Impact of exercise on productivity, behavior, and immune functioning of weaned *Bos indicus*–cross calves housed in drylots

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ABSTRACT: The effects of 2 exercise regimes on cattle productivity, immune function, and behavior were evaluated against a control ($n = 4$ pens/treatment) using weaned *Bos indicus*–cross calves ($n = 203$) housed in drylots (16–18 calves/single sex pens). Three treatments were applied 3 times per week for 4 wk: 1) programmatic exercise (PRO), in which cattle and a stockperson walked in the alleyway behind their home pen for 20 min; 2) free exercise (FREE), in which cattle were moved into the drovers alley for 60 min, not exercised by a stockperson, and were allowed free access to their home pen and alleyway; and 3) control (CON), in which calves were removed from their home pen only for routine husbandry. Behavior observations were conducted on d –2 and –1 relative to treatment implementation (d 0) and on d 5, 6, 12, 13, 19, 20, 26, and 27. Instantaneous scan sampling was used to create behavioral profiles for cattle (posture: stand, lie, and walk; and behavior: feed, drink, and ruminate). Focal observations recorded the incidence of social behaviors (allogrooming,

social play, and agonistic interactions) and animal–environment interactions (AEI; fencepost licking, rock eating, tongue rolling, and cross-suckling). Body weights, exit velocities, and antibody titers to a bovine viral diarrhea virus type 1b vaccine were measured on d –10, 10, and 28. A linear mixed model (PROC MIXED) was used to evaluate the impact of exercise treatment, sex, time, and their interactions on cattle behavior, health, and productivity. Statistical differences were not observed ($P = 0.11$) for overall ADG among cattle receiving FREE ($1.00 \text{ kg} \pm 0.04$) PRO ($0.85 \text{ kg} \pm 0.04$), or CON ($0.86 \text{ kg} \pm 0.05$) exercise treatments. Allogrooming ($P = 0.05$), lying ($P < 0.01$), AEI ($P < 0.01$), rumination ($P < 0.01$), and agonistic interactions ($P < 0.01$) increased over time. Comfort-related behaviors (e.g., lying, rumination) increased over the evaluation period, suggesting that calves became acclimated to the environment. Exercise did not alter behaviors or vaccine response and did not reduce the performance of production-critical (e.g., feeding, resting, ruminating) behaviors.

Key words: beef cattle, behavior, exercise, feed lot, management strategies, welfare

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INTRODUCTION

Livestock managers seek practices that enhance animal well-being and productivity, especially those that reduce stress and increase coping and thus reduce morbidity and mortality. Exercising cattle is a management practice that does not require substantial infrastructure changes or extensive personnel training. Testimonial reports suggest that exercised cattle have increased BW gains, reduced respiratory morbidity, shorter recovery times, decreased prevalence of dark cutters, and im-

proved emotional attitude compared with nonexercised cattle (Wilson, 2006; Shepherd, 2010). Employees engaged in exercising cattle reported more job satisfaction (Shepherd, 2010) and these consistent, positive human–animal interactions enhance productivity and profitability (Hemsworth, 2003). Cattle in feed yards are typically not overtly exercised due to concerns that exercise reduces gain or efficiency, increases the risk of animal or handler injury, unnecessarily increases labor requirements, and/or negatively impacts meat quality. Yet a comprehensive analysis has not been conducted to empirically evaluate these tradeoffs.

Exercise may be most effective during periods when cattle are experiencing increased stress (e.g., weaning, arrival in the feed yard), which is associated

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with negative impacts on productivity. In humans, moderate exercise enhanced immune function (Nieman, 1994; Nieman and Pedersen, 1999; Davis et al., 2004), alleviated psychological stress (Salmons and Henriksson, 1981; Salmon, 2001), reduced muscle soreness (Andersen et al., 2013), facilitated muscle development (Salmons and Henriksson, 1981), and reduced the probability of suffering from respiratory infections (Nieman, 1994). Therefore, moderate exercise may similarly enhance cattle well-being and productivity. The objective of this experiment was to evaluate the effects of exercise regimes on BW gain, measures of immunocompetence, and cattle behaviors in recently weaned, crossbred calves.

MATERIALS AND METHODS

Animals and Housing

All procedures for this study were approved by the Texas A&M University Institutional Animal Care and Use Committee (IACUC 2016-0259).

Crossbred calves ($n = 203$; three-fourths to seven-eighths Angus, Hereford, or a combination and one-fourth to one-eighth Nellore) were used for the study. Prior to weaning (d -31), calves were weighed and exit velocity (EV; m/s) was measured as described by Burrow et al. (1988), where the time taken for the animals to traverse 1.8 m was recorded using electronic timers (FarmTek, Inc., Wylie, TX). Calves were blocked by sex, stratified by BW and EV, and randomly assigned within strata to 1 of 12 groups (16 to 18 calves/single-sex group).

At weaning (study d -10), pen groups were randomly assigned to 1 of 12 soil-surfaced receiving pens at the Texas A&M University Beef Cattle Systems research unit 12 km west of College Station, TX. Pens provided 35 cm of linear bunk space per calf and 15.7 m² of pen floor space per calf. The study was conducted during the early fall in south-central Texas, where the average high temperature was 24°C, with an average dew point of 17°C. During behavioral observations on d 20, a thunderstorm caused observers to end data collection at 1530 h.

Calves were vaccinated against common clostridial (Covexin 8; Intervet, Inc., Madison, NJ) and viral pathogens (infectious bovine rhinotracheitis, bovine viral diarrhea type 1 and type 2, parainfluenza type 3, and bovine respiratory syncytial viruses) before weaning (d -26; Vira-Shield; Elanco Animal Health, Greenfield, IN) and at weaning (d -10; Titanium 5; Elanco Animal Health). Calves were fed a growing ration (Table 1) once daily at 0600 h, and calves had ad libitum access to water in automatic fountain drinkers.

Table 1. Dietary composition of growing ration provided to *Bos indicus* cross calves throughout the duration of the study

Ingredient	Percent as fed
Ground corn	31.8
Dry distillers grain	30.0
Alfalfa hay	28.7
Mineral premix ¹	2.5
Molasses	7.0

¹Mineral contained 1,587 mg/kg lasalocid.

Treatments

Ten days after weaning (study d 0), exercise treatments ($n = 3$ treatments; 4 pens/treatment) were applied on d 0, 2, 4, 7, 9, 11, 14, 16, 18, 21, 23, and 25. All exercise treatments were performed 1 h after feeding. Each pen was assigned to 1 of 3 treatments. In the control (CON) treatment, calves remained in their home pen except for routine husbandry and health purposes. Calves receiving programmatic exercise (PRO) were moved into the drovers alley behind the pen by a stockperson on foot. The stockperson walked behind the cattle up and down the alleyway for 20 min with the goal of keeping all animals walking for the duration of the exercise session. Cattle were then returned to their home pen. Calves undergoing free exercise (FREE) were moved into the alleyway behind the pen by a stockperson on foot. The gate to their home pen remained open for 60 min allowing cattle to freely move between their home pen and the alleyway. The handler did not engage with the cattle during this time. At the end of 60 min, a stockperson on foot returned the cattle to their home pen. Based on infrastructure limitations, only 2 pens could be simultaneously exercised. Therefore, all exercise sessions were conducted between 0700 and 1000 h, and the order when each pen was exercised was rotated across days.

Productivity and Physiology

All calves were weighed on d -10, 10, and 28, and BW (kg) were used to calculate ADG for each individual. Calves were weighed 1 h after feeding (0700 h) on days that they were not exercised.

On days that BW and EV were measured, a 7-mL blood sample was collected via jugular venipuncture into evacuated tubes. Blood samples were allowed to clot for 2 h at 1°C and then centrifuged at $960 \times g$ for 6 min at 4°C. Serum was decanted and frozen at -80°C until analysis. Serum samples were analyzed for antibody titers to bovine viral diarrhea virus type 1b by the Texas A&M Veterinary Medical Diagnostic Laboratory (Amarillo, TX). Antibody titer data were transformed (log base 2) prior to statistical analysis.

Table 2. Description of behaviors recorded from *Bos indicus* cross calves housed in drylots

Posture/behavior	Definition
Posture	
Lie	Calf is recumbent, not supported by legs (lying laterally or sternally)
Stand	Calf is upright and supported by legs
Walk	Movement of calf's legs, resulting in a change in space
Behavior	
Feed	Calf has head in feed bunk
Ruminate	Calf is regurgitating bolus of feed from stomach, chewing, and reswallowing
Drink	Calf has its head in the water trough and appears to be swallowing
Rest	Calf is either standing or lying and is not performing any other behaviors for >5 s
Solitary play	Calf is engaging in solitary locomotor play (e.g., skip, buck, head toss)
Social play	Calf is engaging in social play (e.g., mount, play fight, butt, chase)
Allogrooming	Licking movements by one cow carried out on the body of another. Characterized by repetitive back-and-forth head movements performed by the actor in direct contact with the reactor. Once the actor stops grooming the reactor for more than 30 s, the bout is finished.
Agonistic behavior	Any behavior associated with conflict or fighting between 2 individuals. Can include bunting, forceful, nonforceful, pushing, and contact.
Animal–environment interactions	Any behavior that is performed repeatedly and inhibits normal functioning of the calves (e.g., repeated rubbing in the absence of disease, tongue rolling/aerophagia, pica/licking or chewing solid objects, eating soil/sand/dirt, navel sucking, ear sucking)

Behavioral Observations

Live behavioral observations were conducted by 2 trained observers on days that cattle were not exercised (d -1, -2, 5, 6, 12, 13, 19, 20, 26, and 27) from 0800 to 1200 h and from 1300 to 1700 h using a 10-min instantaneous scan sampling strategy (48 scans·pen⁻¹·d⁻¹) beginning no earlier than 1 h after feed delivery. Behavioral observations were conducted such that there were 2 consecutive sampling days within each week of the trial. Posture (stand, walk, and lie) and behavior (eat, drink, ruminate, and rest) were observed during the scan sampling. Posture and behavior were considered mutually exclusive; therefore, the simultaneous posture and behavior of each calf was recorded (Table 2). The total number of calves in each pen performing each posture and behavior were recorded. During the time between scan samples, 10-min-long focal observations were used to count incidence of social behaviors (aggressive interaction, allogrooming, play, and vocalizations) and animal–environment interactions (AEI; repeated rubbing in the absence of disease, tongue rolling/aerophagia/vacuum grazing, pica/licking or chewing solid objects, eating soil/sand/dirt, navel sucking, and

ear sucking) within a single pen. Focal observations of each pen were conducted in a set order once every 2 h for a total of 40 min/pen on each day of observations.

Statistical Analysis

For all response data, pen served as the experimental unit. Three different gain responses were computed: overall ADG (d -10 to 28), Period 1 ADG (d -10 to 10), and Period 2 ADG (d 10 to 28). Subsequently, 3 different G:F responses were calculated: overall G:F (d -10 to 28), Period 1 G:F (d -10 to 10), and Period 2 G:F (d 10 to 28). Similar calculations were performed for DMI. The impact of treatment, sex, and their interaction on ADG, DMI, G:F, EV, and antibody titer levels were evaluated with a linear mixed model (PROC MIXED; SAS Inst. Inc., Cary, NC). The model included a random effect of pen within sex × treatment interaction. Differences among means were identified using pairwise *t*-tests when model fixed effects were significant.

On observation days, instantaneous scan samples were combined within pen to calculate daily mean proportions of calves performing each posture and behavior and then daily values were pooled within week. Total number of social behaviors and AEI per 10-min focal observation period was averaged within pen for each day. Instantaneous and focal means were converted to proportions of each pen, and these proportions were arcsine square root transformed to achieve normality and homogeneity of error variance.

On a pen basis, transformed posture, behavior, social behaviors, and AEI responses were evaluated as repeated measures using a linear mixed model (PROC MIXED; SAS version 9.4). Treatment, week, sex, and their interactions served as fixed effects in the model. The repeated factor was week of observation; the subject effect was specified as pen nested within treatment, week, and sex interaction; and covariance structure was specified as compound symmetry. Pen nested within treatment and sex interaction and week within pen, treatment, and sex interaction were random effects used to correctly specify error terms. Means were separated among levels of fixed effects using paired *t*-tests when the fixed effect was significant. Differences were considered statistically significant at $P \leq 0.05$, and effects with $0.05 < P \leq 0.10$ were considered meaningful tendencies.

RESULTS

Productivity and Physiology

A sex × treatment interaction was observed for ADG during Period 1 (from weaning until d 10; Fig. 1a; $P = 0.04$). During Period 1, PRO steers had

Figure 1. Average daily gain (kg) for each sex–treatment combination for (a) the early portion of the study (Period 1: d –10 to 10) and (b) the late portion of the study (Period 2: d 10 to 28). Dry matter intake (kg/d) for each sex–treatment combination for (c) the early portion of the study (Period 1: d –10 to 10) and (d) the late portion of the study (Period 2: d 10 to 28). The G:F for each sex–treatment combination for (e) the early portion of the study (Period 1: d –10 to 10) and (f) the late portion of the study (Period 2: d 10 to 28). Control (CON) calves remained in their home pen except for routine husbandry and health purposes. Calves receiving programmatic exercise (PRO) were moved into the alleyway behind the pen by a stockperson on foot. The stockperson walked behind the cattle in the alleyway for 20 min with the goal of keeping all calves walking for the duration of the exercise session. Cattle were then returned to their home pen. Calves experiencing free exercise (FREE) were moved into the alleyway behind the pen by a stockperson on foot. The gate to their home pen remained open for 60 min allowing cattle to freely move between their home pen and the alleyway. The handler did not engage with the cattle during this time. At the end of 60 min, a stockperson on foot returned the cattle to their home pen. ^{a,b}Differences ($P < 0.05$) among means are represented by lowercase letters.

lower ADG than CON ($P = 0.03$) and FREE steers ($P = 0.03$). Furthermore, CON heifers had lower ADG than CON steers ($P = 0.01$) and FREE steers ($P = 0.01$). A sex $\times$ treatment interaction was observed for ADG during Period 2 (d 10 to 28; Fig. 1b; $P = 0.01$), where PRO steers had greater ADG than CON steers ($P = 0.05$) and CON heifers had greater ADG than PRO heifers ($P = 0.02$) and CON steers ($P = 0.01$). Steers tended to have greater ADG during Period 2 than heifers ($P = 0.08$; Table 3), and CON heifers had greater ADG than CON steers ($P = 0.02$). Neither exercise treatment ($P = 0.11$) nor the sex $\times$ treatment interaction ($P = 0.78$) were significant effects on study ADG (Table 3).

A sex $\times$ treatment interaction tended to influence overall DMI ($P = 0.08$), did not influence DMI during Period 1 (Fig. 1c; $P = 0.12$), but tended to influence DMI during Period 2 (Fig. 1d; $P = 0.06$). A greater overall DMI was observed in FREE heifers compared with all other treatment–sex combinations ($P < 0.05$). A similar pattern was observed in DMI during Period 2 ($P > 0.08$). Treatment did influence DMI during Period 1 ($P = 0.03$), in which FREE cattle ate more than PRO or CON cattle.

A treatment $\times$ sex interaction was observed for Period 1 G:F (Fig. 1e; $P = 0.03$), where CON heifers had less G:F than FREE ($P = 0.01$) and CON ($P = 0.01$) steers. Less G:F was observed in PRO steers than in CON ($P = 0.04$) or FREE ($P = 0.03$) steers. A treatment $\times$ sex interaction was observed for Period 2 G:F (Fig. 1f; $P = 0.02$). Heifers receiving CON had greater G:F than FREE heifers ($P = 0.04$) or CON steers ($P = 0.01$). Steers receiving PRO had greater G:F than CON steers ($P = 0.05$). No interactions were observed for overall G:F ($P = 0.27$). Overall G:F was affected by treatment ($P = 0.05$), where PRO cattle had greater G:F than CON ($P = 0.05$) or FREE ($P = 0.02$) cattle, which were similar ($P = 0.52$).

No sex $\times$ treatment interactions were observed for antibody titer levels on d –10 ($P = 0.65$), 10 ($P = 0.34$), or 28 ($P = 0.44$). Neither sex ($P > 0.20$) nor exercise treatment ($P > 0.29$) influenced titer levels on d –10, 10, or 28 (Table 3).

Behavior

Exit velocity (Table 3) was not influenced by the treatment and sex interaction ($P > 0.23$) or the main effect

Table 3. Physical measurements of *Bos indicus* × *Bos taurus* calves ($n = 203$) experiencing 1 of 3 exercise treatments across a 4-wk period taken during on d −10, 10, and 28 relative to exercise program implementation (d 0) including ADG (kg), DMI (kg/d), G:F, exit velocity (m/s), and serum-neutralizing antibody titer to bovine viral diarrhea virus type 1b. Responses for ADG, DMI, and G:F are reported for the overall duration of the study (d −10 to 28), Period 1 (d −10 to 10), and Period 2 (d 10 to 28). Calves experienced 1 of 3 treatments 3 times per week for 4 wk. Measurements were taken on days that the calves were not exercised. Mean values are presented with standard error of the mean in parenthesis

Item	Evaluation period	Exercise treatment ¹			<i>P</i> -value	Gender		<i>P</i> -value
		CON	FREE	PRO		Steer	Heifer	
ADG, kg	Overall	0.86 (0.05)	1.00 (0.04)	0.85 (0.04)	0.11	0.96 (0.04)	0.85 (0.04)	0.08
	Period 1	0.67 (0.09)	0.83 (0.10)	0.61 (0.09)	0.28	0.83 (0.07)	0.58 (0.08)	0.04
	Period 2	1.16 (0.10)	1.15 (0.11)	1.12 (0.11)	0.96	1.10 (0.08)	1.19 (0.09)	0.45
DMI, kg/d	Overall	92.26 (1.20)	92.14 (1.62)	86.15 (1.13)	0.04	90.72 (1.78)	89.95 (1.51)	0.55
	Period 1	71.82 (0.88)	72.30 (1.18)	69.28 (0.97)	0.20	71.57 (1.09)	70.70 (0.83)	0.53
	Period 2	116.11 (1.93)	115.29 (2.29)	105.84 (1.90)	0.02	113.06 (2.70)	111.76 (2.50)	0.61
G:F	Overall	0.23 (0.01)	0.20 (0.01)	0.19 (0.01)	0.06	0.22 (0.01)	0.20 (0.01)	0.07
	Period 1	0.15 (0.02)	0.17 (0.02)	0.13 (0.02)	0.64	0.18 (0.02)	0.12 (0.02)	0.06
	Period 2	0.16 (0.01)	0.14 (0.01)	0.16 (0.01)	0.38	0.15 (0.01)	0.16 (0.01)	0.59
Exit velocity, m/s	d −10	1.71 (0.12)	1.61 (0.13)	1.67 (0.11)	0.72	1.73 (0.10)	1.59 (0.09)	0.34
	d 10	2.02 (0.19)	1.78 (0.13)	2.21 (0.14)	0.09	2.07 (0.13)	1.96 (0.12)	0.55
	d 28	2.32 (0.10)	2.39 (0.11)	2.39 (0.12)	0.26	2.72 (0.10)	2.55 (0.10)	0.26
Antibody titer ²	d −10	0.65 (0.15)	0.72 (0.15)	0.78 (0.14)	0.82	0.84 (0.12)	0.60 (0.11)	0.20
	d 10	4.82 (0.28)	4.77 (0.34)	5.40 (0.26)	0.29	4.77 (0.21)	5.23 (0.26)	0.21
	d 28	5.75 (0.21)	5.94 (0.20)	5.87 (0.18)	0.87	5.78 (0.15)	5.92 (0.17)	0.73

¹Control (CON) calves remained in their home pen except for routine husbandry and health purposes. Calves receiving programmatic exercise (PRO) were moved into the alleyway behind the pen by a stockperson on foot. The stockperson walked behind the cattle in the alleyway for 20 min with the goal of keeping all calves walking for the duration of the exercise session. Cattle were then returned to their home pen. Calves experiencing free exercise (FREE) were moved into the alleyway behind the pen by a stockperson on foot. The gate to their home pen remained open for 60 min allowing cattle to freely move between their home pen and the alleyway. The handler did not engage with the cattle during this time. At the end of 60 min, a stockperson on foot returned the cattle to their home pens.

²Means and SE are the log₂ concentration.

of sex ($P > 0.26$) across all observation days. Exit velocities on d 10 tended to be slower in FREE-treated cattle compared with PRO- and CON-treated cattle ($P = 0.09$).

A week × treatment × sex interaction ($P = 0.04$) was observed for the proportion of calves in the pen feeding (Fig. 2). A smaller proportion of CON-treated heifers in the pen were observed feeding compared with all other treatment–sex combinations ($P < 0.05$), except for FREE steers ($P = 0.06$), prior to treatment implementation (wk −1). After treatment implementation, a smaller proportion of CON-treated heifers in the pen were observed feeding compared with FREE-treated heifers during wk 1 ($P = 0.02$) and 2 ($P = 0.02$).

No interaction effects were observed for the proportion of calves in the pen lying (Fig. 3a; $P > 0.20$), standing (Fig. 3b; $P > 0.32$), or walking (Fig. 3c; $P > 0.53$). Similarly, no interaction effects were observed for the proportion of calves in the pen drinking (Fig. 4b; $P > 0.26$), ruminating (Fig. 4c; $P > 0.24$), or resting (Fig. 4d; $P = 0.11$).

The proportion of calves in the pen lying ($P < 0.0001$), drinking ($P < 0.0001$), and ruminating ($P = 0.001$) increased as calves aged whereas the proportion

of calves in the pen standing ($P < 0.0001$) decreased as calves aged. Walking and drinking are difficult to capture using instantaneous sampling and, therefore, these results may not be an accurate representation of the performance of these behaviors (Altmann, 1974; Daigle and Siegford, 2014; Mitlöhner et al., 2001; Madruga et al., 2017). In spite of this known challenge, there are no clearly superior alternative methods.

No interaction effects were observed for the proportion of calves in the pen performing AEI (Fig. 5a; $P > 0.14$), allogrooming (Fig. 5b; $P > 0.15$), social play (Fig. 5c; $P > 0.14$), or agonistic interactions (Fig. 5d; $P > 0.11$) during the 10-min observation period. Allogrooming ($P = 0.03$), agonistic interactions ($P = 0.008$), social play ($P > 0.09$), and AEI ($P < 0.0001$) increased as the calves aged.

DISCUSSION

Long-term benefits of exercise for beef cattle are unknown, and the optimal method of cattle exercise needs to be further evaluated. Increases in the proportion of the pen lying down, ruminating, and allogrooming

Figure 2. Proportion of cattle feeding throughout the duration of the 5-wk study for each sex–treatment combination. Control (CON) calves remained in their home pen except for routine husbandry and health purposes. Calves receiving programmatic exercise (PRO) were moved into the alleyway behind the pen by a stockperson on foot. The stockperson walked behind the cattle in the alleyway for 20 min with the goal of keeping all calves walking for the duration of the exercise session. Cattle were then returned to their home pen. Calves experiencing free exercise (FREE) were moved into the alleyway behind the pen by a stockperson on foot. The gate to their home pen remained open for 60 min allowing cattle to freely move between their home pen and the alleyway. The handler did not engage with the cattle during this time. At the end of 60 min, a stockperson on foot returned the cattle to their home pen. ^{a,b}Differences ($P < 0.05$) among means within week are represented by lowercase letters.

across the study period indicated that cattle acclimated to pens as the study progressed. Lying and ruminating are both comfort-related behaviors important to cattle productivity (Haley et al., 2000). Angus/Hereford cows (Bristow and Holmes, 2007) with greater cortisol concentrations were observed to spend less time ruminating. Dairy cattle with greater milk yields spent more time ruminating, and higher-parity cows displayed longer lying bouts (Stone et al., 2017). Exercise did not mitigate the performance of these behaviors by cattle in this study, illustrating that treatment did not influence cattle acclimation or comfort.

Allogrooming (i.e., social licking) is an important component of social bonding, (Šárová et al., 2016). Cattle that receive allogrooming experience a decrease in heart rate during the allogrooming event, and cattle giving allogrooming experience an increase in heart rate during the allogrooming event (Laister et al., 2011) demonstrating that physiological changes are induced by engaging in this behavior. A positive relationship between allogrooming and duration of time housed together has previously been observed in *Bos taurus* cattle (Sato et al., 1991). The sociopositive behaviors and interactions of grazing *Bos indicus* × *Bos taurus* cross cattle were positively correlated with forage conditions, suggest-

ing that when basic needs (e.g., nutrition, shelter) are met, cattle will spend more time engaging in allogrooming and will maintain a stable linear social hierarchy (Améndola et al., 2015). Social hierarchies become unstable when competition for food increases (Val-Laillet et al., 2009), and changes in stocking density (Huzzey et al., 2006) and social groupings (Bouissou et al., 2001) can increase agonistic interactions. The increases in allogrooming behavior observed in this study suggest that the longer calves remained in the same physical and social environment, the more comfortable they became.

Exercise did not influence bovine viral diarrhea virus type 1b antibody titers. Although others have observed benefits of exercise on immunological responses (Raidal et al., 2000; Andriichuk and Tkachenko, 2017), the exercise regimes imposed here may not have been sufficient to induce similar outcomes. Amount, duration, and intensity of exercise can influence exercise efficacy on antibody titers (Pedersen and Hoffman-Goetz, 2000), and identifying an optimal exercise regime will be challenging because optimal exercise regimes may be species- and context- (e.g., weather, nutritional status, reproductive status) specific (van Dijk and Matson, 2016).

Increases in AEI, social play, and agonistic interactions across duration of the study may be due to

Figure 3. Proportion of cattle within a pen (a) lying, (b) standing, and (c) walking across the 5-wk study period. Control (CON) calves remained in their home pen except for routine husbandry and health purposes. Calves receiving programmatic exercise (PRO) were moved into the alleyway behind the pen by a stockperson on foot. The stockperson walked behind the cattle in the alleyway for 20 min with the goal of keeping all calves walking for the duration of the exercise session. Cattle were then returned to their home pen. Calves experiencing free exercise (FREE) were moved into the alleyway behind the pen by a stockperson on foot. The gate to their home pen remained open for 60 min allowing cattle to freely move between their home pen and the alleyway. The handler did not engage with the cattle during this time. At the end of 60 min, a stockperson on foot returned the cattle to their home pen. The units for all y-axes are the arcsine square root transformation of the proportion of the pen performing the behavior described in the y-axis. ^{a,b}Differences ($P < 0.05$) among weeks are indicated by lowercase letters.

Figure 4. Proportion of cattle within a pen (a) feeding, (b) drinking, (c) ruminating, and (d) resting across the 5-wk study period. Control (CON) calves remained in their home pen except for routine husbandry and health purposes. Calves receiving programmatic exercise (PRO) were moved into the alleyway behind the pen by a stockperson on foot. The stockperson walked behind the cattle in the alleyway for 20 min with the goal of keeping all calves walking for the duration of the exercise session. Cattle were then returned to their home pen. Calves experiencing free exercise (FREE) were moved into the alleyway behind the pen by a stockperson on foot. The gate to their home pen remained open for 60 min allowing cattle to freely move between their home pen and the alleyway. The handler did not engage with the cattle during this time. At the end of 60 min, a stockperson on foot returned the cattle to their home pen. The units for all y-axes are the arcsine square root transformation of the proportion of the pen performing the behavior described in the y-axis. ^{a,b}Differences ($P < 0.05$) among weeks are indicated by lowercase letters.

Figure 5. Proportion of cattle within a pen performing (a) animal–environment interactions, (b) allogrooming, (c) social play, and (d) agonistic interactions across the 5-wk observation period. Control (CON) calves remained in their home pen except for routine husbandry and health purposes. Calves receiving programmatic exercise (PRO) were moved into the alleyway behind the pen by a stockperson on foot. The stockperson walked behind the cattle in the alleyway for 20 min with the goal of keeping all calves walking for the duration of the exercise session. Cattle were then returned to their home pen. Calves experiencing free exercise (FREE) were moved into the alleyway behind the pen by a stockperson on foot. The gate to their home pen remained open for 60 min allowing cattle to freely move between their home pen and the alleyway. The handler did not engage with the cattle during this time. At the end of 60 min, a stockperson on foot returned the cattle to their home pen. The units for all y-axes are the arcsine square root transformation of the proportion of the pen performing the behavior described in the y-axis. ^{a-c}Differences ($P < 0.05$) among weeks are indicated by lowercase letters.

changes in eating modality, social hierarchy establishment, or an unfulfilled motivation for physical activity. With the Lorenzian psychohydraulic model of motivation (Lorenz, 1950), if the internal state of the animal is satisfied, then the animal would not be motivated to perform the behaviors needed to return the animal to homeostasis because the behavioral need has been fulfilled. Although calves may not have been unsatisfied with regard to aggression, they may have had an unfulfilled motivation to engage in physical activity.

The pragmatic and economic needs of beef industry sustainability dictate that cattle spend part of their life in feed yards. Living in a feed yard requires cattle to change the mode in which they eat (e.g., transition from grazing to feeding). This change in eating modality typically shortens the duration of time spent per day that cattle use their mouths to acquire food and ruminate. Cattle on pasture spent 6.8 to 13 h/d engaged in grazing, 4.7 to 13.0 h/d engaged in ruminating behaviors, and 0.2 to 2.9 h/d walking 1.7 to 12.6 km/d (Kilgour, 2012). Conversely, feedlot cattle spent up to 1.4 h/d feeding (Schwartzkopf-Genswein et al., 1999) and 4.1 to 5.1 h/d ruminating (Gentry et al., 2016). Therefore,

the duration that feedlot cattle are engaged in orally centered behaviors is shorter than that of cattle housed on pasture. This change in eating behavior results in cattle having unfulfilled motivations to use their mouths. As a consequence, cattle may engage in orally directed behaviors (e.g., tongue rolling, fencepost licking) that resemble stereotypic behaviors observed in zoo-housed giraffes and okapis (Redbo and Nordblad, 1997; Orban et al., 2016). Exercise did not mitigate the performance of these behaviors by cattle in this study, illustrating that exercise is not a management strategy that can be implemented to mitigate the performance of these behaviors.

Moderate exercise for cattle is a management practice that has the potential to improve cattle welfare and feedlot productivity. Based on observed effects of exercise in humans, mice, and dairy cattle, engaging cattle in moderate exercise during times of transition facilitates the maintenance of homeostasis and has been demonstrated to be beneficial to tie-stall dairy calf health and welfare (Popescu et al., 2013). Results from this study illustrate that different types and intensities of physical activity influence the efficacy of this management practice, because cattle may

have perceived the forced continuous activity experienced during PRO as aversive. Therefore, if therapeutic exercise sessions are to be used, they should be short in duration and conducted at a low intensity. However, further empirical evaluation is needed.

Exercising feedlot cattle can yield benefits and is accompanied with risks including animal injury, exposure of healthy cattle to sick cattle in a different pen, potentially compromising air quality through increased generation of dust, and employee health and safety. Cattle in the FREE and PRO treatments yielded production benefits, yet it is unknown if the economic benefits from these gains outweigh the cost of implementation and risk exposure. Increases in comfort behaviors illustrate that calves habituate to their environment within 2 wk; however, after this 2-wk period, increases in AEI suggest that they become bored and seek mental and physical stimulation. A cost-benefit analysis is needed before recommending changes in husbandry and animal management.

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