Pair Housing of Dairy Calves in Modified Individual Calf Hutches: An On-farm Demonstration

by

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Abstract

The objective of this study was to determine if pair housing using a modified calf hutch on a commercial dairy farm would provide similar benefits to those previously described in research settings. Despite many benefits (e.g. improved weight gain and reduced fearfulness) of housing calves in small groups, individual calf hutches are still common in North America. This study took place on a commercial farm in the lower Fraser Valley region of British Columbia from May to December 2016. A week after birth, calves were randomly assigned to individual (n = 14) or paired (n = 8 pairs) hutches. Our modified pair hutch consisted of 2 individual hutches placed next to each other with both calves having access to both hutches and a common run. Calves were fed milk 2/day (d) using a nipple bottle, 6 Litres (L)/d from d 1 to d 7, 10 L/d from d 8 to d 35, and 6 L/d until d 60 (weaning). Ad libitum access to calf starter (solid food) and water was offered throughout the experiment. Feed intake was measured weekly until calves were 67 ± 5 d old. Body weight (BW) and health measures were recorded weekly until the calves were 88 d old. Calves were exposed to a novel food test at 60 d; the amount of food consumed in 30 minutes, and the latency to approach the novel food was measured. Pair housed calves ate more starter (0.89 (0.72 - 1.08) vs. 0.48 (0.42 - 0.56) kg/d; geometrical mean (confidence interval)) than individually housed calves. Pair housed calves also ate almost 3 times more food during the novel food test (154.13 ± 26.85 vs. 57.84 ± 19.55 g). There was no difference in BW or in the latency to approach the novel food. In conclusion, joining adjacent hutches is an option for pair housing that results in reduced fearfulness and increased solid food intake relative to individual hutches.

Lay Summary

Dairy calves are commonly housed individually in small, white, plastic houses called hutches. Despite many studies showing benefits of housing calves in small groups, farmers appear to be hesitant to switch to group housing, possibly due to perceived costs associated with infrastructure changes and concerns regarding disease transmission if calves are group housed. However, there is little investment required if two hutches were joined so that calves could socialize. Weekly visits were made to a commercial dairy farm in British Columbia where calves were housed individually (one hutch), or with a partner (two hutches). Over 2.5 months, calf health, dry food consumption, and how each calf reacted when given a new food was monitored. Paired calves ate more food, and were less fearful of new food. Pair housing by joining adjacent hutches appears to provide benefits to calves on a commercial farm.

Preface

I completed this thesis under the supervision of Dr. Marina A. G. von Keyserlingk. In addition to Dr. von Keyserlingk, my supervisory committee included Drs. Daniel M. Weary and Sean Smukler, all from the University of British Columbia. The study described in this thesis was approved by the University of British Columbia's Animal Care Committee (#A14-0245). The animals were cared for according to the guidelines outlined by the Canadian Council of Animal Care (2009).

Chapter 2 was co-authored with M. A. G. von Keyserlingk and D. M. Weary (University of British Columbia). Co-authors supervised, helped analyse data, and edited drafts. The main ideas were developed in collaboration by all three authors, but I was responsible for the data collection and day-today running of the study.

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List of Abbreviations

BW: body weight

CI: confidence interval

cm: centimetre

d: day

dL: decilitre

g: gram

GM: geometrical mean

h: hours

kg: kilogram

L: litre

M: million

m: metre

min: minutes

s: seconds

TMR: total mixed ration

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Thank you has always seemed too simple. In some situations, the phrase is over-used, and in other cases under-used. But on this paper, I want you each to know that it conveys gratitude from the bottom of my heart, and is genuine and true.

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To the babies.

Chapter 1: Introduction

The study of animal welfare arose when society began asking questions about the lives of animals under human care. Traditionally animal caregivers responded to these questions with assurances that animals were healthy and functioning well (Fraser et al., 1997). However, over the last 50 years, questions regarding animals' emotional lives and whether they can live reasonably natural lives have also come to the forefront of conversations (Harrison, 1964; Lund, 2006).

Though farm animal care was originally coined as animal husbandry, today many view the changes since World War II as industrialized and lacking appreciation for an animal's *telos*, or nature and needs (Rollin, 2011). In 1997, Fraser et al. published a paper in Animal Welfare calling for the integration of three constructs (biological functioning, natural living, and affective states), arguing that the risk of animals experiencing poor welfare increases when practices do not account for all three areas of concern. Evaluating animal welfare is an ethical question, which means that conflicting values can make answers elusive and complicated (Rollin, 2011; Thompson et al., 2011). Finding ethical answers for animal care may be reached through dialogue, captured through social science research, that investigates the gaps between animal industries and the public (Weary and von Keyserlingk, 2017; von Keyserlingk and Weary, in press).

In this review, I will first provide a definition of animal welfare, followed by a brief description of the North American dairy industry as it looks in 2017. Given that my thesis work was focused on the milk-fed calf, I will describe the management practices associated with the young calf that are common on dairy farms today and how these practices align with societal expectations. As the public appears to be particularly interested in the opportunity for an animal to engage in natural behaviours (Vanhonacker et al., 2008; Spooner et al., 2014), I will discuss how calf care deviates from natural living. Throughout, I will also identify the gaps in knowledge and where science is needed to find practical solutions that improve the welfare of calves on commercial dairy farms.

1.1 The Three Constructs of Animal Welfare

It is widely accepted that biological functioning can be an indicator of welfare, for any state that results in poor biological functioning will also result in poor welfare (e.g. injured, sick, or malnutrition). Though veterinarians, farmers and industry consultants are concerned with a variety of issues pertaining to animal welfare (Ventura et al., 2015), many place a great weight on health and biological functioning (Te Velde et al., 2002; Vanhonacker et al., 2008). For instance, some farmers cite growth rate as one of the major attributes used to assess welfare (Te Velde et al., 2002; Lassen et al., 2006). The importance placed on biological functioning has been reflected in science; for example, in the Journal of Dairy Science, over 1800 articles have been published relating to health (von Keyserlingk and Weary, in press).

How an animal feels is also a concern for the public (Lassen et al., 2006). Some scientists consider an animal’s feelings as the most important welfare aspect (Duncan and Petherick, 1991; Duncan, 2005). Minimizing negative feelings, such as pain and fear (Mason and Mendl, 1993), and optimizing positive states, such as exploration and satisfaction (Boissy et al., 2007) are important qualifications to consider (Duncan, 2005). Assessing animal feelings has also become an increasingly common research focus (Weary et al., 2017).

Finally, allowing animals to live reasonably natural lives is also an important dimension to animal welfare (Fraser et al., 1997). This aspect is often the most difficult for producers to conceptualize, yet naturalness is a major concern for many lay people (without industry experience) (Te Velde et al., 2002; Lassen et al., 2006). For example, when asked about an ideal dairy farm, the majority of the lay respondents stated that cows should have access to pasture (Cardoso et al., 2016). This is in contrast to reality where less than 8% of lactating dairy cows in the US have routine access to pasture (USDA, 2016). Another key example is the common practice of feeding calves milk from a pail (in one Canadian survey, 92.0% of producers fed milk from a bucket; Vasseur et al., 2010) – a practice that is very different from the calf suckling from its dam (Reinhardt and Reinhardt, 1981; Vitale et al., 1986). Given these types of disconnects, it is not surprising that, from a natural living perspective, the intensive housing systems common on many North American farms are considered a concern (Spooner et al., 2014).

1.2 The Dairy Industry in 2017

Over the past 50 years there has been dramatic infrastructure changes observed in the North American dairy industry. Farm sizes have increased dramatically, with over 60% of the US milk supply now being produced on farms with more than 500 cows (von Keyserlingk et al., 2013; Barkema et al., 2015; USDA, 2016). Larger farms are more likely to be mechanized using specialized processes to facilitate efficiencies (Barkema et al., 2015), which can translate into improved farm incomes (see Robbins et al., 2016). These large farms present both benefits and challenges to the welfare of the dairy cow and calf. For example, milking cows today is a strategic process where groups of animals are either brought up to be milked in a parlour, or cows have access to robotic milking machines (Wagner-Storch and Palmer, 2003). Concrete walking surfaces allow for cleanliness, but not necessarily comfort for the cow (Juarez et al., 2003; Espejo and Endres, 2007). Additionally, given that the milk produced by the cow is saleable, the calf is a hindrance to keep with the cow (Combellas and Tesorero, 2003).

To produce milk, cows must become pregnant and have a calf nearly once every year. Presently there are approximately 9.3 million (M) and 0.96 M calves born in the US and Canada, respectively, every year (USDA, 2017). Calves are normally removed from the dam within 14 hours of birth (USDA, 2016). Calves rely on passive transfer of immunity (Larson et al., 1980) and thus must be provided with high quality colostrum within the first few hours of birth (Weaver et al., 2000). Although most female calves are reared as replacements for the herd, there is a dearth of information on the fate of the male calves. Recent work by Renaud et al. (2017) indicates that on-farm care of male calves varies in Canada, with much room for improvement (e.g. colostrum and food quality).

1.2.1 Milk Feeding

Calves are commonly separated almost immediately from the dam (USDA, 2016). Given that they are born with a non-functioning rumen, they must be fed milk for the first weeks of life until they can be transitioned to solid feed (Suárez et al., 2006; Khan et al., 2011). Milk quantity provided to calves varies from farm to farm, but is commonly approximately 10% of a calf's body weight (BW) (USDA, 2016). In the US, over 50% of operations feed 3.8-4.7 L of milk or milk replacer per day, while 22.3% feed 7.6 L or more (USDA, 2016). However, there is a growing body of research indicating that calves gain more weight, have less disease, play more, and are more efficient when given approximately 20% of their BW in milk (Khan et al., 2011; Jensen et al., 2015). When provided with low milk allowances, calves will make more unrewarded visits to the milk feeder which indicates hunger (Rosenberger et al., 2017).

As mentioned above, provision of milk has traditionally been done using buckets, which requires calves to learn to drink from the bucket (Friend and Dellmeier, 1988). Bucket feeding does not allow calves to show their natural sucking behaviour, and may lead to frustration, non-nutritive sucking, and poor health, such as presence of diarrhoea (Friend and Dellmeier, 1988; Margerison et al., 2003). Though some have described access to milk via a teat (Horvath et al., 2017) or simply access to artificial teats as enrichment (Pempek et al., 2017), feeding calves with teat bottles promotes natural nursing behaviours such as sucking and head-butting (Appleby et al., 2001; de Passillé, 2001), and reduces cross-sucking (Jensen and Budde, 2006). As sucking is part of a calf's behavioural repertoire (de Passillé, 2001), nipple-feeding should be looked at as a necessity, not an enrichment. Coupling nipple-feeding with high milk allowance allows for higher growth rates, a more complete behavioural repertoire, and may decrease frustration (Friend and Dellmeier, 1988; Jasper and Weary, 2002).

1.2.2 Housing of the Milk Fed Calf

In North America, most pre-weaned heifer calves (female calves still consuming milk) are housed individually (69.7% of US operations, Figure 1.1), with outdoor hutches (white, plastic houses suitable for one calf, Figure 1.2) or pens being the most common form of housing (37.9% of 1261 dairies) (USDA, 2016). Some farms also provide a small outdoor run in front of the hutch (Coleman et al., 1996). In Canada, the National Farm Animal Care Council (2009) recommends housing calves either individually or in groups of less than 10 animals.

Figure 1.1 USDA (2016): Pre-weaned heifer housing- the percentage of farms using an indicated housing type for pre-weaned heifers.

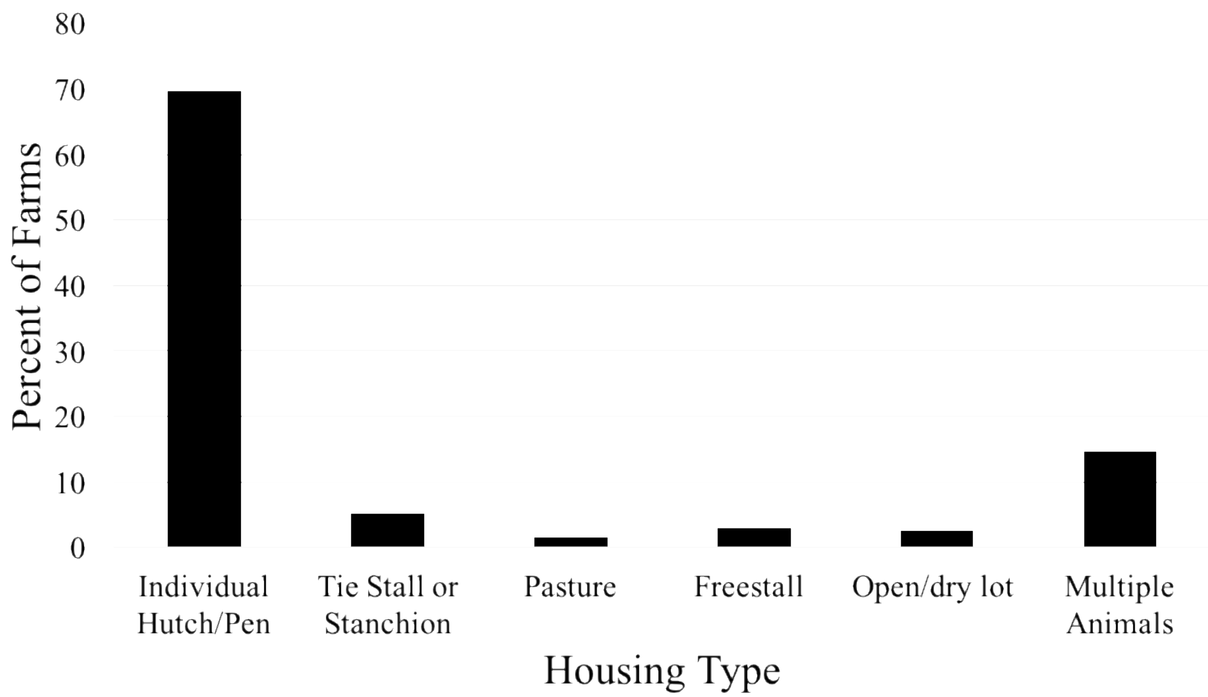


Figure 1.2 A calf hutch with an outdoor run. This type of hutch is commonly used to house calves individually. Photo credit: Laura Whalin, 2016.

Individual housing of dairy calves is popular for several reasons. Traditionally, farmers and industry specialists perceived benefits in terms of heath, arguing that since calves are isolated, transmission of diseases between calves is reduced (Quigley, 1997). However, early work comparing group verses individual housing often failed to provide equivalent space allotments on a per calf basis between treatments (Davis et al., 1954), thus biasing results. Concerns associated with cross-sucking, or non-nutritive sucking on other calves (Lidfors, 1993), have also been raised when calves are housed in groups (Friend and Dellmeier, 1988; Pempek et al., 2016). When cross-sucking becomes extreme it can lead to poor health and injuries (Lidfors, 1993; Veissier et al., 2013). However, cross-sucking is often noted in situations with bucket feeding and low milk allowances (e.g. Pempek et al., 2016), and likely a consequence of hunger which is not a concern when nipple-feeding higher milk allowances (Appleby et al., 2001).

Some have also argued that calves housed individually are easier to handle (Lensink et al., 2001); hand-fed calves are reported to be more readily approached by people (Krohn et al., 2001). However, others have shown individual calves to be more fearful when confronted with a novel conspecific compared to pair housed calves (de Paula Vieira et al., 2012; reviewed by Mandel et al., 2016). Work by Meagher et al. (2015, 2016) also provides evidence that individually housed calves on farms are more fearful of novelty than group housed calves.

An alternative to individual housing is to house calves in small groups, for large groups can present health risks (reviewed by Costa et al., 2016). A Swedish study found that respiratory illness was more prevalent in groups containing 8 to 12 calves than in smaller groups (Svensson and Liberg, 2006), while a second study showed more severe cases of diarrhoea in large groups than in individual pens, and a tendency for small groups to have fewer cases of severe diarrhoea than large groups (Svensson et al., 2003). A study in the US also found that groups of calves greater than 7 had higher mortality rates than smaller groups and individually housed animals (Losinger and Heinrichs, 1997). Housing calves in small groups may offer benefits to farmers by allowing them to save time by taking care of animals as groups, especially with automatic milk feeding (Kung et al., 1997; Hötzel et al., 2014). Perhaps most importantly, group housing offers benefits to calves, such as improved growth (Costa et al., 2015) and social interactions (Jensen et al., 2015). Even grouping calves with hutches allows for social behaviours, and is a feasible alternative for farms (Wormsbecher et al., 2017). These benefits will be described in more detail in subsequent sections of this review.

1.2.3 Weaning of Dairy Calves

Weaning from milk can be stressful for calves, especially because weaning often occurs earlier (typically 6 - 10 weeks; Vasseur et al., 2010) than in more naturalistic systems (where weaning takes place at approximately 10 months; Reinhardt and Reinhardt, 1981). In nature, weaning is usually coupled with a gradual reduction in milk, independence from the dam, and increased consumption of solid food (Weary et al., 2008). In farm settings, the exact time that milk is withdrawn is frequently a function of how much solid feed the calf is eating (Greenwood et al., 1997).

As previously described, high milk allowances offer benefits, such as improved calf weight gain (Quigley et al., 2006; Borderas et al., 2009), but for weaning, high milk allowances can be a challenge (de Passillé et al., 2011). Calves provided more milk will consume less calf starter (solid food) before weaning (Terré et al., 2007; Borderas et al., 2009); when calves are fed a low milk allowance (10% BW) they will consume nearly two times more starter than calves fed higher milk quantities prior to weaning (Jasper and Weary, 2002), probably because they are more hungry. It is important for calves to eat dry food for rumen development (Suárez et al., 2006), and as a criterion for when weaning should be initiated (Greenwood et al., 1997). A delay in the transition to consuming dry feed could make weaning more stressful, as seen when calves lose weight after being weaned abruptly from high milk quantities (12 L/d) (de Passillé et al., 2011).

One way to mitigate weaning distress is through step-down, or gradual weaning, where milk quantity is decreased gradually, which encourages calves to transition to dry feed (Khan et al., 2007, 2011). One example is to feed 20% BW until day 26 at which time milk is gradually decreased to 10% BW and calves are weaned gradually from day 46-50 (Khan et al., 2007). This type of gradual weaning encourages calves to eat more starter and hay than conventionally fed calves (10% BW), and these advantages are better sustained through the weaning process (Khan et al., 2007). Calves fed through the step procedure consume more dry matter, and have higher weight gains than calves weaned conventionally (Khan et al., 2007), a much more positive outcome than those weaned abruptly (de Passillé et al., 2011; Sweeney et al., 2010). Given the stresses associated with weaning, gradual weaning allows the calves to better adapt to the transition from milk feeding to solid feed, thus reducing vocalizations compared to conventionally fed calves (Khan et al., 2007).

1.3 Negative Consequences of Social Isolation

1.3.1 Approach to Novelty

When in novel environments, individually housed calves perform more reactive behaviours (e.g. defecation, kicking) compared to pair-housed calves (de Paula Vieira et al., 2012). In novel social situations, individually housed calves take longer to interact with a social partner than pair housed calves (Jensen and Larsen, 2014). This apprehension of novelty is also extended to new foods (Costa et al., 2014). Food neophobia, or the avoidance of new foods (Cooke et al., 2006), has been examined in a variety of species.

In nature ruminants typically consume a diverse diet (Provenza et al., 2003). Some work has also shown that in the case of sheep, monotonous diets may induce stress (Villalba et al., 2011). Common practice in many production systems is to offer the same diet every day (Villalba et al., 2010). However, as animals age, they also go through dietary transitions (e.g. milk to solid feed), a process that requires them to experience new foods (Khan et al., 2011). Some animals prefer varied diets (Meagher et al., 2017). Clearly, practices that reduce fear of new feeds could be good for welfare. In lambs, individual sociality (Villalba et al., 2009), and social group composition influence willingness to eat foods (Provenza and Burritt, 1991). Similarly, calves will eat more food (Phillips, 2004) and gain more weight when housed in groups (Xiccato et al., 2002). Calves raised in social groups will also consume more novel feed than individually housed calves (Costa et al., 2014). Individually housed calves seem to lack the skills that allow them to deal with novelty (Costa et al., 2016).

1.3.2 Social Isolation in Different Species

Research in a variety of species has shown deleterious effects of social isolation. Harlow et al. (1965) reported that infant monkeys raised in total isolation were fearful, lacked social skills and experienced emotional shock when removed from isolation. Since this initial work, social isolation has been found to lead to both short- and long-term effects such as aggression in rats (Haller et al., 2014), increased distress in piglets (Kanitz et al., 2009), suppression of immunity in monkeys (Shanks and Lightman, 2001), and decreases in maternal behaviours in rats (Lovic et al., 2011). Isolation in many young mammals negatively affects them socially (Harlow et al., 1965), psychologically (Haller et al., 2014), and biologically (Shanks and

Lightman, 2001). Given this evidence, it is not surprising that calves are also affected when raised individually.

1.3.3 Flexibility and Learning

Individually housed calves struggle with flexibility and learning. Studies have shown that individually housed calves have poor reversal learning skills compared to paired (Gaillard et al., 2014) or dam-reared calves (Meagher et al., 2015). In these studies, calves were trained to go to one colour for a reward (e.g., red), and to avoid the second colour (e.g., white). Once this task was learned, the colours were reversed so that the reward colour (red) was now the non-reward, and the original avoidance colour (white) was now the reward colour. Individually housed calves learned the first task, but when the task was reversed, the individually housed calves had poorer learning performances compared to socially reared calves (Gaillard et al., 2014; Meagher et al., 2015). These studies indicate that calves housed individually may not be able to learn and adapt to change as well as calves housed in groups.

1.3.4 Play and Sociability

Presence of play behaviour is considered an indicator of positive affective states (Held and Špinka, 2011). Though failure to play is often cited simply as having poor welfare, being able to engage in play may also have other positive benefits such as emotional pleasure, health and psychological benefits (Held and Špinka, 2011). Individually housed calves have been found to play less than calves in groups (Duve et al., 2012; Valníčková et al., 2015). This lack of play could be due to lack of space, or absence of companionship (Valníčková et al., 2015).

Individually housed calves also perform fewer social behaviours (e.g., social licking, social sniffing, or mock fighting) than calves in small groups (Duve and Jensen, 2011, 2012). In nature, calves spend the first few weeks of life in groups with other calves (Johnsen et al., 2015b), and will often form strong bonds with one another (Duve and Jensen, 2011). Social housing also encourages social feeding behaviour, where pair housed calves spend more time feeding with group mates, which may make weaning transitions easier (Miller-Cushon and DeVries, 2016).

1.3.5 Coping Abilities

Calves raised in groups appear to cope better during weaning than individually housed calves as shown through increased consumption of dry food (Babu et al., 2004), more time spent at the feeder (de Paula Vieira et al., 2010), and fewer vocalizations (Bolt et al., 2017). It appears that when group housed calves face change, such as moving to a new pen, they are able to more quickly adapt (de Paula Vieira et al., 2010). Some have also suggested that having a companion may allow for social buffering, or a decrease in stress response due to the presence of a companion (Cohen and Wills, 1985; Rault, 2012), with these effects greatest during stressful times such as weaning (Boissy and Le Neindre, 1996; Færevik et al., 2006). Pairing calves earlier in life allows them to form bonds and lasting social networks, which can promote social buffering during stressful situations (Bolt et al., 2017). Regardless, the lack of sociability in individually housed calves may be indicative of lower affective states.

Additionally, calves fed high milk allowances and raised individually have reduced feed intake resulting in poorer growth rates compared to calves reared in small groups (de Paula Vieira et al., 2010; Jensen et al., 2015). Recent work suggests that even when fed low milk allowances (<5 L/d), calves in pairs tend to have better growth than individually reared calves (Pempek et al., 2016).

1.3.6 Deviation from Naturalness

Rearing conditions on many dairy farms differ considerably from what happens in natural systems. For instance, beef calves (McBride and Mathews Jr., 2011) and calves born in a semi-wild Maremma herd in Italy (Vitale et al., 1986) spend the first 6-9 months suckling from their mothers and slowly becoming nutritionally and socially independent. Beyond relying on their mothers for milk, the young calves are also able to socialize with other cows and calves (Vitale et al., 1986). When calves are raised in complex groups they perform appropriate social behaviours (Flower and Weary, 2001; Stěhulová et al., 2008; Wagner et al., 2012), and, compared to limit fed calves, gain more weight (Flower and Weary, 2001).

There have been a number of studies showing that lay people prefer keeping cows and calves together, frequently citing a lack of naturalness as a criticism of current systems that prevent mother calf interactions (Ventura et al., 2013; Busch et al., 2017; Hötzel et al., 2017). Moreover, when cows and calves are separated, there is some evidence that calves experience low moods (that may be indicative of emotional pain) (Daros et al., 2014), increased in heart rate, and increased vocalizations (Stěhulová et al., 2008). Unfortunately, few studies have looked at the effects of cow-calf separation, and the studies to date have focused almost exclusively on the acute effects, such as, measuring vocalizations in response to separation (Stěhulová et al., 2008; Roth et al., 2009; Johnsen et al., 2015a).

There is considerable evidence suggesting that calves thrive when raised in pairs and small groups, including recent work indicating positive effects of pair housing in hutches (Wormsbecher et al., 2017). Despite this research, farms seem hesitant to switch to pair or group housing.

1.4 Research Aims

The aim of this research is to replicate previous social housing studies, in controlled settings, on a commercial farm where calves are housed in hutches. I hypothesized that pair housed calves would eat more starter, have higher average daily gains, consume more novel feed, and take less time to approach a new feed compared to individually housed calves.

Chapter 2: Pair Housing of Dairy Calves in Modified Individual Calf Hutches

2.1 Introduction

In North America, dairy calves are predominantly housed individually; the USDA (2016) reported that in 2014 approximately 70% of the operations surveyed housed pre-weaned heifer calves individually, and across all types of operations, outdoor hutches or pens were the most common housing for pre-weaned heifers (37.9% of respondents). Individual housing of pre-weaned heifers is also prevalent across all farm sizes with 56.6% of farms with fewer than 30 cows, 66.1% of farms with 30-99 cows, 84.7% of farms with 100-499 cows, and 69.9% of farms with over 500 cows housing calves in individual hutches or pens (USDA, 2016).

However, raising calves in small groups provides numerous welfare benefits without impairing health (Costa et al., 2016). Compared to individually housed calves, group housed calves during the milk feeding period results in reduced distress during restraint (Duve et al., 2012), decreased vocalizations at weaning (Bolt et al., 2017), higher solid feed intake during the milk feeding period (de Paula Vieira et al., 2010; Bernal-Rigoli et al., 2012; Costa et al., 2015), and increased play behaviour (Valnickova et al., 2015). These effects may be indicative of social buffering that mitigate some of the negative effects of stressful events (Boissy and Le Neindre, 1996; Bolt et al., 2017).

Improving the ability for young calves to cope with new or stressful management procedures may have long-term benefits. For example, as calves mature they must navigate through a variety of new experiences, including behavioural disruptions following regrouping (von Keyserlingk et al., 2008), movement to new pens (Heinrichs et al., 1987; Pettersson et al., 2001), transition to new diets (reviewed by Weary et al., 2008; Enríquez et al., 2011), or introduction to the milking parlour (Sutherland and Huddart, 2012). At weaning, calves transition from relying on milk as their primary source of nutrition to being dependent on solid feed (Khan et al., 2011). An additional challenge is that at weaning, calves are often moved to a new pen (Heinrichs et al., 1987; Pettersson et al., 2001), and for individually reared calves, this could be the first time that they contact another calf. Not surprisingly, weaning has been associated with responses such as vocalizations (Watts and Stookey, 2000; de Paula Vieira et al., 2010; Bolt et al., 2017), and suppressed weight gains (Chua et al., 2002) in the period immediately following. Decreasing the magnitude of these stressors, and improving the calf's ability to cope with these novel experiences may mitigate these negative consequences (Rault, 2012; Costa et al., 2014; Jensen and Larsen, 2014)

Despite these known benefits, the adoption of social housing on farms has been slow (75% individually housed in 2007 (USDA, 2010) to 70% in 2014 (USDA, 2016)). Though farmers acknowledge restrictions of natural behaviour and space as being related to decreased welfare, health is still valued as the primary welfare parameter (Vanhonacker et al., 2008). This focus on health and biological functioning may help explain the use of individual housing, which is perceived to provide health benefits (Quigley, 1997).

Additionally, the adoption of social housing may require infrastructure changes, as most farms are currently designed for individual housing (USDA, 2016). However, the results of two recent studies suggest that pair housing with hutches may provide some benefits and be a feasible option for farmers. When pair housed calves had access to one hutch, these calves tended to have better weight gains, but also performed more non-nutritive oral behaviours than single housed calves (Pempek et al., 2016). In a second study, pairs of calves housed in hutches exhibited improved social behaviour (but no improvement in growth) compared to individually hutch housed calves (Wormsbecher et al., 2017). These two studies did not investigate the effects of pair housing on dry feed intake, weaning, or reaction to novelty, nor did they take place on a commercial dairy farm.

The aim of this study was to assess differences in performance and response to novelty between pair versus single housed calves in hutches on a commercial dairy to validate past work completed in research facilities. We predicted that pair housed calves would have greater starter intake, improved average daily gains, increased consumption of novel feed, and take less time to approach a new feed compared to individually housed calves.

2.2 Materials and Methods

This study took place on a commercial dairy farm located in Abbotsford, British Columbia from May to December 2016. All procedures received approval from the UBC Animal Ethics committee #A14-0245.

2.2.1 Animals and Treatments

Thirty female Holstein calves were separated immediately from their dam and fed 4 L of colostrum replacer (Calf's Choice Total™ HiCal, The Saskatoon Colostrum Company, SK) within 6 h of birth. At 24 h, serum proteins were analysed with a Reichert AR 200 digital hand-held refractometer (Reichert AR 200, Reichert Inc., Depew, NY). All calves entering the study had serum protein levels above 5.4 g/dL. At d 5, calves were randomly assigned to either individual housing (n = 14 calves) or pair housing (n = 8 pairs). Calves were paired based on birthdate and weight. When calves were 30 d old they were dehorned with a hot iron by a veterinary technician using a lidocaine block, followed by an analgesic (Metacam™, Boehringer Ingelheim, Ingelheim, Germany).

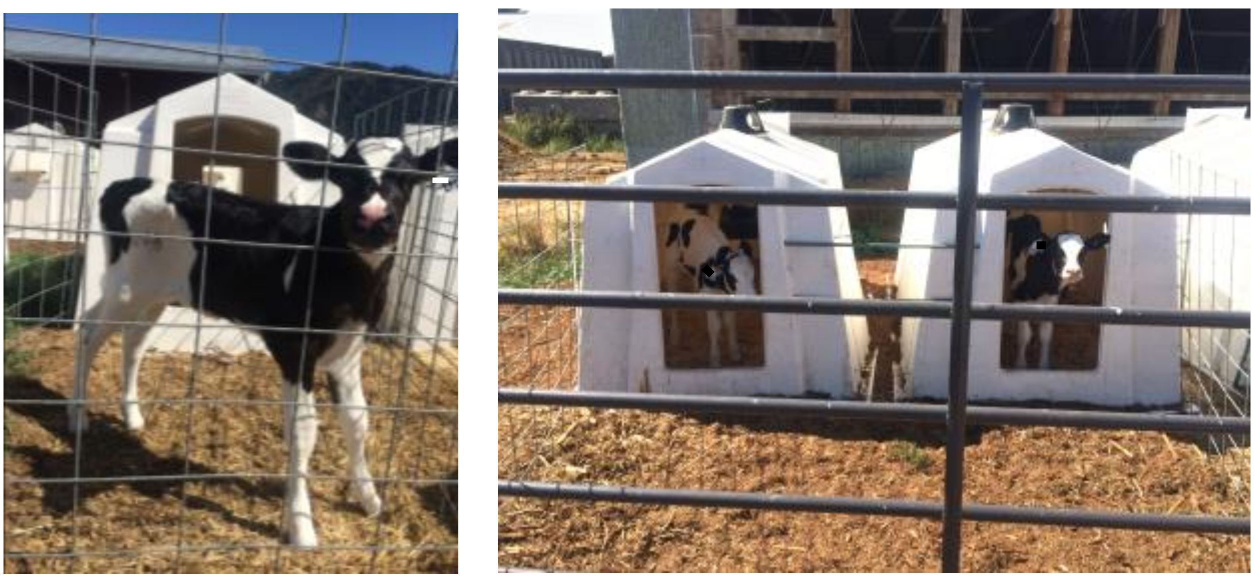
2.2.2 Housing

Individually housed calves were housed in a hutch (2 x 1.2 m; Figure 2.1 A) that included an outdoor space (1.8 x 1.2 m). Pair housed calves were housed in the same type of hutch but two calves were provided access to two hutches, that included a shared outdoor space (2.9 x 1.8

m; Figure 2.1 B). Calves were weaned, on average, at 60 d and were then moved to an indoor group pen (2.8 x 5.5 m) that housed up to 6 calves. All pens were cleaned as needed as per standard farm procedures.

Figure 2.1 (A) An individual hutch with a run used to house calves individually, and (B) a modified pair hutch with a run used to house calves in pairs. Both were used during the experiment undertaken on a commercial dairy farm located in the lower Fraser Valley region of British Columbia that tested the effects of pair housing on performance and behaviour. Photo credit: Laura Whalin, 2016.

A **B**



2.2.3 Milk Feeding Regime

All calves were bottle-fed, from a nipple bottle, a minimum of 6 L of milk per day (divided into two meals) until d 7. From d 8 to d 35 calves were provided 10 L of milk divided into two meals. The twice daily milk ration was then reduced to 6 L/d over a 2-d period and continued until d 58 at which time milk volumes were reduced to 0 over 2 d, such that weaning was completed by d 60. During the milk feeding period, all pair housed calves were observed for cross-sucking once per week using 5-minute (min) scan sampling for 30 min immediately following the afternoon milk feeding during 14 observational weeks.

2.2.4 Solid Feeding Regime

Throughout the experiment, calves were also offered ad libitum calf starter and hay. Starter intake was recorded, on average, twice per week by disappearance; the amount of starter feed provided at 0800h was subtracted from the amount remaining after 24 hours.

2.2.5 Performance and Health

As a description, and to account for possible effects on treatment, calves underwent a health check once per week, from birth until 85 ± 5 d, following Costa et al. (2015). During these individual health checks, BW, temperature, heart rate, and incidence of respiratory and digestive disorders were recorded. The BW measures were estimated using heart-girth tape (Heinrichs et al., 1992). For consistency when measured, each calf stood with all legs straight on an even part of ground with her head upright, her neck straight, and her back flat. A standard 150-cm measuring tape was placed around the circumference of the calf's chest- behind the front legs, around the chest, and over the back- to gain the measurement. One observer was trained by an experienced assessor by completing an on-farm taping session prior to the study at the University of British Columbia's Dairy Education and Research Centre (Agassiz, BC, Canada). Respiratory health was assessed by visually inspecting the nasal discharge, and a veterinarian or veterinary technician listening for sounds of pulmonary infection during auscultation. At the time of examination, air temperature was also recorded. Diarrhoea scoring followed de Paula Vieira et al. (2010), where 1 = normal faeces, 2 = plaques but not watery, 3 = watery and body temperature < 39.5°C, and 4 = watery and body temperature ≥ 39.5°C. All calves displaying signs of illness were subject to a full veterinary exam and treated according to standard operating procedures for the farm.

2.2.6 Food Neophobia

A food neophobia test (adapted from Costa et al. 2014) was done when the calves were 60 ± 4 d. The first 3 pairs and 1 individual were given approximately 900 g of novel feed (total mixed ration, TMR) in a white bucket placed in the run area of the hutch. Because the calves could see each other, the methodology was changed for the rest of the calves so that the TMR was placed a black bucket (same type of bucket used for the calf starter), and was placed in the feeding area inside the hutch, where calves could not see other calves. Calves were individually given access to the novel feed for 30 min in their home pen. In the case of the pair housed calves, the combined hutch was temporarily separated for the duration of the 30-min test into two single hutches using a gate divider. Behaviours during the test were recorded with a camera (Panasonic HDC TM, Taiwan) on a tripod, positioned so that the feed bucket was fully visible. The latency to approach the feed (muzzle <5 cm from the bucket) was recorded. The amount of novel feed consumed was measured by disappearance at the end of the 30-min trial.

2.2.7 Statistical Analyses

All analyses were performed with SAS (version 9.4; SAS Institute Inc., Cary, NC) using pen (i.e., individual calf or pair) as the experimental unit. Intake of calf starter (kg/d), BW (kg), novel feed intake (g/30 min) and latency to approach the feed (s) were considered dependent variables. Data were scrutinized using the UNIVARIATE procedure in SAS.

Treatment differences in starter intake (kg/d) and body weight (kg) over the trial were analysed using an autoregressive covariance structure in a model (PROC MIXED) that included pen (specified as subject), treatment, age, and an interaction between treatment and age. Starter intake was transformed using a natural log to normalize residuals.

Novel feed intake (g/30 min) was analysed with the GLM procedure including age, treatment, and the interaction between age and treatment. Analyses were completed with all the calves, and without the first 7 calves, and there were no differences, so all calves were kept in the final analysis.

The distribution of latency to approach the novel feed (seconds, s) could not be normalized by transformation. Treatment differences in this variable were analysed using the Kolmogorov-Smirnov test. In this case, age and the interaction and treatment were not considered.

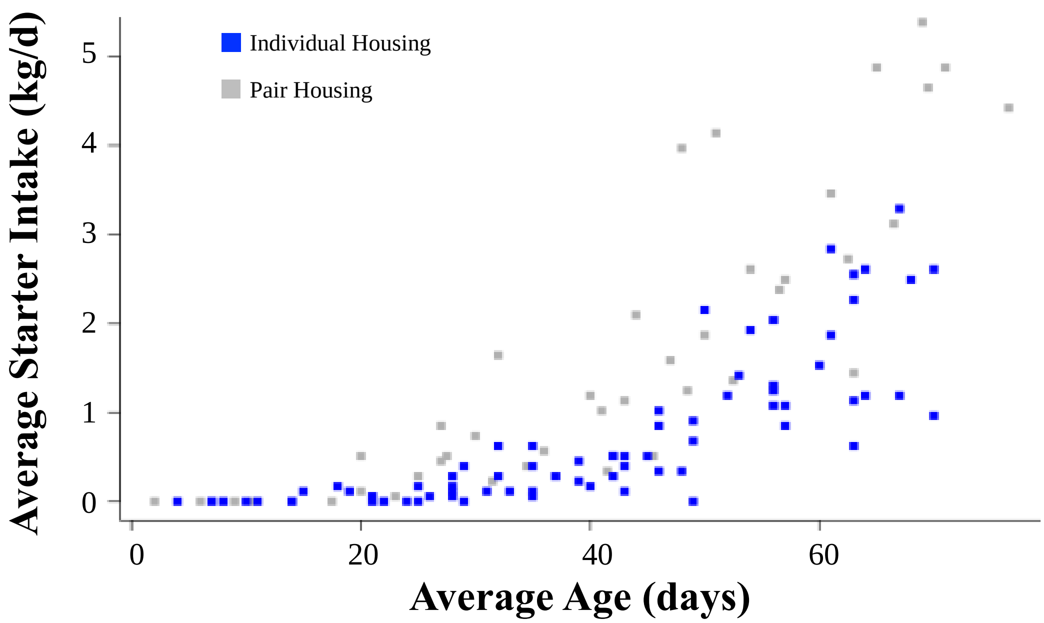
Results are presented as least squares means and standard errors of the mean for BW and novel feed intake, results of the back-transformed data for starter intake are presented as geometric means and confidence intervals, and results for latency to approach are presented as medians with inter-quartile ranges. We report F-values in the format $F_{(\text{between-group df, within-group df})}$. Significance was declared at $P < 0.05$.

2.3 Results

2.3.1 Solid Feed

Age ($F_{1,139}$ = 380.58; $P < 0.001$) and housing ($F_{1,20}$ = 26.93; $P < 0.001$) affected the amount of starter calves consumed (Figure 2.3), but there was no interaction between age and housing ($F_{1,139}$ = 1.67; $P = 0.20$). Over the entire experiment, pair housed calves ate more starter than individually housed calves (0.89 (0.72 - 1.08) vs. 0.48 (0.42 - 0.56) kg/d; GM (CI)).

Figure 2.2 Mean daily starter intake for each pair or individual, measured in kilograms. Values are shown separately for calves individually housed (n = 14; blue), and in pairs (n = 8; grey). Analyses were based on natural log- transformed data; original data are presented.



2.3.2 Performance and Health

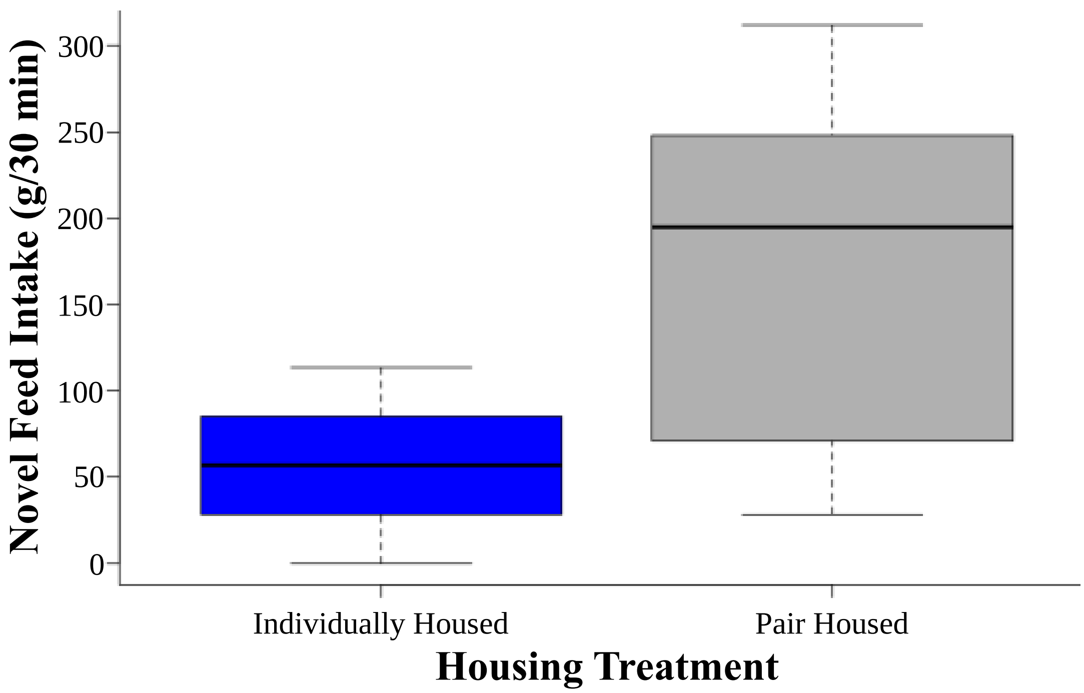
Body weight changes were influenced by age ($F_{1,247}$ = 2334.22; *P* <0.001), but not by treatment ($F_{1,20}$ = 1.08; *P* = 0.31) or the interaction of age and treatment ($F_{1,247}$ = 0.43; *P* = 0.51). Across the experimental period, calves in pairs weighed 72.78 ± 0.81 kg, compared to 71.74 ± 0.60 kg in individually housed calves.

Five calves had faecal scores of 4 (one individual and 4 pair housed), but none exhibited fevers. One individual calf displayed signs of respiratory infection. On 21 occasions calves displayed temperatures ≥ 39.5 (16 different calves; 7 pair-housed, 9 individually housed). Fourteen of these days had temperatures above 25 °C.

2.3.3 Food Neophobia

Pair-housed calves consumed more of the novel food than individually housed calves (150 ± 27 vs. 58 ± 20 g/30 min; Figure 2.4). Both age (*P* = 0.03) and treatment (*P* = 0.007) affected novel feed intake (Figure 2.4), but there was no interaction between age and treatment (*P* = 0.27). Group housing did not affect the latency to approach the novel feed.

Figure 2.3 Least squares means of intake of novel feed (g/ 30 minutes) for individually housed (n = 14) and pair housed (n = 8) calves. Calves were offered a novel feed (total mixed ration, TMR) for 30 minutes when they were 60 d old.



2.3.4 Cross-Sucking

Over 14 weeks of the study, cross-sucking was noted 5 times in 4 different pairs.

2.4 Discussion

Over the past 20 years, many effects of socially housing calves have been studied (Jensen et al., 1997; de Paula Vieira et al., 2010; Costa et al., 2016). Recently there has been interest in applying pair housing to common farm settings (Cobb et al., 2014; Pempek et al., 2016;

Wormsbecher et al., 2017). Cobb et al. (2014) found that calves had better performance when raised in a group outside, than individually housed calves, but used two different types of hutches, which may not be readily available on farms. Pempek et al. (2016) also reported that pair-housed calves in hutches tended to have better weight gains compared to individually housed calves. However, in this latter study calves were fed less than 5 L/d of milk from buckets, and the experiment suffered from a major confound given that both individually and pair-housed calves had access to a single hutch (Pempek et al., 2016). Finally, Wormsbecher et al. (2017) looked at pairing calves in hutches with resource allocation controlled for calf number (e.g. two calves were provided two hutches and the single housed calf provided one hutch), but calves did not enter the study until 24 d, colostrum quality was unknown, and the focus was on space usage and social behaviours rather than growth and feed intake. Our study builds on these previous studies by comparing individual versus pair housing of calves reared in hutches on a commercial farm, but controlling for space per calf, providing high milk allowances delivered through nipple bottles, and following performance, feed intake and reaction to novelty.

From our results, it can be concluded that socially housed calves are less food neophobic (fearful of new foods), suggesting that these calves would be less likely to avoid new foods when subjected to changes in diet later in life (Cooke et al., 2006). Novelty, or lack of experience, is known to contribute to fear (Villalba et al., 2010). For example, when raised individually calves are more reactive in a novel environment, and take longer to interact with novel conspecifics than calves raised in pairs (de Paula Vieira et al., 2012). As calves age they are expected to go through a variety of transitions, such as movement to new pens (Heinrichs et al., 1987; Pettersson et al., 2001) and changes in diets (Sweeney et al., 2010). Practices that reduce fearfulness of novelty, such as social rearing, may make these transitions easier. Our results are consistent with Costa et al. (2014) who found that when calves are raised in complex social environments, they are less food neophobic than calves raised individually. Pair-housed calves have been reported to be more likely to explore (Jensen et al., 1997; de Paula Vieira et al., 2012), but calves in the current study did not differ in latency to approach the feed. Our failure to identify latency differences in treatment may have been a consequence of the bucket containing the novel feed being placed in the same location as the calf starter bucket. This placement was used to more directly assess the calves' reaction to the feed rather than the location of the bucket.

One constraint associated with research on a commercial farm was that we were unable to use a dedicated testing apparatus; instead calves were tested in their home pen, and pair-housed calves were separated by a gate in the middle of the pen during the novel food test. It is possible that this added a stressor during the test.

In addition to eating more novel feed, pair-housed calves in this study consumed more calf starter. These results complement previous work showing that early paired calves eat more starter than individually housed calves (de Paula Vieira et al., 2010; Bernal-Rigoli et al., 2012). All calves in the study were encouraged to eat starter as a result of step-down weaning, where milk was gradually decreased in two steps (Khan et al., 2007). Other studies have used social housing to encourage feed intake. For example, lambs are more willing to eat more food when housed in social groups (Provenza and Burritt, 1991), and calves will consume more food (Phillips, 2004) when in groups (Costa et al., 2015). Group housed calves have been found to exhibit social feeding behaviour, such that they eat more concentrate than individually housed calves before and after weaning (Miller-Cushon and DeVries, 2016). This behaviour may be a result of social learning - a feeding response is elicited in one animal when it sees others performing the behaviour (Launchbaugh and Howery, 2005). Recent work has found calves raised in social groups outperform individually housed calves at reversal learning tasks (Gaillard et al., 2014; Meagher et al., 2015). Individually housed calves may also struggle with flexibility and learning, which could make future transitions challenging such as learning how to navigate the milking parlour or automated milking systems for the first time.

In addition to social learning, providing calves with a companion may facilitate social buffering (Rault, 2012). Social buffering is particularly pronounced during high stress situations, such as weaning (Boissy and Le Neindre, 1996; Færevik et al., 2006). In calves, a recent study reported that pairing calves early provides social buffering due to decreased vocalizations at weaning, and increased preference to be with familiar animals at regrouping (Bolt et al., 2017). A combination of social learning and social buffering may have been contributing to the improved feed intake in the current study.

Despite the benefits in increased solid feed intake, we failed to observe differences in body weight gains. Our use of the weight measuring tape may have contributed to some measurement error, although several studies have reported that this method provides reliable estimates of body weight (Heinrichs et al., 1992; Bond et al., 2015). Other studies comparing pair to individually housed calves have found similar growth rates when fed high allotments of milk (Chua et al., 2002; de Paula Vieira et al., 2010; Duve and Jensen, 2012).

Many groups in the livestock industry, such as veterinarians and farmers, value health as a primary welfare concern (Te Velde et al., 2002; Vanhonacker et al., 2008), and this concern has been reflected in much of the available science (von Keyserlingk and Weary, in press). Though health checks were completed on calves, this information was recorded as a description to be informative for calves needing to be treated, or as a reference if we noticed drastic changes in weight gain or starter intake. Our study was not designed to assess health differences between treatment groups.

Few incidences of cross-sucking were noted in the current study. Recent work has indicated concern that pair housing can result in cross-sucking (Pempek et al., 2016). However, the latter study used bucket feeding and low milk allowances. Calves fed from buckets still need to suck (Hammell et al., 1988), so bucket feeding may lead to non-nutritive sucking (Friend and Dellmeier, 1988; Margerison et al., 2003). Feeding calves from nipple bottles allows them to suck naturally (Appleby et al., 2001; de Passillé, 2001), and has been found to decrease the prevalence of cross-sucking (Jensen and Budde, 2006). The combination of nipple-feeding and high milk allowance not only allows for improved growth, but likely contributes to reduced cross-sucking (Friend and Dellmeier, 1988; Jasper and Weary, 2002). From this perspective, nipple-feeding should not be seen as a form of enrichment (Horvath et al., 2017; Pempek et al., 2017), but rather as a requirement to promote natural milk feeding behaviour.

The opportunity to express natural behaviour is a concern for many people (Te Velde et al., 2002; Lassen et al., 2006). Calves reared in semi-natural situations are able to socialize in herds with cows and other calves (Vitale et al., 1986). Dairy calves, too, will begin interacting with conspecifics when they are only a few days of age (Duve and Jensen, 2012). Thus, pair housing beginning soon after birth promotes some social contact for these herd animals (Jensen and Larsen, 2014; Jensen et al., 2015).

Future studies should investigate farmer's perceptions and attitudes towards social housing to better identify barriers to change. When moving calves to the group pen the farmer in the present study commented that the pair-housed calves were easier to move, perhaps because they were less fearful of humans. Studies in the future should specifically assess ease of handling pair housed calves in hutches.

2.5 Conclusions

Pair-housing in hutches allows for increased starter intake and decreased fearfulness in novel foods, which may make transitions easier for the calves. Pairing by joining adjacent hutches may provide a feasible method for providing social contact on commercial dairies.

Chapter 3: General Discussion

The overall objective of my research was to explore the effects of providing a social environment for dairy calves on a commercial dairy farm in terms of reaction to novel food, starter intake, and growth. In this chapter, I discuss the findings, and how they contribute to the current knowledge on calf housing. I will also describe the strengths and limitations of the work and offer topics for future research.

3.1 Thesis Findings

In Chapter 1 I reviewed the literature covering the different components of calf housing, the current system's deviation from naturalness, and the risks and benefits of socially housing dairy calves. When raised individually, calves are more reactive in novel situations (Costa et al., 2014), which could be due to poor learning skills, or lack of experience with conspecifics (which can allow for social buffering and social learning; Launchbaugh and Howery, 2005; Bolt et al., 2017). The review also summarizes the available evidence regarding reaction to novelty when calves are housed in groups compared to individually housed calves. Collectively this literature provides strong evidence that socially reared calves are less fearful of novelty (de Paula Vieira et al., 2012; Costa et al., 2014). My thesis work now provides evidence that pair housing provides benefits for milk fed dairy calves on commercial dairy farms.

Chapter 2 examined calves' reactions to novel feed (at 60 d of age) to see if there were differences between pair and individually housed calves raised in hutches. In agreement with the previous work, and in support of my original hypothesis, the pair housed calves in my study were less food neophobic compared to the individually housed calves. This finding adds to recent work describing differences in behaviours of individually and pair housed calves housed in hutches (Wormsbecher et al., 2017) by demonstrating that, on a commercial dairy, early social housing effects feeding intake and reaction to novelty. The decreased food neophobia noted in the pair housed calves in my study may be due to social buffering that enabled calves to better cope during a stressful event when paired with a conspecific (Bolt et al., 2017). An alternative explanation may be that socially reared calves are more flexible and thus better able to cope with new experiences compared to individually housed calves (Gaillard et al., 2014; Meagher et al., 2015); indeed, work on other species has shown that social isolation can cause cognitive rigidity, neophobia, decreased synaptic plasticity, and fear (reviewed by Fone and Porkess, 2008).

In contrast to my original hypothesis, I was unable to show differences in latencies to approach the novel feed, but did show increased intake of the novel food. The lack of differences in the latencies may be explained by the fact that the calves were habituated to the feeding buckets used in the food neophobia test, and thus the individual calves were not initially fearful of the bucket itself but then did respond in a more fearful manner to the novel feed.

Other work undertaken at the University of British Columbia has also found that calves raised in social settings consume more solid feed before and after weaning compared to individually housed calves (Costa et al., 2015). Given this previous work, I was not surprised that in my own study, despite all calves being fed a high milk allowance (10 L/d), the calves raised in pairs consumed more solid feed throughout the study (before and after weaning) than individually housed calves. My thesis work thus supports pair housing dairy calves in hutches on commercial farms; this type of social setting results in the calves consuming more solid feed and better able to cope with novelty.

As in other studies where calves were fed high milk allowances, my results do not show differences in weight gains between housing treatments. The lack of difference in body weight may have been a consequence of all calves, regardless of treatment, being provided high milk allowances in sufficient volumes to maximize growth; an explanation provided by others also investigating the effects of social housing on growth in young dairy calves. The increased starter intake may, however, play a role in easing the transition from milk fed diet to a solid diet. The pair housed calves in my trial were eating more calf starter than the individually housed calves, perhaps making the weaning process less stressful. In fact, other work indicates that calves consuming more starter during weaning have less non-nutritive visits to the milk feeder compared to calves consuming less starter (de Passillé et al., 2011).

3.2 Strengths and Limitations

This thesis builds on past work detailing the effects of social housing in milk fed dairy calves, and incorporates research in other areas of calf care, such as providing milk with a nipple bottle. One strength of this research is that it made use of well-established methodologies. Calves were also followed from birth through the entire milk feeding period plus an additional three weeks after weaning. Very recent work, that used similar methodologies to that described in my own study, only began following calves at 24 days of age (Wormsbecher et al. 2017), thus failing to take into consideration a key period in the neonate's life when they naturally would have had close contact with their dam (Vitale et al., 1986) and would have been learning how to socialize (Duve and Jensen, 2012). Wormsbecher et al. (2017) also did not control for failure of passive transfer. In contrast, my own work controlled for colostrum intake and passive immunity status;

thus, minimizing the potential differences between the treatment groups that may have potentially confounded the findings. In my study, also in contrast to Wormsbecher et al. (2017), I was able to track average daily gain as well as capture the effects of social housing on weaning and moving to a new barn.

Despite some challenges (see below) another strength of my study, in the context of the body of available literature, is that the experiment was completed on a commercial farm (rather than a research institution), where calf care standards were already high (e.g. 4 L of colostrum, 10 L of milk/d). Establishing a positive collaboration with the farmer and veterinarian was key to collecting high quality data. This collaboration also allowed me to gain a more in depth understanding of the values of these two key stakeholders. As animal welfare has an ethical dimension, working with stakeholders to discover their values provided me with a unique insight that many graduate students never see. For instance, by collecting detailed health and performance data, the farmer was also able to first hand visualize the effect of housing type on his calves.

By exploring the calves' reactions to new feed, I was also able to demonstrate how calves could react to future novel events, such as new diets, and learning the milking parlour routine. This on-farm trial provides evidence that even in less controlled situations, providing social housing during the milk feeding period has profound effects on calf behaviour.

As described in Chapter 1, provision of colostrum, milk quantity fed, process of how the milk was fed, and weaning methodology can all influence calf health and welfare. Unlike other studies conducted with hutches, the enthusiastic support from the farmer and veterinarian allowed me to incorporate best practices in calf management. For instance, all calves were dehorned using best practices, including pain mitigation (NFACC, 2009).

My work has important applications to the dairy industry. As this study took place on-farm, it can be viewed as an important demonstration study for other farmers. In addition to the benefits described in terms of improved solid feed intake and reduced food neophobia, I was able to demonstrate that pair housing can be achieved with minimal changes in infrastructure. Indeed, farmers with existing hutches do not need to build a new calf barn or purchase new group hutches. They simply need to move two individual hutches adjacent to one another and provide a common run area that allows pairs of calves to have access to the two hutches.

Despite the enthusiasm expressed by the farmer and the veterinarian, the on-farm setting still came with some challenges in terms of study design and data collection. For example, given that the farmer measured the starter intake twice weekly for me for the entirety of the study, I was required to assume that he was always precise in his measurements (which may not have been the case given that there was some missing data). The timing of events, such as moving to the group pen, also varied between calves. This was primarily due to the amount of space available in the calf barn, which sometimes resulted in pressure to move calves earlier than planned. This resulted in some animals either remaining in the hutches for longer periods than others, or exiting the hutches sooner than others, thus leading to variation in the number of data collection days. Finally, despite attempts to balance the number of replicates in each of the treatments, there were more individual calves than pair housed calves. This arose because the farmer was concerned that the paired calves would suffer from sickness when the weather turned poor; thus, he was reluctant to pair calves when the weather was not optimum from his perspective. This was especially true towards the end of the study when the farmer made the executive decision to dismantle the pair housed calves.

Additionally, there was no test-pen available to use for the food neophobia test on the farm. This meant that all data were collected in the hutches, or group pens. This likely created some additional challenges, for instance, as mentioned above, the calves were already habituated to the black buckets that contained their starter feed. So, when the black buckets were filled with TMR and placed in the feeding area, calves may have approached in a normal manner given that they could have been expecting their calf starter, thus possibly influencing the latency measure. Having a designated test-pen with a different type of bucket would have allowed me to confidently say that being habituated to the feeding area was not a contributing factor. A second limitation of the food neophobia test was that it was conducted when the calves were weaned from milk, and established on solid feed. Pair housed calves at weaning were eating more dry food than the individually housed calves, which may also explain the increased intake of the novel feed, possibly reflecting the calves' willingness to eat rather than their neophobia towards novel feeds.

Another commonly discussed topic raised by those working with calves is health differences between calves in social groups or as individuals. An epidemiological study designed to test this question requires a much larger sample size (likely hundreds of animals), and thus my study was not designed to test health. I encourage the reader to review the suite of studies that have investigated calf rearing practices on health (Pettersson et al., 2001; Svensson and Liberg, 2006; Vasseur et al., 2010). In contrast, my study was designed to describe the effects of housing on calf health, and future work on commercial farms should include health as an outcome, in part because this will facilitate future meta analyses looking at the effects of social housing on health.

A limitation for the application of this study is farm management and the motivation expressed by the farmer to look at social housing. If a farm is not prepared to feed calves high milk allowances through teat bottles, and spend time teaching calves where to access bottles, they may fail to achieve the numerous benefits of social housing. This application requires initial training of employees, and consistent care of calves to be successful.

3.3 Future Research Directions

Individual housing has been known to cause developmental issues in young animals for decades (Harlow et al., 1965; Fone and Porkess, 2008), and some of this work has been translated to dairy calves (Jensen et al., 1997; de Paula Vieira et al., 2010). Future work should focus on capturing farmers' views and values regarding calves and calf housing, and identifying potential barriers inhibiting adoption of social housing in young calves. Though described as a limitation, the incident of farmer non-compliance at the conclusion of the study can be viewed as an unintended outcome that should not be overlooked. By taking place on a commercial dairy farm, my research encompassed how some farmers may react to a change in calf housing. The scientific literature would benefit from more on-farm work so that we can better recognize barriers to change, the farmers' specific points of interest, and perceptions of calves. This work should be done using established social science methods such as direct interviews that allow us to describe the deeply held values and perceptions of farmers, and experimental studies where researchers can work regularly on farms collecting data to better conceptualize the barriers a farmer might face. Discovering these themes may better inform our research directions, and how to make changes that promote welfare of dairy calves. Additionally, studies assessing how to affect changes on farms may show how to better transfer research to on-farm practice.

In the current study, I often noticed pair-housed calves trying to elicit their partner to engage in play, and sleeping together in the same hutch, but these behaviours were not assessed systematically. Play has been described as a positive welfare state (Held and Špinka, 2011), and has been a behaviour of interest in research settings (Jensen et al., 2015). In hutches, Wormsbecher et al. (2017) investigated the amount of space used by calves housed in hutches, but failed to assess play. I encourage future work on play when comparing calves housed individually compared to pair housed in hutches to better understand the affective states of these calves.

My study, like many others, supports socially housing calves in small groups. It is becoming increasingly recognized that social housing is an important welfare parameter for dairy calves, but other housing factors may also influence calf welfare. With an increasing interest in natural living, perhaps the next frontier for socially housing dairy calves is to test the effects of more complex natural components, such as managing cow-calf groups, offering pasture access, or adding more choices (environmental enrichment) for calves. Cow-calf separation is a topic of increased concern (Ventura et al., 2013), and practical solutions of how to make these types of systems work will likely will be needed in the future . Forthcoming work should focus on developing different management techniques that may allow cows and calves to live together for lengthy periods of time, but are still practical for the farmer. The bond between the cow and calf may allow for more pronounced, or different benefits to calves that are yet unknown. We already know that calves in complex social housing are less food neophobic, but perhaps there are other benefits (such as social behaviours) that are gained when living in complex herds.

Dairy calves go through a variety of food transitions as they grow older, yet are often exposed to only three types of feed (milk, a single type of hay, and calf starter) prior to weaning.

Calves in natural settings are able to suckle from their dam as well as explore the pasture setting where they likely experience a variety of forages. Dairy calves reared in in barren environments are rarely allowed the opportunity to explore different forages. Examining the effects (e.g. food neophobia) of socially rearing calves with pasture access may offer interesting insights to the environment we offer calves from a feeding behaviour perspective.

Finally, there is a gap in the literature on calves' choice in their housing and diets. An extension of the pasture access question is to explore calves' preference for choices for aspects of their environment. For example, we know little about when calves prefer to be on pasture versus being inside a barn. Using methodologies such as preference and motivational tests to better understand calves' desire for more choices in life may clarify preferences and allow for additional improvement in how young calves are housed. We also know little about individual variation in calves, for example, why some calves consume more starter prior to weaning than others, and thus there is much to explore in terms of the effects of personality on calf welfare.

3.4 General Conclusions

My thesis work contributes to the growing body of literature showing that calves raised in social settings eat more solid feed and are less fearful of novelty. This study replicates these findings in a commercial setting; pair housed calves showed improved feed intakes and decreased fearfulness. In the future, studies should explore farmer perceptions of the effects of social housing, the continued study of calf health, and work uncovering the different components of natural living that may be important for a calf.

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