the animal. Tagged stallions and mares were combined for analyses.

We determined that horse behavior was not affected by collar shape (Supplementary Table 1), so collar type was pooled for further analyses of collar effects. Differences in each behavior between treatment and control jennies, mares, and stallions were analyzed using Wilcoxon Signed Rank tests. Behaviors in the category "other" were too rare for meaningful statistical analyses and are not discussed further.

Weekly body condition scores were analyzed using Wilcoxon Signed Rank tests, evaluating differences between treatment and control jennies, mares, and stallions. Some individuals lacked a body condition score for certain weeks, and the number of body condition scores on stallions was related to their behavioral observation sample size; however, sample sizes were similar for treatment and

control groups for each species and sex. For all analyses, statistical significance was assumed at a probability of $P < 0.05$.

Results

Collar fit and wear

Collars caused some small chafing (i.e., minor skin irritation and hair loss), sores (small surface wounds) and minor scabs (healed wounds). These were only seen on a few occasions and almost entirely among stallions (Tables 2, 3, and 4). No neck marks were observed on controls. None of the physical effects of collars on the necks of jennies, stallions, or mares were severe; any sores were superficial and healed without treatment while the individual was still wearing a collar and were covered by hair again (no scar visible) after 3 months. Stallions had collars go over their ears on several occasions (Figure 3), which had the potential to cause discomfort. In at least 1 case, the collar appeared to go over the ears and then right itself, evidenced by a fur indent on the forehead and a sweaty dirt line where the collar had been (see Figure 1B for dirt line across forehead). We never observed collars pass over the ears on mares or jennies, nor saw any evidence that it had occurred but righted itself. Collars spun around on the necks of jennies, mares, and stallions and were occasionally observed fully upside down (Table 5). This had no noticeable impact on the wearer of the collar.

Figure 3. Photograph of a radio-collar in the "over-the-ears" incorrect position on a stallion during a study of collar fit and wear on feral horses (*Equus ferus caballus*) and burros (*E. asinus*), Pauls Valley Adoption Facility, Oklahoma, USA, 2015–2016. This collar was removed, neck inspected for injury (none), and redeployed in correct position (photo courtesy of P. Hoffman, Bureau of Land Management).

Table 5. Proportion of observations in which radio-collars were partly spun around or fully upside down on the animal's neck during weekly monitoring (1x/week) from March 3 to May 28, 2015, in a study to test fit and wear of radio-collars on feral horses (*Equus ferus caballus*) and burro jennies (*E. asinus*), Bureau of Land Management Pauls Valley Adoption Facility, Oklahoma, USA, 2015–2016.

Collar, shape	Burro	Mare	Stallion
Collar A, oval	0.21	0.00	[1]n/a
Collar C, oval	0.83	0.64	0.87
Collar B, teardrop	0.79	0.83	0.88
Collar D, teardrop	0.14	0.07	0.00

[1]This collar not tested on stallions.

Behavior effects

We observed all mares and jennies for 1,120 minutes each, for a total of 40,320 animal-minutes (672 animal-hours) of observation time. All but 4 stallions were observed for 1,120 minutes each. The exceptions were: 1 control stallion who died from pre-existing respiratory problems after 400 minutes of observation; 1 control stallion who was removed for gelding and adoption after 520 minutes of observation; 2 stallions observed for a total of 960 and 1,040 minutes, each of which were removed for 2 consecutive weeks (observations from May 13–21) and 1 week (observations from May 28–29), respectively, to be placed with mares in a different enclosure; we did not observe these stallions when not in stallion pens. One collar model was on horses for differing amounts of time due to repeated material failure (Tables 2, 3, and 4); all other collars were worn throughout the entire behavioral observation study period.

Burros

There was no difference between collared and control burros in feeding, moving, lying down, or grooming (feeding: Wilcoxon $Z_{4,4} = 1.299$, $P = 0.1939$; moving: $Z_{4,4} = 1.876$, $P = 0.606$; lying down $Z_{4,4} = 0.581$, $P = 0.4678$; grooming: $Z_{4,4} = 0.433$, $P = 0.665$), but collared burros stood more than control burros ($Z_{4,4} = -2.165$, $P = 0.0304$; Figure 4).

Mares

There was no difference between collared and control mares in any of the behavioral

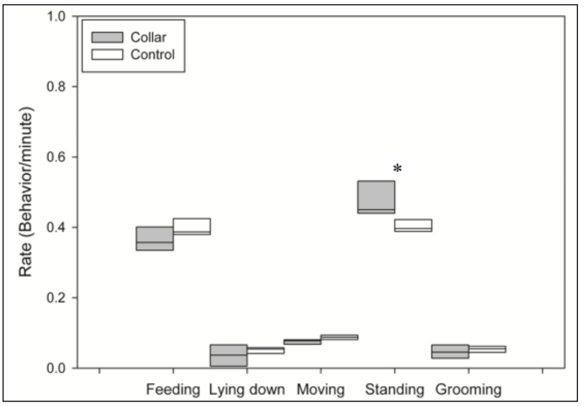

Figure 4. Differences in behavior between collared and control burros (*Equus asinus*) in a test of collaring feral equids in a captive setting, Pauls Valley Adoption Facility, Oklahoma, USA, 2015–2016. Asterisk denotes a statistically significant difference between collared and control animals.

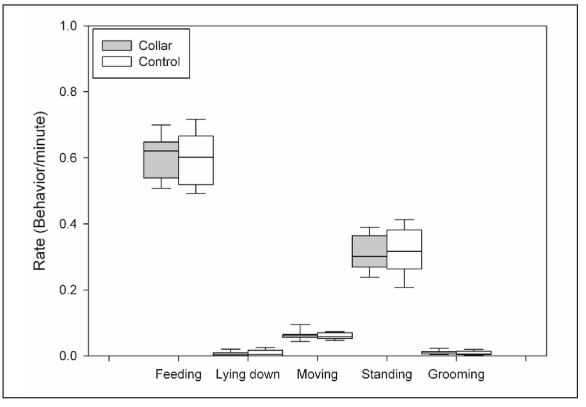

Figure 5. Differences in behavior between collared and control mares in a test of radio-collaring feral equids in a captive setting, Pauls Valley Adoption Facility, Oklahoma, USA, 2015–2016. There was no statistical difference between collared and control individuals for any behavior; whiskers show the ninety-fifth percentile.

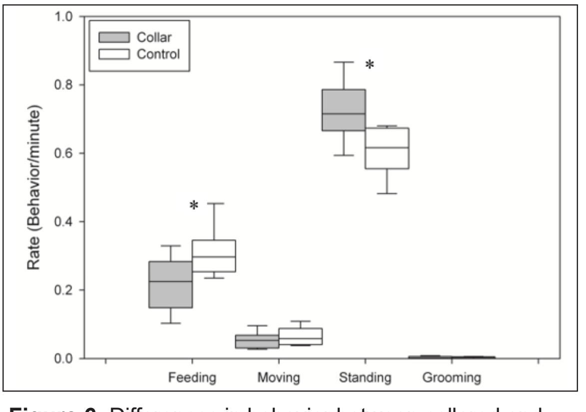

Figure 6. Differences in behavior between collared and control stallions in a test of radio-collaring feral equids in a captive setting, Pauls Valley Adoption Facility, Oklahoma, USA, 2015–2016. Observations of lying down were too rare to include in analyses. Whiskers show ninety-fifth percentile; asterisk denotes a statistically significant difference between collared and control animals.

parameters measured (feeding: $Z_{12,12}$ = -0.202, P = 0.8399; moving: $Z_{12,12}$ = -0.348, P = 0.7281; lying down: $Z_{12,12}$ = 0.059, P = 0.9526; standing: $Z_{12,12}$ = 0.491, P = 0.6235; grooming: $Z_{12,12}$ = -1.049, P = 0.2942; Figure 5).

Stallions

Collared stallions fed less ($Z_{9,9}$ = 2.208, P = 0.0273) and stood more ($Z_{9,9}$ = -2.649, P = 0.0081) than controls (Figure 6). There was no difference in moving ($Z_{9,9}$ = 1.150, P = 0.2503) or grooming ($Z_{9,9}$ = 0.090, P = 0.9282) between collared and control stallions. Lying down was not analyzed because only 2 stallions were observed prone (1 collared, 1 control) on 21 observation points during the 14-week observation period.

Mane and tail tags

There were no differences in behavior of mares and stallions wearing tags compared to controls (feeding: $Z_{5,5}$ = 0, P = 1; moving: $Z_{5,5}$ = -0.524, P = 0.6004; standing: $Z_{5,5}$ = 0, P = 1; grooming: $Z_{5,5}$ = 1.16, P = 0.2463). The duration of time mane and tail tags remained in the hair varied (Table 6), but tail tags lasted longer on stallions than mares.

Body condition

Both collared and control burros had a mean Henneke body condition score (Henneke et al. 1983) of 5.0 (i.e., a moderate body condition – neither thin nor fat) during the first 14 weeks of the study (Figure 7). There was no difference in body condition between treatment and control burros (Wilcoxon $Z_{52,52}$ = 1082.5, P = 0.6049). There was no difference in body condition of collared (mean = 5.1) and control (mean = 5.0) mares ($Z_{156,156}$ = 8607, P = 0.09788; Figure 7). All stallions tended to have higher body condition scores than mares and burros (collared stallions had a mean score of 5.5, controls 5.2), but there was no difference between treatment and control stallions ($Z_{117,117}$ = 5080, P = 0.06618; Figure 7). One control stallion was recently brought in from the range for adoption and was thin at the start of the study (score of 3 in 12% of observations); some other control stallions had a body condition score of 7 (fleshy).

Table 6. Maximum number of days global positioning system tags remained on Bureau of Land Management (BLM) horses (*Equus ferus caballus*) in pastures (mares) or in pens (stallions) at BLM's Pauls Valley Adoption Facility, Oklahoma, USA, 2015–2016. A cord connected to tags was braided into the mane and tail of horses and fixed in place with epoxy and zip ties.

Horse ID	Sex	Mane tag duration (days)	Tail tag duration (days)
3777	Mare	218	187
3779	Mare	187	77
7145	Stallion	187	218
8652	Stallion	187	365–395
8627	Stallion	84	260

Discussion

Collars caused fewer callouses, chafing, and hair loss on mares and jennies than stallions. Only stallions had any noteworthy sores from friction with the collar, and even these healed fully while the collar was still being worn and were covered with hair after 3 months. Very few studies of equids have reported on the effects of collars (Hennig et al., in press); however, in a zebra study (Brooks et al. 2008), it was noted after collars were removed that there was no evidence of any chafing. Horse necks vary in size, shape, and length by breed, and their body size also varies greatly by breed and season.

There is individual variation in all species of ungulates, but it is particularly pronounced in feral horses, which are a mix of different domestic breeds. All collars tended to move around the animal's necks and were off-center or upside down at some point. Collars appeared looser or tighter on different observation occasions, indicating some seasonal change in fit should be expected.

Our results indicated that none of the minor fit and wear effects of collars, or the presence of collars, were meaningful in terms of altering mare behavior. There were some behavioral effects of wearing collars on stallions, despite the small sample size. The greater incidence of sores and hair loss for stallions compared to mares and jennies is likely related to neck:face ratios of individuals in our study. We previously used neck and face measurements from a random subset of 10 study horses (USGS, unpublished data) to compare mare and stallion morphology. Stallions had 29% larger, thicker necks than mares relative to the size of their faces (see Figure 1A–B). We noted that stallions with the most rubbing sores had the thickest necks, whereas stallions that had smaller, more "mare-sized" necks did not incur any effects.

In a previous study (Collins et al. 2014), collars were deployed on geldings as well as mares, but geldings (not mares) were found with collars part way over their head (over 1 ear or both ears). Authors of that study elected not to deploy collars on stallions in the wild due to this issue. We had similar results placing collars on males and having them slip over the forehead in front of ears.

Burros do not have such broad variation in neck shape and size as horses, so we anticipated more consistency in effects. Although jennies wearing collars exhibited some behavioral differences from controls, this may have been related to weight of collars. In a study of zebras, a collar weight of 1.8 kg (0.6% of total body mass) reduced feeding behavior of zebras (Brooks et al. 2008); in our study, the average collar weight was 902 g, or 0.4% of total burro body mass (average burro weight ~228 kg). Although <5% of body mass has been suggested as an acceptable standard for the maximum weight of a tracking collar (Macdonald 1978), collared burros in our study did not reduce feeding time but stood more than controls. We suggest a slightly lighter-weight collar may mitigate this effect on jennies.

Studies that directly compare behavior of collared and uncollared individuals of any species are rare. However, inference in our study about stallion response is limited due to the artificial housing (pens), which caused them to have greater contact with each other. Stallions had a social dynamic in pens that affected their access to hay feeders and even their ability to lie down. This likely influenced their behavior and possibly confounded collar results for stallions. While frequent aggression and play were observed in stallions, they were never observed using collars as leverage. Collar-related wounds were almost entirely observed on stallions' jaws and poll, so they

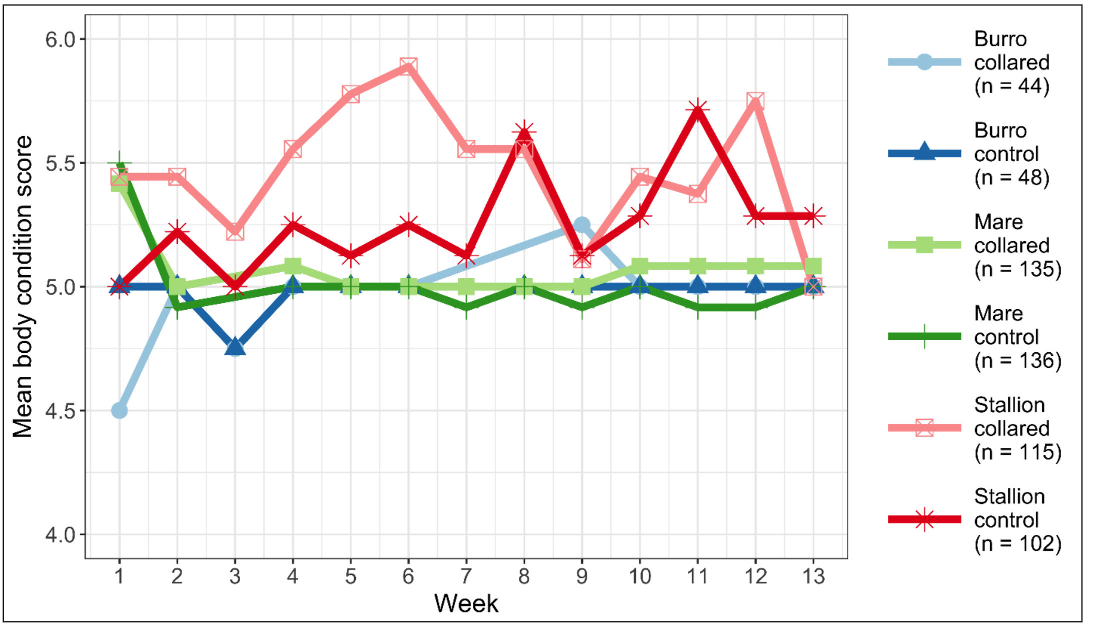

Figure 7. Henneke body condition score of treatment and control mares, stallions, and jennies between February and May 2015 in a study of collar fit and wear at Pauls Valley, Oklahoma, USA. Sample sizes represent the number of observations for each category. Samples differ between groups due to varying number of individuals and because body condition was not recorded for some animals in some weeks.

were not likely related to interactions, though this cannot be ruled out.

The lack of difference in body condition score between treatment and control individuals was not surprising because all animals had their diet supplemented with hay. Some things cannot be adequately tested in a captive or semi-captive setting. For example, the extent of neck expansion and contraction that occurs in free-roaming animals as they gain and lose weight from summer to winter is not inferable with animals that receive supplemental hay and maintain high body condition all year. Testing effects of changes in weight on collar fit and wear will require observations of free-ranging feral horses and burros wearing radio-collars through different seasons.

Mane tags did not persist well in our study. Only tail tags on stallions remained for longer than 8 months. Tail tags had greater longevity than mane tags, possibly due to greater rubbing or grooming by conspecifics in the mane area. Horse tail hair grows continuously, eventually expelling tags. This limits their utility, but they are non-invasive compared to radio-collars and could be useful for seasonal studies of wild or feral equids.

Management implications

Our results suggest collaring feral horse mares and burro jennies could be a feasible tool to improve our understanding of feral equid ecology; however, our results may not characterize collar fit and wear on free-roaming horses and burros. Our research highlights that collaring feral equids is less straightforward than for other North American ungulates due to large differences in their neck size depending on their behavior (grazing with head down versus alert with head up). Fitting collars on feral horses therefore requires an even greater level of care and attention than for other species. Our study provides optimistic information about fit and wear of radio-collars over the period of 1 year, but a more thorough investigation on free-roaming feral horse and burros over a longer duration would be useful.

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Literature cited

Andersen, K. F. 1992. Size, design and interspecific interactions as restrictors of natural behavior in multi-species exhibits. 1. Activity and intraspecific interactions of plains zebra (*Equus burchelli*). Applied Animal Behaviour Science 34:157–174.

Asa, C. S. 1999. Male reproductive success in free-ranging feral horses. Behavioural Ecology and Sociobiology 47:89–93.

Bartlam-Brooks, H., M. C. Bonyongo, and S. Harris. 2011. Will reconnecting ecosystems allow long-distance mammal migrations to resume? A case study of a zebra *Equus burchelli* migration in Botswana. Oryx 45:210–216.

Brooks, C. J., M. C. Bonyongo, and S. Harris. 2008. Effects of global positioning system collar weight on zebra behavior and location error. Journal of Wildlife Management 72:527–534.

Brooks, C. J., and S. Harris. 2008. Directed movement and orientation across a large natural landscape by zebras, *Equus burchelli antiquorum*. Animal Behaviour 76:277–285.

Bureau of Land Management (BLM). 2019*a*. Public land statistics 2018. Volume 203. Bureau of Land Management, U.S. Department of the Interior, Washington, D.C., USA.

Bureau of Land Management (BLM). 2019*b*. Program data. Bureau of Land Management, U.S. Department of the Interior, Washington, D.C., USA, <https://www.blm.gov/programs/wild-horse-and-burro/about-the-program/program-data>. Accessed September 10, 2019.

Buuveibaatar, B., T. K. Fuller, A. E. Fine, B. Chimeddorj, J. K. Young, and J. Berger. 2013. Changes in grouping patterns of saiga antelope in relation to intrinsic and environmental factors in Mongolia. Journal of Zoology 291:51–58.

Cain, J. W., III, N. Owen-Smith, and V. A. Macandza. 2011. The costs of drinking: comparative water dependency of sable antelope and zebra. Journal of Zoology 286:58–67.

Collins, G. H., S. L. Petersen, C. A. Carr, and L. Pielstick. 2014. Testing VHF/GPS collar design and safety in the study of free-roaming horses. PLOS ONE 9(9): e103189.

Creel, S., and D. Christianson. 2009. Wolf presence and increased willow consumption by Yellowstone elk: implications for trophic cascades. Ecology 90:2454–2466.

Creel, S., and J. A. Winnie, Jr. 2005. Responses of elk herd size to fine-scale spatial and temporal variation in the risk of predation by wolves. Animal Behaviour 69:1181–1189.

Creel, S., J. A. Winnie, Jr., B. Maxwell, K. Hamlin, and M. Creel. 2005. Elk alter habitat selection as an antipredator response to wolves. Ecology 86:3387–3397.

Field, I. C., R. G. Harcourt, L. Boehme, P. J. N. de Bruyn, J.-B. Charrassin, C. R. McMahon, M. N. Bester, M. A. Fedak, and M. A. Hindell. 2012. Refining instrument attachment on phocid seals. Marine Mammal Science 28:E325–E332.

Fischhoff, I. R., S. R. Sundaresan, J. Cordingley, and D. Rubenstein. 2007. Habitat use and movements of plains zebra (*Equus burchelli*) in response to predation danger from lions. Behavioral Ecology 18:725–729.

Fortin, D., M.-E. Fortin, H. L. Beyer, T. Duchesne, S. Courant, and K. Dancose. 2009. Group-size-mediated habitat selection and group fusion-fission dynamics of bison under predation risk. Ecology 90:2480–2490.

Ganskopp, D. C., and M. Vavra. 1986. Habitat use by feral horses in the northern sagebrush steppe. Journal of Range Management 39:207–212.

Girard, T. L., E. W. Bork, S. E. Nielsen, and M. J. Alexander. 2013. Seasonal variation in habitat selection by free-ranging feral horses within Alberta's Forest Reserve. Rangeland Ecology & Management 66:428–437.

Goodloe, R. B., R. J. Warren, D. A. Osborn, and C. Hall. 2000. Population characteristics of feral horses on Cumberland Island, Georgia and their management implications. Journal of Wildlife Management 64:114–121.

Goyal, S. P., B. Sinha, N. Shah, and H. S. Panwar. 1999. Sardar Sarovar Project—a conservation

threat to the Indian wild ass (*Equus hemionus khur*). Biological Conservation 88:277–284.

Hampson, B. A., M. A. de Laat, P. C. Mills, and C. C. Pollitt. 2010*a*. Distances travelled by feral horses in "outback" Australia. Equine Veterinary Journal 42:582–586.

Hampson, B. A., J. M. Morton, P. C. Mills, M. G. Trotter, D. W. Lamb, and C. C. Pollitt. 2010*b*. Monitoring distances travelled by horses using GPS tracking collars. Australian Veterinary Journal 88:176–181.

Henneke, D. R., G. D. Potter, J. L. Kreider, and B. F. Yeates. 1983. Relationship between condition score, physical measurements and body fat percentage in mares. Equine Veterinary Journal 15:371–372.

Hennig, J. D., J. L. Beck, and J. D. Scasta. 2018. Spatial ecology observations from feral horses equipped with global positioning system transmitters. Human–Wildlife Interactions 12:75–84.

Hennig, J. D., J. L. Beck, J. D. Scasta, K. A. Schoenecker, and S. R. B. King. In press. Systematic review of equids and telemetry collars: implications for deployment and reporting. Wildlife Research.

Hogan, E. S., K. A. Houpt, and K. Sweeney. 1988. The effect of enclosure size on social interactions and daily activity patterns of the captive Asiatic wild horse (*Equus przewalskii*). Applied Animal Behaviour Science 21:147–168.

Kaczensky, P., O. Ganbaatar, H. von Wehrden, and C. Walzer. 2008. Resource selection by sympatric wild equids in the Mongolian Gobi. Journal of Applied Ecology 45:1762–1769.

Leverkus, S. E., S. D. Fuhlendorf, M. Geertsema, B. W. Allred, M. Gregory, A. R. Bevington, D. M. Engle, and J. D. Scasta. 2018. Resource selection of free-ranging horses influenced by fire in northern Canada. Human–Wildlife Interactions 12:85–101.

Low, B., S. R. Sundaresan, I. R. Fischhoff, and D. I. Rubenstein. 2009. Partnering with local communities to identify conservation priorities for endangered Grevy's zebra. Biological Conservation 142:1548–1555.

Macdonald, D. W. 1978. Radio-tracking: some applications and limitations. Pages 192–204 *in* B. Stonehouse, editor. Animal marking. Palgrave, London, United Kingdom.

Manly, B. F., L. McDonald, D. L. Thomas, T. L. McDonald, and W. P. Erickson. 2002. Resource selection by animals: statistical design and analysis for field studies. Second edition. Kluwer Academic Press, Dordrecht, Netherlands.

Millspaugh, J. J., and J. M. Marzluff. 2001. Radio tracking and animal populations. Academic Press, San Diego, California.

National Research Council. 1991. Wild horse populations: field studies in genetics and fertility: report to the Bureau of Land Management, U.S. Department of the Interior. National Academies Press, Washington, D.C., USA.

Owen-Smith, N. 2013. Daily movement responses by African savanna ungulates as an indicator of seasonal and annual food stress. Wildlife Research 40:232.

Owen-Smith, N., E. Le Roux, and V. Macandza. 2013. Are relatively rare antelope narrowly selective feeders? A sable antelope and zebra comparison. Journal of Zoology 291:163–170.

Robinson, B. G., and E. H. Merrill. 2013. Foraging-vigilance trade-offs in a partially migratory population: comparing migrants and residents on a sympatric range. Animal Behaviour 85:849–856.

Scasta, J. D. 2018. Why are humans so emotional about feral horses? A spatiotemporal review of the psycho-ecological evidence with global implications. Geoforum 103:171–175.

Scasta, J. D., J. L. Beck, and J. D. Hennig. 2018. Framing contemporary U.S. wild horse and burro management processes in a dynamic ecological, sociological, and political environment. Human–Wildlife Interactions 12:31–45.

Stabach, J. A., S. A. Cunningham, G. Connette, J. L. Mota, D. Reed, M. Byron, M. Songer, T. Wacher, K. Mertes, J. L. Brown, P. Comizzoli, J. Newby, S. Monfort, and P. Leimgruber. 2020. Short-term effects of GPS collars on the activity, behavior, and adrenal response of scimitar-horned oryx (*Oryx dammah*). PLOS ONE 15(2): e0221843.

Stewart, K. M., R. T. Bowyer, J. G. Kie, and N. J. Cimon. 2002. Temporospatial distributions of elk, mule deer, and cattle: resource partitioning and competitive displacement. Journal of Mammalogy 83:229–244.

Sundaresan, S. R., I. R. Fischhoff, and D. I. Rubenstein. 2007. Male harassment influences female movements and associations in Grevy's zebra (*Equus grevyi*). Behavioral Ecology 18:860–865.

Tomkiewicz, S. M., M. R. Fuller, J. G. Kie, and K. K. Bates. 2010. Global positioning sys-

tem and associated technologies in animal behavior and ecological research. Philosophical Transactions of the Royal Society B 365:2163–2176.

White, G. C. 1996. NOREMARK: population estimation from mark-resighting surveys. Wildlife Society Bulletin 24:50–52.

White, G. C., and R. A. Garrott. 1990. Analysis of wildlife radio-tracking data. Academic Press, San Diego, California, USA.

Whiting, J. C., R. T. Bowyer, and J. T. Flinders. 2008. Young bighorn (*Ovis canadensis*) males: can they successfully woo females? Ethology 114:32–41.

Zero, V. H., S. R. Sundaresan, T. G. O'Brien, and M. F. Kinnaird. 2013. Monitoring an endangered savannah ungulate, Grevy's zebra *Equus grevyi*: choosing a method for estimating population densities. Oryx 47:410–419.

Supplementary Table 1. Results of analyses on whether feral horse (*Equus ferus caballus*) behavior was affected by collar vendor (using Kruskal-Wallis tests on the 4 vendors) or collar shape (using Wilcoxon rank sum tests on the 2 collar shapes) in a captive trial over 3 months at the Bureau of Land Management Pauls Valley Adoption Facility, Oklahoma, USA. Data on all feral horses (mares and stallions) fitted with collars were combined for this analysis ($n = 21$ individuals). Observations of horses lying down were rare, so they were not included in this analysis.

Behavior	Vendor	Collar shape
Feeding	$H = 1.5714$, $P = 0.6659$	$W = 47$, $P = 0.6511$
Standing	$H = 1.3667$, $P = 0.7134$	$W = 62$, $P = 0.5939$
Moving	$H = 1.6699$, $P = 0.6436$	$W = 70.5$, $P = 0.2549$
Grooming	$H = 5.5643$, $P = 0.1348$	$W = 68$, $P = 0.3353$

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