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Original Article

Influence of Landscape Characteristics on Retention of Expandable Radiocollars on Young Ungulates

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ABSTRACT One tool used for wildlife management is the deployment of radiocollars to gain knowledge of animal populations. Understanding the influence of individual factors (e.g., species, collar characteristics) and landscape characteristics (e.g., forested cover, shrubs, and fencing) on retention of expandable radiocollars for ungulates is important for obtaining empirical data on factors influencing ecology of young-of-the-year ungulates. During 2001–2009, we captured and radiocollared 198 white-tailed deer (*Odocoileus virginianus*) fawns, 142 pronghorn (*Antilocapra americana*) fawns, and 73 mule deer (*O. hemionus*) fawns in South Dakota, Minnesota, and California, USA. We documented 72 (36.4%), 8 (5.6%), and 7 (9.6%) premature (<270 days post-capture) collar losses among white-tailed deer, pronghorn, and mule deer, respectively. Probability of a collar being retained for 270 days was 0.36 (SE = 0.05, 95% CI = 0.27–0.47), 0.91 (SE = 0.03, 95% CI = 0.82–0.96), and 0.87 (SE = 0.05, 95% CI = 0.73–0.94) for white-tailed deer, pronghorn, and mule deer fawns, respectively. Agricultural fencing, which varied among study areas and thus species, seemed to influence collar retention; fencing density was 69% lower in areas where fawns retained collars ($\bar{x} = 1.00$ km/km^2, SE = 0.1, $n = 75$) compared with areas where fawns shed collars ($\bar{x} = 3.24$ km/km^2, SE = 0.1, $n = 56$) prior to 270 days. Researchers of fawns should consider that radiocollars can be shed prematurely when estimating desired sample size to yield a suitable strength of inference about some natural process of interest.

KEY WORDS expandable radiocollar, fawn, fencing, habitat, landscape, retention, ungulate.

Ungulates are typically most vulnerable to mortality as fawns; therefore, it can be important to obtain empirical data on factors influencing their ecology to guide population management (Porath 1980, Roseberry and Woolf 1991, Bowden et al. 2000, Rohm et al. 2007). Obtaining accurate estimates of survival, sources of mortality, and habitat use requires that fawns be fitted with radiocollars (Diefenbach et al. 2003). Expandable radiocollars have been developed for fawns of numerous ungulates, including white-tailed deer (*Odocoileus virginianus*; Diefenbach et al. 2003), mule deer (*O. hemionus*; Steigers and Flinders 1980, Bleich and Pierce 1999), pronghorn (*Antilocapra americana*; Keister et al. 1988), and elk (*Cervus elaphus*; Smith et al. 1998). Using expandable radiocollar technology, researchers have collected empirical data on habitat characteristics associated with bed sites (Verme 1977, Huegel et al. 1986, Nelson and Woolf 1987, Jacques et al. 2007*a*, Grovenburg et al. 2010), survival and cause-specific mortality (Nelson and Woolf 1987, Brinkman et al. 2004, Vreeland et al. 2004, Rohm et al. 2007,

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Grovenburg et al. 2011), and dispersal of young ungulates (Jacques and Jenks 2007).

Only a few studies have reported premature loss of expandable radiocollars among fawns. In Pennsylvania, USA, in 2 study areas containing 38% and >80% forested cover, 21 of 218 (9.6%) radiocollared fawns were censored due to lost contact with transmitter or collars prematurely dropping off fawns (Vreeland et al. 2004). In Michigan, USA, in a study area containing 32% forested cover and 28% row crops, radiocollar retention ranged from 40 to 448 days, with 21 of 75 (28%) fawns losing collars (Pusateri-Burroughs et al. 2006). In Illinois, USA, in 2 study areas containing 39% forested cover (17% agricultural) and 51% forested cover (11% agricultural), researchers were unable to determine the fate of 12 of 166 (7.2%) radiocollared fawns, possibly due to collar failure (Rohm et al. 2007). Additionally, 6% collar loss <180 days post-capture was reported in southern Michigan in a study area with 52% agricultural land use and approximately 15% forested cover (Hiller et al. 2008).

Expandable radiocollars were expected to deteriorate and drop off animals between 266 and 365 days (Pusateri-Burroughs et al. 2006), yet studies have documented collar loss as early as <6 weeks post-capture (Vreeland et al. 2004, Pusateri-Burroughs et al. 2006, Grovenburg et al. 2012). Collars are designed to minimize premature loss (6%) prior to 270 days post-capture (Diefenbach et al. 2003); however, early collar loss decreases sample size, resulting in reduced statistical power to detect potential effects of interest. For instance, decreases in sample size because of early collar loss could result in single (i.e., unstratified), rather than multiple (e.g., stratified by sex, season), estimates of survival or prevent documentation of autumn migrations. Therefore, *a priori* knowledge of factors limiting radiocollar retention among fawns during study design could improve efficiency of data collection, reduce costs associated with the study, and improve estimates of demographic parameters. Limited empirical data documenting the influence of variables beyond normal deterioration on premature collar loss are available. Therefore, our objective was to estimate the influence that animal and landscape characteristics have on retention of expandable radiocollars for white-tailed deer, mule deer, and pronghorn fawns.

STUDY AREA

Our study was conducted in South Dakota, Minnesota, and California, USA (Fig. 1). We monitored collar retention of pronghorn in western South Dakota in Fall River, Harding, and Custer counties. Wind Cave National Park (Custer County) was located in the southern Black Hills and was characterized by ponderosa pine (*Pinus ponderosa*) forests and prairies consisting of western wheatgrass (*Pascopyrum smithii*), buffalograss (*Bouteloua dactyloides*), needlegrass (*Stipa* spp.), and big (*Andropogon gerardii*) and little bluestem (*Schizachyrium scoparium*; Lovaas 1973, Varland et al. 1978); the Park was enclosed by a 2.5-m woven-wire fence with cattle guards to prevent emigration by ungulates (Jacques et al. 2007*a*). The western South Dakota study areas were characterized by a mosaic of mixed-grass prairie interspersed

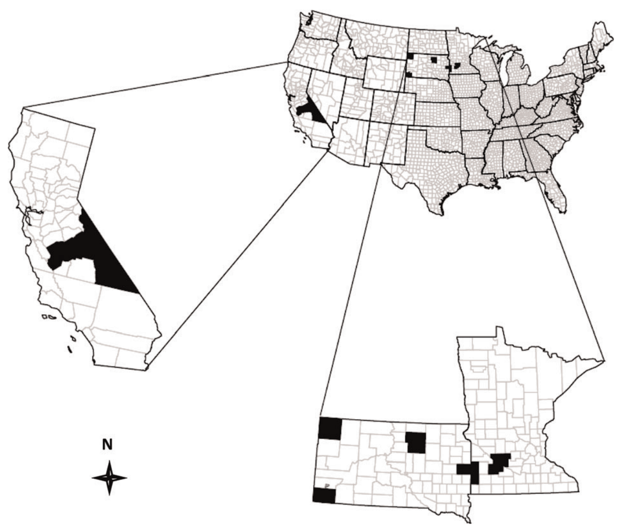

Figure 1. Fawn white-tailed deer (*Odocoileus virginianus*), mule deer (*O. hemionus*), and pronghorn (*Antilocapra americana*) study areas where we documented radiocollar loss (shaded) in California, South Dakota, and Minnesota, USA, 2001–2009.

with shrubs (big sagebrush [*Artemisia tridentata*], silver sagebrush [*A. cana*], western snowberry [*Symphoricarpos occidentalis*], wild rose [*Rosa* spp.], common juniper [*Juniperus communis*]), and patches of predominantly ponderosa pine forest. Topography was rolling prairie with occasional buttes and intermittent streams (Kalvels 1982, Johnson 1988).

We monitored white-tailed deer fawns in north-central and eastern South Dakota and southwest Minnesota. North-central South Dakota (Edmunds and Faulk counties) was characterized by previously glaciated, rolling prairie interspersed with abundant pothole wetland complexes, cultivated agricultural land, intermittent streams, and river floodplains (Bryce et al. 1998). The region was dominated by row-crop agriculture activities (Smith et al. 2002). Eastern South Dakota (Brookings County) lies in the Prairie Coteau Region formed by the Wisconsin Glaciation (Westin et al. 1959). The Coteau historically contained numerous wetlands and in eastern South Dakota, approximately 35% were drained through anthropogenic modifications (e.g., agriculture; Dahl 1990, Johnson and Higgins 1997, Johnson and Larson 1999). Southwest Minnesota was characterized by flat to rolling topography (Albert 1995). Lincoln and Pipestone counties occurred within the Prairie Coteau Physiographic Region, whereas Redwood and Renville counties occurred within the Minnesota River Valley. The Minnesota River Valley was a linear corridor heavily forested with small interspersed grassland remnants and adjacent lands comprised primarily of cultivated crops (Grovenburg et al. 2011). Deer habitat in the region was fragmented and dominated by intense row-crop agriculture (Brinkman et al. 2004).

Mule deer fawns included in our study were captured in the Sierra Nevada of California, in Fresno, Inyo, Madera, and Mono counties. The Sierra Nevada is a northwest–southeast-oriented mountain range that extends 249 km from Lake Almanor in the north, to Tehachapi Pass in the south (Storer et al. 2004). Summer range for mule deer in the Sierra Nevada occurred on both sides of the Sierra crest at elevations ranging from 2,200 m to >3,000 m (Monteith et al. 2011). Summer ranges west of the Sierra crest were substantially more mesic and forested than those east of the crest (Bleich et al. 2006, Monteith et al. 2011). The western slope of the summer range was dominated by the upper montane and mixed-conifer vegetation zones; whereas, the eastern slope of the Sierra Nevada, up to approximately 2,130 m, was dominated by the sagebrush vegetation zone (Storer et al. 2004).

METHODS

We captured fawn white-tailed deer during 15 May–15 June 2001–2004 in eastern South Dakota and southwestern Minnesota (Brinkman et al. 2004, Swanson et al. 2008, Grovenburg et al. 2011), and from 15 May to 15 June 2007–2009 in north-central South Dakota (Grovenburg et al. 2010, 2012). We captured fawn pronghorn during late May and early June 2002–2005 in western South Dakota (Jacques et al. 2007*b*) and fawn mule deer in California during mid-June through mid-July 2005–2007 (Monteith 2011). We used vaginal implant transmitters (VITs; model M3930, Advanced Telemetry Solutions, Isanti, MN; Swanson et al. 2008), postpartum behavior of reproductive females (Downing and McGinnes 1969, White et al. 1972, Huegel et al. 1985), and observations (Byers 1997) to locate fawns prior to capture. We recorded capture locations, determined sex, and fitted all fawns with expandable radiocollars (model M4210, Advanced Telemetry Solutions; model CB-6, Telonics Inc., Mesa, AZ; model TS-37, Telemetry Solutions, Concord, CA). Animal handling methods used in this project followed guidelines approved by the American Society of Mammalogists (Sikes et al. 2011) or followed California Department of Fish and Game protocols for wildlife restraint, and were approved by the Institutional Animal Care and Use Committee at South Dakota State University (Approval nos. 04-A009, 00-A038, 02-A037, 02-A043, 02-A001, 02-A002) and an Independent Institutional Animal Care and Use Committee at Idaho State University (650-0410).

We monitored radiocollared fawns daily through 30 days of age and ≥1 time/week through 270 days of age using a truck-mounted null-peak antenna system with an electronic digital compass (C100 Compass Engine; KVH Industries, Inc., Middletown, RI; Lovallo et al. 1994, Brinkman et al. 2002), Cessna 182 and 185 aircraft (Cessna Aircraft Co., Wichita, KS) fitted with 2, 2-element Yagi antennas, or a hand-held 4-element Yagi antenna. Ground personnel located the collar within 12 hours when we detected a mortality signal (i.e., collar switched to mortality mode after 4 hr of inactivity). We recorded evidence at the collar site to distinguish between mortality of a fawn and whether a collar was shed prematurely. We used evidence of struggle, blood (on ground or collar), or remains as indications of cause of fawn mortality; these collars were right-censored from our analysis at time of death. Collars attached to fencing, trees, or shrubs, and collars with all folds expanded with no evidence of mortality in the immediate area (50-m radius) were considered prematurely shed.

We created buffered areas around capture locations of individual fawns to investigate habitat characteristics potentially influencing collar retention. We followed recommendations regarding use of a standard shape (i.e., circle) and a set size to investigate effects of habitat characteristics (Kie et al. 2002, Bowyer and Kie 2006). Because we monitored fawns to ≥270 days, we chose spatial scales representative of adult summer home ranges among study areas and species; therefore, we chose the spatial scale (1,000 m) that best represented adult summer home-range size for >50% of our data (Brinkman et al. 2005, Grovenburg et al. 2009, Jacques et al. 2009). We delineated circular areas at a 1,000-m radius centered on capture locations of each fawn. Within each buffered area, we determined percent of each land-cover type using the 2001 National Land Cover Data set (Homer et al. 2007). We reclassified land cover into 10 categories: open water, snow, developed, barren, forest, shrub, grassland, pasture, crops, and wetlands. To determine whether fencing influenced collar retention, we ground-verified fences where possible, digitized a unique fence coverage for each study area, and measured linear km of fence within each buffered area using ArcGIS 9.2. We standardized fence values as linear km of fence/km^2 for buffered areas of each fawn. To test for potentially confounding relationships, we evaluated collinearity between predictor variables using Pearson's correlation coefficient ($r > |0.50|$). We used multivariate analysis of variance (MANOVA) in SAS version 9.2 (PROC GLM; SAS Institute, Cary, NC) to determine differences in land-cover variables (forest and shrubs) and fencing between areas where neonates retained and shed collars. We used the Kaplan–Meier estimator in Program MARK with known fate to estimate collar retention (Kaplan and Meier 1958, White and Burnham 1999).

RESULTS

During May–July 2001–2009, we captured and radiocollared 413 fawns (198 white-tailed deer, 142 pronghorn, and 73 mule deer) throughout study regions; 87 collars were shed prematurely. Premature collar loss (<270 days post-capture) ranged from 25.3% to 50.6% among study areas for white-tailed deer (Table 1) and 56 (77.8%) were lost <180 days post-capture. For fawn pronghorns, collar loss ranged from 0% to 12.1% among study areas and 7 (87.5%) were shed <180 days post-capture. For mule deer, premature collar loss was 9.6% and 6 (85.7%) fawns shed collars <180 days post-capture. Probability of a collar being retained for 270 days was 0.36 (SE = 0.04, 95% CI = 0.27–0.47), 0.91 (SE = 0.03, 95% CI = 0.82–0.96), and 0.87 (SE = 0.05, 95% CI = 0.73–0.94), for white-tailed deer, pronghorn, and mule deer fawns, respectively (Fig. 2). Collar failure was most associated with agricultural fencing (Table 1).

Multivariate analysis of variance indicated differences ($F_{3,170} = 11.78$, $P < 0.001$) in land cover among areas where fawns retained collars and where they shed collars. We did not have accurate fencing data for all study sites; however,

Table 1. Capture and expandable radiocollar loss data for white-tailed (WT) deer, pronghorn (P), and mule deer (M) young in South Dakota, Minnesota, and California, USA, 2001–2009. * indicated that collar type was not used.

Study area[a]	Species	Year	N^b	Manufacturer[c]			Failure type[d]			Total[e]
				ATS	Tel.	TS	F	T/S	Shed	
SWMN	WT	2001–2004	95	56 (16)	39 (8)	*	14	4	6	24
ESD	WT	2002–2003	22	22 (7)	*	*	6	0	1	7
NCSD	WT	2007–2009	81	81 (41)	*	*	38	3	0	41
NWSD	P	2002, 2004	58	58 (7)	*	*	3	4	0	7
SWSD	P	2003–2005	58	58 (1)	*	*	0	0	1	1
WCNP	P	2002–2003	26	26	*	*	0	0	0	0
CA	M	2005–2007	73	28 (5)	*	45 (2)	0	2	5	7

[a] SWMN, southwestern Minnesota; ESD, eastern South Dakota; NCSD, north-central South Dakota; NWSD, northwestern South Dakota; SWSD, southwestern South Dakota; WCNP, Wind Cave National Park; CA, California.
[b] No. of young captured and collared.
[c] No. of collars of each manufacturer used and (prematurely shed), ATS, Advanced Telemetry Systems; Tel., Telonics; and TS, Telemetry Solutions.
[d] F, collar found on or within 50 m of agricultural fencing; T/S, collar found on or within 50 m of trees or shrubs; Shed, collar appeared to have been shed by fawn and was not found within 50 m of agricultural fencing, shrubs, trees, or other structure associated with catching of collar.
[e] Total collars shed <270 days post-capture.

fencing (linear km/km^2) for remaining sites was 69% less ($F_{1,172} = 34.88$, $P < 0.001$) between areas where fawns retained collars for 270 days ($\bar{x} = 1.0$ km/km^2, SE = 0.1, $n = 75$) and areas where fawns shed collars ($\bar{x} = 3.2$ km/km^2, SE = 0.1, $n = 56$) prior to 270 days. Mean fencing was 37%, 39%, and 83% less in areas where white-tailed deer, pronghorn, and mule deer young, respectively, retained collars for 270 days than in areas where fawns shed collars. Mean fencing for white-tailed deer, pronghorn, and mule deer young that shed collars was 3.5 (SE = 0.2, $n = 41$), 2.3 (SE = 0.6, $n = 8$), and 1.2 km/km^2 (SE = 0.5, $n = 7$), respectively. Conversely, mean fencing for young that retained collars was 2.2 (SE = 0.8, $n = 8$), 1.4 (SE = 0.2, $n = 55$), and 0.2 km/km^2 (SE = 0.4, $n = 12$) for white-tailed deer, pronghorn, and mule deer, respectively. Amount of fencing was positively correlated with increasing area of cultivated crops ($r = 0.70$) and pasture ($r = 0.56$) in our study areas. Overall mean percent forested cover did not differ ($F_{1,172} = 0.92$, $P = 0.34$) between areas where fawns retained collars for 270 days ($\bar{x} = 5.76$, SE = 1.1, $n = 155$) and areas where fawns shed collars ($\bar{x} = 4.30$, SE = 1.1, $n = 87$) prior to 270 days. Similarly, overall mean percent shrub cover did not differ ($F_{1,172} = 0.47$, $P = 0.63$) between areas where fawns retained collars for 270 days ($\bar{x} = 12.6$, SE = 2.3, $n = 155$) and areas where fawns shed collars ($\bar{x} = 9.6$, SE = 2.1, $n = 87$) prior to 270 days.

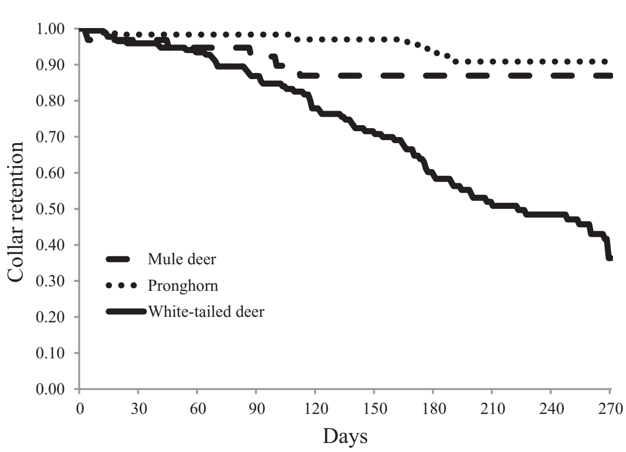

Figure 2. Probability of radiocollar retention to 270 days post-capture for fawn white-tailed deer (*Odocoileus virginianus*), mule deer (*O. hemionus*), and pronghorn (*Antilocapra americana*) in California, South Dakota, and Minnesota, USA, 2001–2009. We used the Kaplan–Meier estimator to estimate collar retention (Kaplan and Meier 1958).

DISCUSSION

During our study, the percentage of expandable collars shed prematurely (<270 days post-capture) for white-tailed deer (25–51%) was greater than previously reported. Although premature collar loss has been documented as early as 40 days post-capture (Pusateri-Burroughs et al. 2006), we observed fawns shedding collars during the hider phase for all 3 species; within 5 days post-capture for white-tailed deer, 3 days for mule deer, and 7 days for pronghorn. During our study, percentage of premature collar loss for fawn mule deer (10%) was somewhat greater than reported in eastern Washington (3%; Johnstone-Yellin et al. 2009). Percentage of premature collar loss was least (4%) for fawn pronghorn, and we were unable to find previous reports in the literature for comparison. Thus, although radiocollars are designed to permit researchers to estimate survival and monitor movements of fawns from birth to about 270 days post-capture with minimal loss (Diefenbach et al. 2003), we documented substantial rates of premature collar loss, particularly for white-tailed deer, with the potential to affect evaluation of study objectives. For instance, if research focused on autumn migration rates of fawns, a robust study design would anticipate 80% reduction in sample size prior to the end of the migratory period. Although poor collar retention can affect the ability of researchers to meet study objectives, we did not observe any concerns regarding animal welfare issues for any of the collar models used in our study (Sikes et al. 2011).

Variation in retention of expandable radiocollars was best explained by species of ungulate, which likely was a result of the disparity in density of fencing encountered by each species. Within each species, amount of agricultural fencing (4-strand barbed wire; linear km/km^2) was greater in areas where juvenile ungulates prematurely shed radiocollars, compared with areas where collars were retained. The majority (>80%) of collars prematurely shed by white-tailed deer fawns were found attached to fences (or <50 m from a fence) with no indication of predation in the area. For instance, in the north-central South Dakota study area, 38 of 41 (93%) collars prematurely shed by white-tailed fawns were found on (74%) or near (<50 m; 26%) fencing, with no evidence of fawn mortality; 3 (7%) prematurely shed collars were found on or near trees or shrubs. White-tailed deer inhabit intensively cultivated regions (e.g., MN and SD) and have readily adapted to anthropogenic alterations in the landscape (Nixon et al. 2001, Brinkman et al. 2004). In this region of the Great Plains, the landscape is fragmented with agricultural fields interspersed among small forested patches, which are mainly shelterbelts and tree plantings, wetlands, and pasture (Smith et al. 2002, Brinkman et al. 2004).

Amount of fencing was positively correlated with increasing area of cultivated crops and pasture in our study area. In pronghorn study areas, farm and ranch lands were used for pasture (Jacques et al. 2007*b*). Although increasing pasture was related to increased fencing, this relationship was minimal for pronghorn because of large, intact tracts of prairie (Smith et al. 2002). Additionally, management guidelines suggest that fencing be minimized on rangelands occupied by pronghorns (Yoakum 2004). Fencing specifications most compatible with pronghorn movements consist of 3 strands of wire (instead of the usual 4), a smooth-bottom wire (instead of barbed) 41–46 cm above the ground, with a total fence height <91 cm (Yoakum 2004), which could mitigate the effect of fencing on collar loss in pronghorn fawns. Similarly, young mule deer in the Sierra Nevada, at elevations >2,200 m with little fencing, experienced minimal collar losses. Average fencing present in ranges occupied by mule deer was lower than that present in study areas for pronghorn and white-tailed deer fawns. Thus, agricultural landscapes such as those inhabited by white-tailed deer in the Great Plains may lead to greater premature collar loss than in less tilled-agricultural or less fragmented regions.

We suggest minor modification to radiocollar design that considers species-specific differences in physical characteristics and landscape features which would reduce premature collar loss. For example, many fawn collars are designed to expand as fawns age by both elastic collar material and the releasing of stitching of multiple folds to increase circumference of the collar. Although not included in this study, during 2008, we modified fawn collars for mule deer in the Sierra Nevada by altering the stitching pattern in an attempt to permit folds to be released in a sequential manner with time, rather than all at once. Accordingly, collar folds were stitched separately, and amount of stitching increased on each subsequent fold. The design modifications resulted in 100% collar retention ($n = 43$) up to 250–270 days, when fawns remaining alive were captured via helicopter on winter range; this indicates that slight modifications may readily improve retention of fawn collars. We observed no animal welfare issues with this modified collar design and collar manufacturers have now incorporated these improvements into their current collar designs.

MANAGEMENT IMPLICATIONS

Obtaining empirical data on factors influencing ecology of juvenile ungulates can be necessary or helpful for successful population management. Researchers studying migration in fawns in agricultural regions containing a substantial density of fencing would have needed to capture and collar about 180 fawns to ensure that ≥30 animals remained collared until the following spring, given baseline mortality rates and unimproved collars from the early 2000s. Design alterations that reduce probability of collars being caught on barbed-wire fences and that expand more reliably as fawns grow are being developed to help improve efficiency of data collection from young-of-the-year ungulates when management direction requires such data.

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