Milk- and starter-feeding strategies to reduce cross sucking in pair-housed calves in outdoor hutches

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ABSTRACT

Social housing of preweaned calves can benefit their welfare, but housing and cross sucking are potential barriers to adoption for farmers. For farms using outdoor hutches, an option is to pair adjacent hutches with a shared fence. Our objective was to investigate milk- or starter-feeding strategies to mitigate cross sucking in this system. Holstein heifers were housed in pairs (n = 32 pairs) and divided into 4 treatments (n = 8 pairs each) in a 2 × 2 factorial design: milk in an open bucket with starter in only a bucket (OB-SB), milk in an open bucket and starter in both a bucket and a specialized teat bottle (Braden bottle; OB-BB), milk in a slow-flow teat bucket with starter in only a bucket (TB-SB), or milk in a slow-flow teat bucket and starter in both a bucket and a specialized teat bottle (TB-BB). When starter was first offered (d 6 ± 1 of life, mean ± SD), calf latency to approach was recorded, averaged within pairs, and compared between starter treatments using a linear mixed model with fixed effect of treatment and random effect of pair within treatment. Calves were initially bottle fed; milk treatments began on d 14 ± 1 of life and ended when calves were completely weaned (d 53 ± 1). Calves were observed for behaviors such as drinking milk and cross sucking twice weekly for 30 min during the afternoon milk meal using continuous video, with values averaged within pairs. Linear mixed models were run separately before (wk 3–6) and after (wk 7–8) weaning, with fixed effects of milk- and starter-feeding treatments, week, and the 2- and 3-way interactions, with week as repeated measure and pair as subject.

Pairs with Braden bottles and buckets approached starter sooner than those with only buckets (Braden bottles vs. no Braden bottles: 13.1 ± 6.1 vs. 33.2 ± 6.1 min, LSM ± SEM). Before weaning, pairs with open buckets for both milk and starter cross sucked for at least twice as long (OB-SB: 2.9 ± 0.3 min) as all other treatments (OB-BB: 1.5 ± 0.3 min; TB-SB: 0.4 ± 0.3 min; TB-BB: 0.5 ± 0.3 min). This pattern held during weaning, when cross sucking increased overall (OB-SB: 3.9 ± 0.4 min; OB-BB: 1.8 ± 0.4 min; TB-SB: 0.9 ± 0.4 min; TB-BB: 1.6 ± 0.4 min). Regardless of starter treatment, calves spent less time cross sucking when fed milk in teat buckets, which extended the milk meal relative to open buckets (teat bucket vs. open bucket: preweaning = 7.0 ± 0.2 vs. 1.6 ± 0.2 min; weaning = 3.0 ± 0.1 vs. 0.6 ± 0.1 min). When calves are fed milk in open buckets, a novel option for reducing cross sucking is to provide starter through a specialized bottle. Nonetheless, providing milk in slow-flow teat buckets had the greatest effect on reducing cross sucking by directing suckling to the teat instead of another calf or pen objects.

Key words: social housing, group housing, oral behavior

INTRODUCTION

In the United States, 70% of preweaned dairy calves are housed individually (USDA, 2016). However, housing multiple calves together before they are weaned has shown benefits for both their growth and welfare (reviewed by Costa et al., 2016). Specifically, socially housed calves have been shown to have greater BW gains and solid feed intake during the milk-feeding stage and immediately after weaning when first regrouped (De Paula Vieira et al., 2010; Bernal-Rigoli et al., 2012; Jensen et al., 2015). Regarding welfare, the addition of a social companion and increased space allows for greater display of natural behaviors such as play (Jensen et al., 1998; Duve et al., 2012) and allogrooming (Duve and Jensen, 2012). Increased social interaction leads to improved social development (Babu et al., 2004), resulting in calves displaying less aggression and fear. When compared with individually reared calves, socially housed calves approach novel penmates sooner when placed into mixed groups (De Paula Vieira et al., 2012) and show lower heart rates when interacting with novel conspecifics in a testing situation (Jensen et al., 1997). Socially reared calves have demonstrated greater behavioral flexibility relative to single-housed...
calves when learning reversal tasks (Meagher et al., 2015; Horvath et al., 2017), which translates into their ability to adapt to changes in their environment, such as learning how to use novel feeders sooner (De Paula Vieira et al., 2010).

The aforementioned benefits have all been observed in calves housed in indoor pens, but recent research has begun to explore pair raising calves using adjacent outdoor hutches with a shared fence, creating a feasible option for producers already using this management system (Pempek et al., 2013; Wormsbecher et al., 2017; Whalin et al., 2018). These studies have found that pair-housed calves in hutches had greater solid feed intake than individually housed calves during the preweaning and weaning periods (Whalin et al., 2018). However, producers still have concerns about how to effectively implement pair housing and mitigate undesirable nonnutritive oral behaviors, such as cross sucking, in an outdoor pair-hutch system. Cross sucking, defined as the act of a calf suckling on the body part of another calf, is rarely observed in natural dam-rearing systems (reviewed by Jensen, 2003). This abnormal behavior could potentially be associated with navel infections,udder deformations, mastitis, and reduced production (Lidfors and Isberg, 2003). However, recent studies found no consistent associations between cross sucking during the preweaning period and navel infections (Größbacher et al., 2018) or between cross sucking persisting postweaning and mastitis or higher SCC in the first lactation (Vaughan et al., 2016). Nonetheless, producers may perceive cross sucking as a nuisance behavior and seek to reduce its occurrence.

Calves are naturally motivated to suckle. This motivation is stimulated with the ingestion of lactose in milk (de Passillé, 2001) and continues after the milk meal is complete (Rushen and de Passillé, 1995; de Passillé, 2001). Without an appropriate suckling outlet, this behavior could then lead to nonnutritive oral behavior directed to objects in the pen or toward other calves, either in the form of cross sucking or allogrooming (social licking). In indoor pens, reduced nonnutritive oral behavior, including cross sucking, has been observed when calves are provided milk through a teat instead of a bucket or by providing a dry teat for calves to redirect suckling behavior away from the pen and other calves (Veissier et al., 2002; Jensen and Budde, 2006). Prolonging the milk meal by reducing the flow rate of milk through the teat and leaving the milk-feeding or dry teat in the pen for at least 20 min after the milk meal can further reduce cross sucking (Jung and Lidfors, 2001). Leaving calves with access to the milk-feeding teat requires management because milk bottles commonly need to be removed from the pen after the meal for cleaning; in contrast, dry teats can be mounted inside the pen, allowing calves continuous 24-h access to a suckling outlet (Seo et al., 1998).

The 2 Canadian studies evaluating pair housing using hutches reported low levels of cross sucking during and immediately after the milk meal (Wormsbecher et al., 2017; Whalin et al., 2018). This may be because both fed high volumes of milk (10–16 L/d) through a teat and provided calves with hay, which has been shown to reduce pen-directed sucking in individually housed calves (Horvath and Miller-Cushon, 2017). In the single previous US study on paired hutches, Pempek et al. (2013) reported less cross sucking when calves were fed milk from bottles rather than buckets. However, that study fed low volumes of milk (4–6 L/d). For US dairy producers, who commonly house calves in outdoor hutches (38% of US operations; USDA, 2016) and feed milk at intermediate volumes compared to previous studies using paired hutches (i.e., 35% of Wisconsin farms feed 8 quarts or 7.6 L/d, the most common strategy reported; J. Van Os, unpublished data), further research is needed to identify feasible cross-sucking mitigation strategies. In particular, although teat-feeding of milk is known to be beneficial, this practice is still relatively uncommon in the US dairy industry (e.g., 33% of Wisconsin farms; J. Van Os, unpublished data). Practical solutions are needed to provide alternative outlets for suckling behavior that producers who bucket feed milk could be willing to adopt. A novel solution for redirecting suckling behavior, similar to a dummy teat, could be a grain bottle with a specialized teat allowing solids to pass through (Braden Start; The Coburn Co., Whitewater, WI; Figure 1B). Another benefit to the grain bottle, relative to a bucket, is less feed wastage and spoilage (Megahee et al., 1992; Quigley et al., 1992). Additionally, calves fed starter through the grain bottle had earlier and greater consumption of solids in wk 1 of life (0.22 vs. 0.02 kg as-fed from grain bottle vs. bucket), although this early starter consumption may have, in part, been driven by hunger due to the low milk allowance (3.6 L/d in Megahee et al., 1992).

To date, there have been no studies on mitigating cross sucking in paired calves in outdoor hutches when fed a milk allowance reflecting recommended practices in the United States, nor has any study investigated grain bottles as a novel cross-sucking mitigation strategy. Our objective was to evaluate the effects of different starter- and milk-delivery methods on nonnutritive oral behavior, particularly cross sucking, in paired calves. We predicted that pairs provided both milk and starter through teats would display the least amount of cross sucking, relative to those fed in open buckets, due to having more appropriate outlets for suckling behavior, and that those fed either milk or starter through a teat would show intermediate levels of cross sucking.
In addition, we predicted that calves fed milk in open buckets would consume their milk more quickly and display more competition than those fed from teats. Finally, we predicted that calves offered starter in both Braden bottles and buckets would approach starter sooner when it was initially offered, relative to calves fed only in open buckets, perhaps due to attraction to the teat of the Braden bottle.

**MATERIALS AND METHODS**

The study was conducted during the late spring to fall (May to November 2019) at the University of Wisconsin-Madison (UW-Madison) Emmons Blaine Dairy Cattle Research Center in Arlington, Wisconsin, with all procedures approved by the Institutional Animal Care and Use Committee (protocol #A006133).

**Animals and Treatments**

Sixty-four Holstein-Friesian dairy heifer calves were enrolled sequentially as they were born and remained on the study until they were completely weaned at 53 ± 1 d of age (mean ± SD). Calves were pair housed, with pairs assigned to 1 of 4 feeding treatments in a 2 × 2 factorial design (n = 8 pairs each): milk and starter delivered in open buckets (OB-SB); milk delivered in an open bucket and starter in an open bucket plus a bottle with a specialized teat allowing solids to pass through (OB-BB; Braden Start, 2.8-L capacity; The Coburn Co., Whitewater, WI; Figure 1B); milk delivered in a slow-flow teat bucket (Milk Bar 1, 3.7-L capacity; The Coburn Co.; Figure 1A) and starter in an open bucket (TB-SB); milk delivered in a slow-flow teat bucket and starter in an open bucket plus the specialized starter bottle (TB-BB). Calves were assigned to hutches sequentially by birth order, with treatments pre-assigned to pairs of hutches in a balanced fashion across the sequence.

**Power Analysis**

Key comparisons for this study were behavioral measures of nonnutritive oral behavior, including cross sucking. In many previous studies, because these types of behavioral responses were not normally distributed, nonparametric analysis was applied (de Passillé et al., 2010, 2011), which could not serve as a basis for a power analysis. Horvath and Miller-Cushon (2017) compared an enriched feeding treatment (milk fed through a teat system and hay provided) to a negative control (milk fed in a bucket, no hay) for individually housed calves. Very large effect sizes (Cohen’s d ≥ 1.2) were found in that study when comparing the proportion of the observation periods calves spent engaging in nonnutritive sucking and other abnormal oral behaviors directed toward surfaces in their housing environment (mean differences: 4.1–4.2% of observation periods; SD: 2.8% of observation periods). Based on this, a sample size of at least n = 7 experimental units per treatment was required to achieve a power of 0.8 or higher, and thus we chose to use n = 8 pairs per treatment.

**Housing and Management**

**Enrollment Criteria.** Calves were separated from their dam, weighed, had their navels dipped with iodine solution, and were fed 3.8 L of colostrum within 6 h of birth (d 1). They also received Clostridium perfringens types C and D antitoxin. Calves weighing <30 or >48 kg were excluded from the trial (more than ± 2 SD from the mean birthweights of the farm’s calves from the 12 mo preceding the start of the trial). Average birthweight was 38 ± 3 kg (mean ± SD). If weight criterion was met, calves were then temporarily housed in individual outdoor plastic hutches (Calf-Tel Deluxe II; Hampel Corp., Germantown, WI) until d 3 ± 1 of life (mean ± SD), with ad libitum access to drinking water from a black plastic pail (C18933; Nasco, Fort Atkinson, WI) hung on the fence. To test for failure of passive transfer of immunity, blood samples were collected from the jugular vein within 48 h after the first colostrum feeding using 10.0-mL 16 × 125 mm BD vacutainer venous blood collection tubes with clot additive. After collection, tubes were stored at room temperature for 30 min to allow for clotting. Tubes were then centrifuged for 15 min at 1,545 × g. Serum was analyzed using a Premiere RHC-200-ATC refrac-
tometer (C&A Scientific Co. Inc., Manassas, VA). Only calves with serum protein >5.1 g/dL (Elsohaby et al., 2019) were enrolled in the trial. To be assigned to the same pair, calves’ birthweights had to be within 10 kg of each other. Once enrollment criteria were met, calves were moved to experimental housing.

**Experimental Housing.** Each pair of calves had 2 adjacent hutches (Calf-Tel Deluxe II, 1.1-m wide × 2.1-m deep × 1.2-m high inside dimensions; Hampel Corp.) connected with a 0.6-m wide × 1.2-m high × 9.5-mm thick white plastic board (High Density Polyethylene Sheet; Hemisphere Design Works, Muskegon, MI) and a 2.7-m wide × 1.8-m deep outdoor area enclosed with 1.2-m-high wire fencing (4.7 m² total space per calf; Figure 2A, B). All hutches and the outdoor enclosure were deep bedded with sand, with additional sand added according to weather conditions; this bedding type was chosen to minimize the possibility of calves consuming bedding during the study (Phillips, 2004; Kertz, 2007). Calves within each pair were initially separated with a wire fencing panel dividing the outdoor enclosure; this period lasted 4 ± 1 d (mean ± SD; range: 2–7 d). Once both calves assigned to the pair were determined by farm staff to be drinking milk consistently, calves were paired by removing the dividing panel by the end of wk 1 (6 ± 1 d of age, mean ± SD, range: 4–9 d of age). Within a given pair, the difference in age was 1 ± 1 d (range: 0–3 d).

**Solid Feed Provision.** Calves were first fed starter immediately after the dividing panel in each pair was removed, between 1230 and 1400 h. The texturized starter (BSF 18; Vita Plus, Madison, WI) was composed of corn (43.5%), soybean meal (28.5%), cottonseed hull pellets (12.5%), molasses (5.0%), roasted soybeans (2.8%), wheat middlings (2.2%), calcium carbonate (1.6%), a mineral and vitamin premix (1.0%), dicalcium phosphate (0.6%), and salt (0.5%). For all calves, starter was fed in a black plastic bucket (C18933, 8-L capacity; Nasco) inside the hutch; in the Braden-bottle treatments, 2 Braden bottles per pair were mounted on the enclosure fence at a height of 86 cm off the ground, relative to the bottom of the teat (Figure 2B). In each pair, calves were initially given starter simultaneously, and those in Braden bottle treatments received starter in both the bottle and bucket at the same time. Starter was topped up twice per day (0600 and 1300 h) and

![Figure 2: Diagram of the paired-hutch layouts.](image-url)
fully replaced twice per week; to ensure ad libitum availability, the amount of starter offered was increased daily based on consumption (>5% refusals by weight). For descriptive purposes, starter intakes on an as-fed basis were collected at the pair level by weighing refusals twice per week and subtracting from the weight of starter delivered since the previous recording. For pairs with Braden bottles, refusals were measured separately for the buckets and Braden bottles. The dry matter percentage of refusals collected from the buckets versus Braden bottles was 86.6 ± 4.2% versus 87.3 ± 8.4% (mean ± SD), respectively.

**Milk and Water Provision.** All calves were fed pasteurized whole milk outside of the hutch twice daily at 0400 and 0530 h, and 1500 and 1600 h. All calves were initially hand fed 1.9 L twice per day by bottle. Once calves were determined by farm staff to be drinking sufficiently (5 ± 1 d of age, mean ± SD), milk volume was increased to 2.8 L twice per day, fed in bottles hung on the fence. When calves reached 14 ± 1 d of age (mean ± SD), milk allowance was increased to 3.8 L twice per day and fed from the assigned milk-feeding treatment (slow-flow teat bucket or open bucket). On the research farm, this is the age at which individually housed calves are stepped up to this maximum milk allowance, fed in open buckets, as is the standard practice (i.e., “bucket breaking”) following initial bottle feeding of milk. The farm staff trained calves to use both of the milk-feeding treatments by leading calves to the buckets and allowing calves to suck on their fingers. For the open buckets, the staff then placed their fingers inside of the buckets to further lure the calves, who took 2 to 3 consecutive feedings before they drank from the open buckets on their own.

Daily pasteurized milk samples from the afternoon milk feeding were collected and analyzed for composition (butterfat: 3.2 ± 0.4%; protein: 3.3 ± 0.2%; lactose: 4.6 ± 0.1%; SNF: 8.9 ± 0.2%; MUN: 13.3 ± 1.5%; SCC (×1,000): 690.4 ± 336.8; mean ± SD; AgSource, Verona, WI). Milk consumption was determined visually, with plastic numbered identification tags, and calves were identified using their coat patterns and ear-tag numbers. Measurements were recorded to the nearest minute. Live observation was performed by 1 to 2 out of 3 trained observers on any given occasion, each watching ≤4 adjacent calves, and video observation was performed by a single observer (the trainer, R. S. S.); interobserver reliability was evaluated as described below for behaviors during milk feeding. Calves who did not approach starter within the observation period (8 calves across 8 different pairs; 2 in the Braden bottle plus bucket treatment, 6 in the bucket-only treatment) were assigned the maximum value of 90 min; the next-longest recorded value was 82 min.

**Disbudding.** Calves were hot-iron disbudded, in conjunction with administration of a lidocaine cornual nerve block and oral meloxicam, at 17 ± 1 d of age (mean ± SD); this age was chosen so the procedure would occur after calves adjusted to the milk-feeding treatments.

**Measures**

**Latency to Approach Starter.** For latency to first approach starter when it was offered, calves were observed for 90 min following starter delivery using a combination of live observation and continuous video recordings. Calves were habituated to the researchers walking the rows of hutches during daily morning tasks. Live observation, performed from 4.3 m away, was used to determine the time calves approached starter inside the hutches where the cameras did not have visibility. Cameras (H9R action camera; Eken, Shenzhen, China) were positioned 4.3 m away from the front fencing panel at a height of 1.3 m. Latency to approach starter provided in either the bucket or Braden bottle was defined as any part of the calf’s muzzle passing below the rim of the bucket or the Braden bottle’s nipple entering her mouth, respectively. Each pair of hutches was identified with plastic numbered identification tags, and calves were identified using their coat patterns and ear-tag numbers. Measurements were recorded to the nearest minute. Live observation was performed by 1 to 2 out of 3 trained observers on any given occasion, each watching ≤4 adjacent calves, and video observation was performed by a single observer (the trainer, R. S. S.); interobserver reliability was evaluated as described below for behaviors during milk feeding. Calves who did not approach starter within the observation period (8 calves across 8 different pairs; 2 in the Braden bottle plus bucket treatment, 6 in the bucket-only treatment) were assigned the maximum value of 90 min; the next-longest recorded value was 82 min.

**Behavior Around Milk Feeding.** From wk 3 to 8 of life, calves were observed during and immediately after the afternoon milk feeding twice per week because suckling behavior increases around milk-feeding times (de Passillé, 2001). These observations occurred on d
18 ± 1, 25 ± 1, 31 ± 1, 39 ± 1, 45 ± 1, and 50 ± 1 of life (weekly mean ± SD). Behavior was recorded to the nearest second using continuous video recording (H9R action camera; EKEN, positioned 4.3 m away from the front fencing panel at a height of 1.3 m) for 30 min from the start of the milk meal.

A live observer checked each bucket 1 to 2 times per minute to determine the time, to the nearest minute, that the calves completed their milk meal because this was not visible on camera. This information was needed to separate nutritive and nonnutritive oral behaviors directed toward the milk buckets and to distinguish milk-meal versus postmeal competition. Milk-meal and postmeal competition were characterized by both total frequency and frequency per minute; the latter was calculated by dividing the former by the total time until the milk was finished (milk-meal competition) and the length of time from when the milk was finished (determined by live observation) to the end of the observation period (postmeal competition), respectively.

Live observations were conducted by 3 trained observers who initially performed simultaneous observations on a subset of 10 pairs of calves; they achieved 100% concordance on all behaviors observed. Video coding was performed using Behavioral Observation Research Interactive Software (BORIS; Friard and Gamba, 2016) by 2 trained observers. Behavioral definitions are given in Table 1. Interobserver reliability was calculated using a subset of video data that included all possible behaviors. For all duration behaviors (cross sucking, consuming bedding, nonnutritive oral behavior, using the Braden bottle, drinking milk, and grooming), pairwise linear regressions between the trainer and each observer had $R^2 > 0.88$, with no slopes or intercepts differing significantly from 1 or 0, respectively (i.e., $P > 0.05$). For frequency behaviors (milk-meal and postmeal competition), the kappa coefficient of concordance was calculated, and all $\kappa = 1$ (high level of agreement; Cohen, 1960).

### Statistical Analysis

All analyses were conducted using SAS software (version 9.4; SAS Institute Inc., Cary, NC). All linear mixed models were constructed using PROC MIXED. The assumption of normality was evaluated by plotting residuals (PROC PLOT) as well as by calculating the Shapiro-Wilk value (PROC UNIVARIATE).

<table>
<thead>
<tr>
<th>Behavior</th>
<th>Definition 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cross sucking</td>
<td>The actor is sucking on the head (muzzle, ear, or skin), belly (navel or udder base), or tail (tail and vulva) of the receiver. The sucking movements are performed with the body part in the mouth. Bout finished when actor stops and turns head away from receiver.</td>
</tr>
<tr>
<td>Milk-meal competition</td>
<td>Competition occurring while milk remains in the bucket (as determined by live observation). Subsets of this behavior: (1) contact–the actor is biting, butting, or pushing with its forehead the receiver’s body or the milk bucket or teat while the receiver is drinking. Bout finished when actor moves away from receiver; (2) displacement–the actor is causing receiver, who is drinking, to leave her bucket as a consequence of contact; (3) replacement–actor replaces the receiver at her bucket after a displacement.</td>
</tr>
<tr>
<td>Postmeal competition</td>
<td>Competition occurring when no milk remains in the bucket (as determined by live observation). Subsets of this behavior defined as with milk-meal competition.</td>
</tr>
<tr>
<td>Consuming bedding</td>
<td>Head lowered with mouth movement and bedding entering calf’s mouth.</td>
</tr>
<tr>
<td>Nonnutritive oral behavior</td>
<td>Sucking, licking, or chewing on parts of fence, hutch, or visibly empty bucket (as determined from live observation) with no milk being ingested. Movements are performed with object in calf’s mouth or tongue in contact with the object. Bout finished when the calf stops movements and turns head away from object. Categorized as directed to the fence, hutch, empty bucket, or teat bucket.</td>
</tr>
<tr>
<td>Using Braden bottle</td>
<td>Sucking, licking, or chewing of the nipple with calf’s mouth on it. Bout finished when calf stops sucking and turns head away from nipple.</td>
</tr>
<tr>
<td>Drinking milk</td>
<td>Calf is ingesting milk either by sucking a teat (calf’s mouth closed around the teat) or drinking from an open bucket (any part of the calf’s muzzle passing below the rim of the bucket). Bout finished when calf takes mouth off teat or muzzle out of the bucket, respectively.</td>
</tr>
<tr>
<td>Grooming</td>
<td>(1) Self-grooming: licking or mouth movement (not sucking) directed toward any part of own body or scratching back of head with foot. Bout finished when calf stops and turns head away; (2) allogrooming: actor displays licking or mouth movement (not sucking) directed toward any part of receiver’s body. Bout finished when actor stops and turns head away.</td>
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1Adapted from Jensen et al. (1998, 2008).
assumption of equal variance among treatments was evaluated by generating boxplots (PROC UNIVARIATE).

**Latency to Approach Starter**

For latency to approach starter, pair was the experimental unit of analysis, and thus values were averaged between calves within each pair. The linear mixed model was evaluated between starter-feeding treatments (32 observations, 16 per treatment) using the fixed effect of starter treatment (bucket only vs. bucket plus Braden bottle), with a random effect of pair within starter treatment. For only the subset of calves offered starter in both a Braden bottle and a bucket, their initial choice of starter receptacle was evaluated on an individual basis (n = 30, excluding 2 who did not approach starter during the testing time, and thus lacked choice data for this test) using a binomial test (Stat Trek, 2012) for the probability that at least that many calves would choose the Braden bottle first, relative to 50%, representing chance. For the same calves, Cohen’s Kappa coefficient of concordance (PROC FREQ) was used to determine the level of agreement between the location (inside vs. outside of the hutch) where a calf began the latency test and the starter source she chose. Cohen’s kappa was also calculated to determine the level of agreement between the starter source chosen by the first and second calf in each pair (n = 14 pairs, excluding 2 pairs with calves who did not approach either starter source during the testing time).

**Behavior Around Milk Feeding**

For behaviors during and after the milk meal, pair was the experimental unit of analysis, and thus all dependent variables were averaged between calves within each pair. All pair values were then averaged between the 2 d of observations per week. The preweaning (wk 3–6; 128 data points, 8 per milk- and starter-feeding treatment per week) and weaning (wk 7–8; 64 data points, 8 per milk- and starter-feeding treatment per week) periods were evaluated separately. The linear mixed models (PROC MIXED) included the fixed effects of milk-feeding treatment (open bucket vs. teat bucket), starter-feeding treatment (bucket only vs. bucket plus Braden bottle), week (preweaning: wk 3–6; weaning: wk 7–8), and the 2- and 3-way interactions, with week as a repeated measure and pair as the subject. Based on the lowest Akaike and Bayesian information criterion (AIC and BIC, respectively) values, a variance components covariance structure was selected for all behaviors in the weaning period and for all non-competition behaviors during the preweaning period, whereas a compound symmetric structure was used for competition behaviors preweaning. All frequency behaviors (milk-meal and postmeal competition) were square-root-transformed because the raw data were not normally distributed, and back-transformed values with 95% confidence intervals are reported. When there were significant ($P < 0.05$) effects or tendencies ($P < 0.10$), pairwise comparisons were conducted using the Tukey-Kramer method.

**RESULTS**

**Latency to Approach Starter and Starter Intake**

Pairs of calves provided starter in both a Braden bottle and an open bucket approached starter sooner than those with only an open bucket (Braden bottle vs. bucket only: 13.1 ± 6.1 vs. 33.2 ± 6.1 min, respectively, LSM ± SEM; $F_{1,30} = 5.3$, $P = 0.029$). Within pairs with the option of either the Braden bottle or an open bucket, 22 out of 30 calves (73%) chose the Braden bottle first, indicating a significant initial preference ($P = 0.008$). Within the Braden bottle treatment, there was no agreement ($\kappa = −0.2$; Cohen, 1960) between the second and first calves for the starter source they first approached. For calves receiving starter in both a Braden bottle (outside) and an open bucket (inside the hutch), we also found no agreement ($\kappa = 0.09$) between the location of each calf when starter was first provided and that of the starter source she first approached. Although the majority of calves in the Braden bottle treatment approached that source when starter was first offered, they eventually ate from both sources. Total starter intake (on an as-fed basis) appeared similar for those fed from only buckets; descriptive results are shown in Figure 3.

**Milk-Drinking Behavior**

Before weaning, there was an overall effect of milk-feeding treatment ($F_{1,28} = 428.5$, $P < 0.001$) in the summed time calves spent actively drinking milk, such that those fed from open buckets (OB-SB vs. OB-BB: 1.7 ± 0.3 vs. 1.5 ± 0.3 min, respectively) consumed milk faster than those fed from teat buckets (TB-SB vs. TB-BB: 7.2 ± 0.3 vs. 6.7 ± 0.3 min, respectively). In addition, there was a weak tendency for a milk-treatment × week interaction ($F_{3,84} = 2.2$, $P = 0.099$): calves fed milk from teat buckets tended to have a more marked decrease in time spent drinking milk across weeks compared with those fed milk from open buckets.

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This tendency for an interaction explained the overall decrease in time spent drinking across weeks ($F_{3,84} = 13.9, P < 0.001$). During weaning, pairs with teat buckets for milk (TB-SB vs. TB-BB: 3.2 ± 0.2 vs. 3.0 ± 0.2 min, respectively) spent more time drinking milk than pairs fed in open buckets (OB-SB vs. OB-BB: 0.6 ± 0.2 vs. 0.6 ± 0.2 min, respectively; $F_{1,28} = 184.3, P < 0.001$; no week effects or interactions, $F_{1,28} ≤ 0.2, P ≥ 0.264$; Figure 4). There were no effects or interactions of starter treatment either before or during weaning ($F_{1,28} ≤ 0.2, P ≥ 0.177$).

**Milk-Meal Competition**

Before weaning, it took calves 2.2 ± 2.2 vs. 8.1 ± 3.4 min (open buckets vs. teat buckets; mean ± SD) on average to completely finish their milk. During weaning, it took them 0.7 ± 0.3 vs. 3.5 ± 1.6 min (OB vs. TB) to completely finish their milk. These time periods were used to separate milk-meal versus postmeal competition. Two calves in the same pair (OB-BB treatment) never engaged in any milk-meal competition during the observation periods.

**Competitive Contacts.** During the preweaning period, the frequency of competitive contacts during the milk meal showed a milk-treatment × week interaction ($F_{3,84} = 2.8, P = 0.045$). Pairs with teat buckets for milk had an increase in contacts from wk 3 to 4 ($P = 0.049$) and tended to perform more contacts in wk 5 relative to wk 3 ($P = 0.053$), which led to an overall tendency for performing more contacts than those fed milk from open buckets [means back-transformed from square-root values (95% CI): TB vs. OB = 0.87 (0.51–1.33) vs. 0.39 (0.16–0.71), respectively; $F_{1,28} = 4.1, P = 0.051$]. When corrected for milk-drinking duration, the pattern reversed, and pairs with open buckets for milk had more contacts per minute [TB vs. OB = 0.12 (0.08–0.18) vs. 0.22 (0.16–0.30), respectively; $F_{1,28} = 5.2, P = 0.031$]. Overall, contacts per minute tended to increase across the preweaning weeks ($F_{3,84} = 2.2, P = 0.093$). There were no starter-treatment effects or interactions ($F_{1,28} ≤ 0.3, P ≥ 0.272$).

Similarly, during weaning, calves fed milk in teat buckets had a higher total frequency of contacts [TB vs. OB = 0.42 (0.28–0.59) vs. 0.18 (0.10–0.30), respectively; $F_{1,28} = 7.3, P = 0.011$]. When accounting for contacts per minute, there were no differences between milk-delivery treatments [TB vs. OB = 0.16 (0.08–0.26) vs. 0.29 (0.17–0.43), respectively; $F_{1,28} = 2.5, P = 0.124$]. There were no starter-treatment or week effects or interactions ($F_{1,28} ≤ 0.0, P ≥ 0.144$) during weaning.

**Displacements and Replacements.** During the preweaning period, pairs fed milk in teat buckets displayed a greater total frequency of both displacements [TB vs. OB = 0.52 (0.28–0.83) vs. 0.15 (0.04–0.34), respectively] and replacements [TB vs. OB = 0.38 (0.21–0.60) vs. 0.11 (0.03–0.24)] during the milk meal than those fed from open buckets ($F_{1,28} ≥ 6.7, P ≤ 0.001$).
There were no differences in displacements per minute [TB vs. OB = 0.08 (0.06–0.12) vs. 0.09 (0.07–0.13), respectively] or replacements per minute [TB vs. OB = 0.08 (0.06–0.10) vs. 0.07 (0.05–0.09); F_{1,28} ≤ 0, P ≥ 0.428]. There were no effects or interactions of starter-feeding treatment for displacements or replacements, whether in total or per minute, and no effects or interactions with week (F_{1,28} ≤ 0, P ≥ 0.107) before weaning.

During weaning, there tended to be a greater total frequency of displacements among calves fed milk from teat buckets relative to those fed from open buckets [TB vs. OB = 0.18 (0.11–0.27) vs. 0.10 (0.05–0.17), respectively; F_{1,28} = 3.1, P = 0.088]. There were no differences in displacements per minute [TB vs. OB = 0.10 (0.05–0.16) vs. 0.12 (0.07–0.18); F_{1,28} = 0.4, P = 0.552] and no starter-treatment or week interactions or effects (F_{1,28} ≤ 0, P ≥ 0.117). The total frequency of replacements showed tendencies for interactions between milk- and starter-feeding treatments (F_{1,28} = 3.1, P = 0.089; F_{1,28} = 4.2, P = 0.051), which were driven by differences in wk 7, such that calves fed milk from teat buckets and starter from only open buckets [TB-SB: 0.17 (0.11–0.26)] tended to show more displacements than those fed both milk and starter from open buckets [OB-SB: 0.07 (0.03–0.12)] and those offered both milk and starter through teats [TB-BB: 0.07 (0.03–0.13); P = 0.063]. However, there were no treatment or week effects or interactions for replacements per min (F_{1,28} ≤ 0, P ≥ 0.124).

Postmeal Competition

Competitive Contacts. Three calves (across 3 pairs) never engaged in any postmeal competition during the observation periods. Before weaning, competitive contacts had a starter-treatment × week interaction, both for total values and when adjusted for the rate per minute (F_{3,84} ≥ 3.5, P ≤ 0.038). These interactions were driven by an increase in contacts in wk 5 among pairs with only open buckets for starter, which drove a tendency for an overall week effect for total contacts (F_{3,84} = 6.7, P = 0.064). Although there were no interactions with milk-feeding treatments (F_{3,84} ≤ 0.1, P ≥ 0.342), there was a main effect such that those fed milk from teat buckets had a higher frequency of contacts [TB vs. OB = 0.71 (0.41–1.08) vs. 0.29 (0.11–0.54), respectively] and contacts per minute [TB vs. OB = 0.13 (0.10–0.16) vs. 0.07 (0.04–0.09)] than those fed from open buckets (F_{1,28} ≥ 9.3, P ≤ 0.035). During weaning, the total frequency [TB vs. OB = 0.90 (0.54–1.35) vs. 0.24 (0.07–0.49), respectively] and frequency per minute [TB vs. OB = 0.11 (0.08–0.15) vs. 0.06 (0.04–0.09)] of contacts were higher for calves fed milk in teat buckets than those fed in open buckets (F_{1,28} ≥ 9.9, P ≤ 0.023), but there were no week effects, starter-treatment effects, or interactions (F_{1,28} ≤ 0, P ≥ 0.270).

Replacements. For preweaning replacements, pairs fed milk from teat buckets had a higher frequency of both total replacements [TB vs. OB = 0.41 (0.25–0.60) vs. 0.08 (0.02–0.18), respectively] and replacements per minute [TB vs. OB = 0.09 (0.07–0.11) vs. 0.05 (0.03–0.06)] than those fed milk in open buckets (F_{1,28} ≥ 14.4, P ≤ 0.001), but there were no effects or interactions of week or starter-feeding treatment (F_{3,84} ≤ 0.2, P ≥ 0.135). During weaning, the total frequency of replacements [TB vs. OB = 0.43 (0.27–0.64) vs. 0.06 (0.01–0.15), respectively] was higher for calves fed milk in teat buckets than those fed in open buckets (F_{1,28} = 18.6, P ≤ 0.001), but there were no effects or interactions of starter treatment or week (F_{1,28} ≤ 0.1, P ≥ 0.213). Replacements per minute had a tendency for a milk-treatment × week interaction (F_{1,28} = 3.6, P = 0.067), with the effect of milk-feeding method most apparent in wk 7 [TB vs. OB = 0.09 (0.07–0.12) vs. 0.04 (0.03–0.06), respectively; P = 0.010]. This interaction drove the tendency for a decrease in replacements per minute, regardless of treatment, between wk 7 and 8 (P = 0.091). There were no starter-treatment effects or interactions (F_{1,28} ≤ 0, P ≥ 0.560).
Cross Sucking and Pen-Directed Nonnutritive Oral Behaviors

During the preweaning period, total nonnutritive oral behavior (directed toward pen objects, cross sucking, and the teat of empty milk bucket, if applicable) had a tendency for a milk-treatment × starter-treatment interaction ($F_{1,28} = 3.7, P = 0.064$; Figure 5A); among those fed milk in an open bucket, pairs with a Braden bottle for starter (OB-BB) tended to show less total nonnutritive oral behavior than calves with only open buckets for starter (OB-SB; $P = 0.091$; Figure 5A).

There were no effects or interactions of week ($F_{3,84} = 0.1, P = 0.730$). During weaning, total nonnutritive oral behavior increased between the 2 wk ($F_{1,28} = 5.3, P = 0.029$), and there was a milk-treatment × starter-treatment interaction ($F_{1,28} = 13.8, P < 0.001$; Figure 5A; no 3-way interaction with week, $F_{1,28} = 0.2, P = 0.682$). Among calves fed milk in an open bucket, pairs with only an open bucket for starter (OB-SB) spent significantly more time performing total nonnutritive oral behaviors compared with pairs with a Braden bottle (OB-BB; $P = 0.006$; Figure 5A). Within the Braden-bottle starter treatment, pairs with teat buckets for milk (TB-BB) spent significantly more time performing total nonnutritive behaviors than pairs with open buckets for milk (OB-BB; $P = 0.008$; Figure 5A) because the aggregate behavior included teat-directed nonnutritive oral manipulation (Figure 6A).

When considering only nonnutritive oral behaviors directed to the hutch, fence, or empty bucket, the duration was higher for pairs receiving milk through an open bucket versus through a teat bucket, both before...
(open bucket vs. teat bucket: 1.2 ± 0.07 vs. 0.1 ± 0.07 min, LSM ± SEM) and during weaning (open bucket vs. teat bucket: 1.6 ± 0.1 vs. 0.4 ± 0.1 min, $F_{1,28} \geq 111.8, P < 0.001$). There were no effects or interactions with starter treatment or week ($F_{1,28} \leq 0.0, P \geq 0.125$) within each milk-feeding period.

Almost all calves displayed cross sucking as the actor at least once, with only 3 calves never performing this behavior during the observation periods (1 in the TB-SB treatment; 2 from different pairs in the OB-BB treatment). Before weaning, 67%, 32%, and 1% of cross sucking was directed toward the head, belly, and tail, respectively; during weaning, 66%, 34%, and 0.3% of this behavior was directed toward those body parts. Cross sucking had a milk-treatment × starter-treatment interaction both before and during weaning ($F_{1,28} \geq 10.5, P \leq 0.009$; Figure 5B). During both milk-feeding periods, pairs with open buckets for milk and starter (OB-SB) spent significantly more time cross sucking than any other pair treatment ($P \leq 0.010$; Figure 5B). In addition, before weaning, pairs with open buckets for milk and Braden bottles for starter (OB-BB) spent significantly more time cross sucking than pairs receiving milk through a teat bucket, regardless of how the latter received starter (i.e., TB-SB or TB-BB; $P < 0.038$; Figure 5B). There were no interactions with week dur-

![Image](https://example.com/image.png)

**Figure 6.** Duration (min, LSM ± SEM) of (A) nonnutritive oral behavior directed toward the milk-bucket teat and (B) Braden bottle (Braden Start; Coburn Co., Whitewater, WI) use, for the calves fed milk or starter, respectively, through those methods. Overall treatment effects within a given milk-feeding period are also indicated by symbols next to the treatment label: **$P < 0.01$; *$P < 0.05$.**
ing either milk-feeding period ($F_{1,28} \leq 0.0, P > 0.368$), although cross sucking increased overall between weeks during weaning ($F_{1,28} = 4.3, P = 0.048$).

Pairs fed milk in teat buckets consistently directed nonnutritive oral behavior toward the teat across the preweaning and weaning periods (no effects or interactions with week, $F_{3,42} \leq 0.1, P \geq 0.227$), regardless of their starter treatment (i.e., TB-SB or TB-BB; $F_{1,14} = 1.47, P = 0.033$; Figure 6B). There were no effects or interactions of week ($F_{1,14} \leq 0.6, P \geq 0.171$; Figure 6B) during either milk-feeding period.

**Other Nonnutritive Oral Behaviors**

Consuming the sand bedding was rare, with 27 calves across 19 pairs never observed engaging in this behavior. Likewise, not all calves performed allogrooming as the actor: 21 calves (across 18 pairs) were not observed allogrooming during the observation periods. Before weaning, allogrooming had a tendency for milk-treatment × starter-treatment interaction ($F_{1,28} = 4.1, P = 0.051$; Table 2). Pairs fed both milk and starter in open buckets (OB-SB) tended to spend more time allogrooming than pairs with open buckets for milk and Braden bottles for starter (OB-BB; $P = 0.059$; Table 2). There were no effects or interactions of week ($F_{3,84} \leq 0.7, P \geq 0.172$). During weaning, there were no treatment or week effects or interactions ($F_{1,28} \leq 0.0, P \geq 0.117$; Table 2). Finally, for self-grooming and consuming bedding (Table 2), there were no treatment or week effects or interactions during either milk-feeding period.

**DISCUSSION**

**Latency to Approach Starter**

Early starter consumption is important for initiating rumen development and can contribute to better performance postweaning (Baldwin et al., 2004). In our study, paired calves fed starter only in open buckets took twice as long to initially approach starter compared with those with Braden bottles. This result supported our predictions and is consistent with Mcgahee et al. (1992), who reported that individually housed calves provided starter on d 1 of life through a Braden bottle initiated grain intake sooner than those fed starter in a plastic bucket. In the current study, however, our descriptive feed intake data did not suggest a treatment difference in the amount of grain consumed over time, and we did not measure rumen development.

The calf’s initial choice of starter receptacle was unaffected by the choice made by the other calf in each pair. Initially, we hypothesized the first calf’s choice could affect that made by the second calf in a pair because social facilitation has been suggested by other authors to influence the postweaning feeding behavior of calves formerly reared in pair or group housing (De Paula Vieira et al., 2010; Costa et al., 2015; Jensen et al., 2015). The potential for social facilitation in our study, however, may have been limited. When starter was first offered, calves were newly allowed full social contact and had only 2 to 7 d of fence-line contact and familiarity with each other. Furthermore, in extensive, multi-age rearing systems, calves begin investigating

<table>
<thead>
<tr>
<th>Behavior</th>
<th>OB-SB</th>
<th>OB-BB</th>
<th>TB-SB</th>
<th>TB-BB</th>
<th>SEM</th>
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<th>P-value</th>
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<td>0.0</td>
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<tr>
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<td>1.6</td>
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<td>4.1</td>
<td>0.051</td>
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<td>13.5</td>
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<tr>
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<tr>
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<td>0.6</td>
<td>8.4</td>
<td>2.6</td>
<td>0.0</td>
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</tr>
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<td>4.0</td>
<td>8.5</td>
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<td>Self-grooming</td>
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<td>18.8</td>
<td>4.1</td>
<td>0.0</td>
<td>≥0.288</td>
</tr>
</tbody>
</table>

a,bSuperscript letters indicate tendencies for differences between treatments ($P < 0.10$).

1No significant week effects or interactions were found, and thus results are summarized by treatment.

2OB-SB = milk delivered in open buckets, starter delivered in open buckets; OB-BB = milk delivered in open buckets, starter delivered in both Braden Start bottles (with specialized teats allowing solids to pass through; Coburn Co., Whitewater, WI) and open buckets; TB-SB = milk delivered in slow-flow teat buckets, starter delivered in open buckets; TB-BB = milk delivered in slow-flow teat buckets, starter delivered in both Braden Start bottles and open buckets.
their surroundings and spending time with other calves within the first 1 to 2 wk of life (Vitale et al., 1986; Kerr and Wood-Gush, 1987), but they do not begin grazing (i.e., consuming solid feeds) until wk 3 of life (Kerr and Wood-Gush, 1987).

Additionally, calves did not consistently choose the starter receptacle corresponding to their own location (inside or outside of the hutch) when starter was first delivered. The lack of either social or starting-location effects in our study suggested that the 73% of calves who first approached the Braden bottle, instead of the open bucket for starter, may have done so because using a teat allowed them to express natural suckling behaviors. In addition, although there was no proximity effect (i.e., no agreement between the location where calves were found when the test began and the starter source they chose), the absolute location of the starter source may have affected this choice because the Braden bottle was offered outside, which was near the where calves were fed milk.

Milk Drinking and Competition

Regardless of milk volume, calves have been shown to drink milk faster from an open bucket than through a teat (as reviewed by Jensen, 2003). This was supported in the current study, in which calves with open buckets for milk spent less time drinking than pairs with slow-flow teat buckets during both the preweaning and weaning periods. Milk-drinking duration decreased across weeks before weaning, which tended to be driven by the teat-bucket treatment. This was due to a floor effect in the bucket treatment, in which calves already averaged only 2.4 min to finish their milk at the beginning of the preweaning period, compared with 8.5 min for those with teat buckets for milk. The duration of milk drinking observed in calves with teat buckets for milk was similar to durations observed in calves raised with their dam (7–10 min/bout of suckling; de Passillé, 2001).

Overall, we observed low amounts of competition both during and after the milk meal, with an average raw frequency of <2 bouts of any competitive interactions during the daily observation period. Although calves receiving milk in teat buckets showed more total contacts, displacements, and replacements during the meal, this was a function of their longer milk-drinking duration, and the intensity of competition (per minute) was the same or greater for calves fed milk in open buckets. In a previous study on pair housing calves in outdoor hutches, Wormsbecher et al. (2017) fed milk through a teat and also reported low amounts of competition (0.8 vs. 1.4 bouts/h in the winter and summer, respectively). Both in that experiment and in the present study, 1 teat per calf were placed on opposite sides of the outdoor fenced area to reduce competition. In our study, the low amount of competition overall and lack of differences in the intensity of replacements during the milk meal suggested that the concern for milk stealing in paired calves is low when using these strategies.

Alternative strategies may also minimize milk competition. For example, to prevent competition in Whalin et al. (2018), calves were separated manually during milk feeding (twice daily, 10 L/d total) and given bottles inside the hutches. However, the producer reported anecdotally that this feeding procedure was labor intensive (L. Whalin, University of British Columbia, Vancouver, BC, Canada; personal communication). Studies in indoor housing have sought to reduce milk competition using other approaches. Jensen et al. (2008) found that the use of a long barrier reduced competition in teat-fed (5, 6, or 12 L/d of milk, depending on the treatment), pair-housed calves. In studies with group-housed calves fed ad libitum amounts of milk, offering more teats per group has been found to decrease competition (von Keyserlingk et al., 2004; Miller-Cushon et al., 2014).

After the milk was consumed in our study, pairs fed milk though a teat bucket had both a higher frequency and frequency per minute of all competitive behaviors. Both before and during weaning, we hypothesized that this was due to the inability of the calves to see inside of the opaque teat bucket, the top of which was above their eye level. To determine if teat buckets were empty, calves had to sample from the teat, whereas calves with open buckets could see inside. Therefore, although producers may observe competitive behavior between pair-housed calves, only some of this behavior occurs when milk is still available, meaning the extent of milk stealing is likely less than perceived.

Regardless of milk-feeding method, preweaning contacts, contacts per minute, and displacements per minute after the milk was finished also had an interaction with starter treatment, driven by wk 5, in which pairs with only open buckets for starter displayed this behavior more than calves with Braden bottles. A potential explanation is that pairs with Braden bottles directed some of their postmeal time to using this resource instead. Indeed, following a milk meal, calves will direct suckling behavior toward teats if they are available (de Passillé et al., 1997; Veissier et al., 2002). However, although we observed calves in Braden bottle treatments using the Braden bottles after milk feeding throughout the preweaning period, there was no corresponding spike in this behavior in wk 5.
Both before and during weaning, total nonnutritive oral behavior (directed toward objects in the pen, cross sucking, and the empty teat bucket, if applicable) was higher among calves fed both milk and starter in open buckets (OB-SB) than those who also had a Braden bottle (OB-BB). The difference (1.4 vs. 2.7 min more, on average, before and after weaning, respectively) was similar to the amounts of time that calves with open buckets for milk spent using the Braden bottle (OB-BB: 0.9 vs. 2.7 min, on average, before and after weaning, respectively), suggesting a redirection of suckling behavior to a more appropriate outlet; the latter behavior was not included in the total of nonnutritive oral behavior because starter could be ingested. Before weaning, total nonnutritive oral behavior did not change over time, in contrast with Horvath and Miller-Cushon (2017), who observed an increase from wk 2 to 4 of life when calves were fed 6 L/d of milk. In the present study, there was an increase in the duration of total nonnutritive behavior in all 4 feeding treatments during weaning. Among calves fed starter in Braden bottles, pairs fed milk through a teat bucket spent more time displaying total nonnutritive oral behavior than calves fed in an open bucket (TB-BB vs. OB-BB: 5.8 vs. 3.1 min, on average), but this was explained by the inclusion of teat-directed nonnutritive oral behavior (3.7 min) in this total. Furthermore, calves in the Braden bottle treatments spent less time using the Braden bottle when fed milk through teat buckets compared with open buckets (i.e., TB-BB vs. OB-BB), supporting the redirection of oral behavior to the teat bucket.

When considering only pen-directed oral behavior, calves fed milk in an open bucket had higher durations of this behavior than those fed milk through teat buckets, differing 10-fold and 4-fold before and during weaning, respectively. Our findings contrast with a previous study on calves in hutches, which did not find differences in oral manipulation of pen fixtures when milk was fed in buckets versus bottles (Pempek et al., 2013). In part, this could be because individual calves, who performed more of this behavior, were combined with pair-housed calves in the analysis, or because those researchers fed calves restricted milk allowances (4–6 L/d at the peak), which increases the expression of abnormal oral behaviors (as reviewed by Jensen, 2003).

Cross sucking in the current study was directed toward the head almost 2 thirds of the time, and almost all calves were observed performing this behavior as the actor. Both before and during weaning, calves with open buckets for both milk and starter (OB-SB) spent the most time cross sucking. Before weaning, the provision of Braden bottles when milk was fed in open buckets (OB-BB) reduced cross sucking by half. Feeding milk from slow-flow teat buckets, regardless of starter treatment (i.e., TB-SB or TB-BB), further reduced cross sucking by 2 thirds. In the teat bucket treatments, the magnitude of preweaning cross sucking (means of 0.4 vs. 0.5 min/30 min, TB-SB vs. TB-BB, respectively) was comparable to the medians of 0.7 to 1.3 min/30 min reported by Jensen et al. (2008), who also fed milk from teat buckets and observed calves continuously for 30 min from the start of the milk meal. During weaning, cross sucking increased across the 2 wk, which is consistent with observations in other studies during this time period (de Passillé et al., 2010).

Providing both milk and starter in open buckets (OB-SB) resulted in at least twice as much cross sucking as any other treatment.

These findings are consistent with a previous US study using paired hutches, which found that bucket feeding of milk resulted in more cross sucking compared with bottle feeding (no means reported; Pempek et al., 2013). In previous Canadian studies that pair housed calves in hutches, low amounts of cross sucking were reported during live interval sampling (0.8% of weekly observations using 5-min scan sampling for 30 min immediately following the afternoon milk feeding in Whalin et al., 2018; 0.1 and 0.4 bouts/h across 7 and 6 nonconsecutive hours of observation during summer and winter study periods, respectively, in Wormsbecher et al., 2017). Those studies fed calves an enhanced milk allowance (10 vs. 16 L/d in Whalin et al., 2018 and Wormsbecher et al., 2017, respectively) using bottles, and both of these practices have been shown to reduce cross sucking (de Passillé et al., 2010).

Studies on socially housed calves in indoor pens have previously identified several factors affecting cross sucking, such as milk allowance, feeding methods, and method of weaning (Bokkers and Koene, 2001; Jensen, 2003). The largest reductions in cross sucking have been observed when calves were fed sufficient quantities of milk (as reviewed by Jensen, 2003); milk was fed through a teat (de Passillé, 2001; Jensen and Bude, 2006), especially when flow rate was reduced to prolong suckling time (Haley et al., 1998; Jung and Lidfors, 2001); when a dummy teat was provided (Loberg and Lidfors, 2001); and when calves were weaned by gradually reducing milk or weaning based off of starter intake (Keil and Langhans, 2001; Nielsen et al., 2008) rather than abruptly. Our results showed that, despite step-down weaning, nonnutritive oral behaviors, including cross sucking, increased during weaning. Providing a Braden bottle, similar to a dummy teat, was beneficial for reducing cross sucking in calves with open buckets for milk (OB-BB), but providing milk through a slow-flow teat bucket (i.e., TB-SB or TB-BB) was the most.
effective method for reducing both cross sucking and pen-directed nonnutritive oral behavior.

Our findings regarding the Braden bottle are novel, as no previous studies have evaluated the potential for a starter-feeding device to redirect suckling behavior. Although the Braden bottle did not reduce cross sucking to the same extent as feeding milk through a slow-flow teat before weaning, these methods had similar effectiveness during weaning. Furthermore, the former can remain in the pen continuously, potentially requiring less management for producers. Nonetheless, we had to replace 5 teats of the Braden bottles during weaning (out of 32); these devices are typically used by producers to initially entice neonatal calves to consume starter, and the long-term durability of the teats as calves develop has not been formally evaluated. Additionally, although many studies have investigated cross suckling before and during weaning, more work is needed on strategies to mitigate cross sucking appearing or persisting after weaning (de Passillé et al., 2011; Vaughan et al., 2016).

We recorded low durations of allogrooming (<55 s) overall. Nonetheless, preweaning allogrooming tended to be higher in calves fed both milk and starter from open buckets (OB-SB) than for those who also had a Braden bottle (OB-BB). Calves in the former treatment also displayed more total nonnutritive oral behavior and cross sucking, and thus the greater amounts of allogrooming could be a result of overall increased oral manipulation observed in this treatment. Although specific to the starter- rather than milk-feeding method, our findings are in line with those of Pempek et al. (2013), who found that pair-housed calves in hutch with open buckets for milk displayed more affiliative behaviors (including allogrooming and social play) than those fed from bottles.

Calves spent more time self-grooming than allogrooming, and all calves showed the former behavior, although durations were also relatively short (<2.4 min). Calves spend more time self-grooming when housed on sand (Panivivat et al., 2004), as in our study, relative to other bedding types, but we did not observe any differences in self-grooming among the milk- or starter-feeding treatments. Past studies with paired calves in outdoor hutch similarly reported low amounts of both self-grooming (3–5% and 0.7% of total time during live behavior observations in Pempek et al., 2013 and 2016, respectively) and allogrooming (0.3% of total time during live behavior observations in Pempek et al., 2016; 1.8 and 2.4 bouts/h during weekly summer and winter observations, respectively, in Wormsbecher et al., 2017). In contrast with our study, in which the milk-feeding method did not affect these behaviors overall, Pempek et al. (2013) found that pair-housed calves in hutch with open buckets for milk displayed more self-grooming than those fed from bottles. Those researchers recorded all behaviors inside and outside of the hutch through live interval observations, whereas we only video recorded behaviors outside of the hutch, which could perhaps account for these differences.

CONCLUSIONS

Both before and during weaning, when pair-housed calves were provided starter in a Braden bottle in addition to a bucket, or when they were fed milk through a slow-flow teat bucket, cross sucking was greatly reduced. Feeding milk with a slow-flow teat, which extended the milk meal and provided an outlet for suckling behavior, reduced pen-directed oral behavior and had the greatest effect on reducing cross sucking before weaning, whereas Braden bottles provided a suckling outlet that remained in the pen continuously. Paired calves showed little competition for milk, regardless of how it was fed. Our study is the first to demonstrate that cross sucking in calves paired in outdoor hutch can be managed using either starter- or milk-delivery strategies, providing a practical method for implementing social housing on commercial dairies.

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