Effects and mitigation of competition for feed access on the behaviour of lactating dairy cows

by
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ABSTRACT

EFFECTS AND MITIGATION OF COMPETITION FOR FEED ACCESS ON THE BEHAVIOUR OF LACTATING DAIRY COWS

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Through two independent experiments, utilizing group-housed lactating Holstein cows, this thesis sought to determine, firstly, the effects of increased feed competition on variability in feeding behaviour between individuals, and secondly, whether increased feed delivery frequency improved access to feed, and reduced variability between cows. In the first study, cows were fed at each of 3 competition levels: low (3:3, cows:feed bins), moderate (3:2), and high (3:1). Under the highest competition: cows maintained dry matter intake through increased feeding rate and decreased feeding time; feed was consumed in fewer, larger and longer meals; and greater variability in feeding patterns was observed within groups. The second study delivered feed to competitively-fed cows (2 cows:1 feed bin), at either a lower frequency (2 ×/d) or a higher frequency (6 ×/d). At the higher frequency, first meals after feed delivery were shorter and smaller, while maintaining dry matter intake. Variability in feeding behaviour, in the second study, was more affected by parity than frequency of feed delivery. These studies suggest that reducing competitive pressure while feeding could reduce potentially deleterious behaviour and limit the variability between individuals. Additionally, more frequent feed delivery could improve access to feed during peak periods of feeding activity.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ACTH – adrenocorticotropic hormone

ADF – acid detergent fibre

AMS – automatic milking system

BW – body weight

CP – crude protein

DIM – days in milk

DM – dry matter

DMI – dry matter intake

ECM – energy corrected milk yield

FCM – fat corrected milk yield

FTIR – Fourier Transform Infrared Spectrometer

MUN – milk urea nitrogen

NDF – neutral detergent fibre

NEFA – nonesterified fatty acid

NE_L – net energy, lactation

NFC – non-fibre carbohydrates

OM – organic matter

PSPS – Penn State Particle Separator

RT – rumination time

SARA – subacute ruminal acidosis

SCC – somatic cell count

SI – success index

Chapter specific terminology

Chapter 2:

Low – 3 cows: 3 feed bins

Mod – 3 cows: 2 feed bins

High – 3 cows:3 feed bins

F1 – feeding 1 (1400 h)

F2 – feeding 2 (2000 h)

F3 – feeding 3 (0800 h)

Chapter 3:

Low – 2 ×/d feeding

High – 6 ×/d feeding

Young – ≤ 2^{nd} lactation

Mature – ≥ 3^{rd} lactation

CHAPTER 1. INTRODUCTION

When resources are limited, competition between individuals for access to those resources is introduced. As herd animals, dairy cows are highly motivated to feed simultaneously with other members of their social group (Nielsen, 1999). If there is insufficient space for all animals to feed together, there may be competition for access to the feed. This poses a problem if the competition reaches a level whereby the health and welfare of individual cows are compromised.

Competitive behaviour is characterized in the literature in two ways: indirect or direct competition (Giraldeau and Caraco, 2000). Indirect competition for feed access is displayed when individuals modify their behaviour to obtain access to the feed bunk, such as shifting feeding times to less busy periods of the day (Forbes, 1995), or increasing the rate of feed consumption (Olofsson, 1999). Direct competition is displayed through acts or threats of physical aggression between individuals; for example, one cow displacing or replacing another from their position at the feed bunk (Proudfoot et al., 2009; Huzzey et al., 2014). Alteration of natural behaviours due to competition between cows, either direct or indirect, may have widespread consequences for both their physiological health, such as instability in the rumen environment (Krause and Oetzel, 2006), and psychological health, such as reduced motivation to feed within a certain distance of more dominant individuals (Rioja-Lang et al., 2012).

Social position within the herd has a great influence on the success of dairy cows in competitive interactions (Bielharz and Zeeb, 1982). Not all individuals are of equal rank within the social hierarchy of the herd (Bouissou, 1981), therefore, dominance is expressed whenever the behaviour of one individual deters the behaviour of another (Bielharz and Zeeb, 1982). Researchers have demonstrated that subordinate cows will trade-off feed quality to avoid proximity to a more dominant individual (Rioja-Lang et al., 2009). Thus, in competitive feeding situations, the social stress imposed by dominant cows may result in a disproportionate impact of increased competition on subordinate cows. As feeding behaviour varies greatly among individual cows within the group (Melin et al., 2005), it is important to examine the factors influencing individual behaviour at different levels of competition.

Cattle naturally display a diurnal feeding pattern, dependent primarily on day-length, whereby cows consume their largest meals each day around the times of sunrise and sunset (Hancock, 1953; Ray and Roubicek, 1971; Gonyou and Stricklin, 1984). Despite this natural behaviour, intensification of dairy operations in North America has resulted in management practices becoming the major stimuli for lactating dairy cows fed a total mixed ration (TMR); the delivery of fresh feed, and to a lesser extent, the return from milking, elicit the greatest motivation for feeding activity in dairy cows (DeVries et al., 2003; DeVries and von Keyserlingk, 2005; King et al., 2016). The typical recommendation for linear feed bunk space is 0.6 m/cow (Grant and Albright, 2001; NFACC, 2009); however, this may be insufficient during peak periods of feeding activity when bunk attendance is highest (DeVries et al., 2003). If cows are unable to gain access to feed when desired, as in the case of spatial feed restriction (such as the physical feed area design or stocking rate) or temporal feed restriction (such as the length of time that feed is available throughout the day), competition between individuals increases. This review will outline the behavioural changes experienced by dairy cows under competition for feed access, as well as discuss potential negative health consequences resulting from those altered behaviours. Lastly the management factors that may contribute to, or mitigate, the effects of competition for feed access on individual dairy cows will be discussed.

1.1 Behavioural Response to Competition for Feed Access

The majority of feeding activity in dairy cows is observed throughout the day and early evening, with considerably less in the early morning and late night hours of the day (DeVries et al., 2003). High producing dairy cows generally spend between 3-5 h/day consuming feed, in approximately 9-14 meals/day (Grant and Albright, 2001), however, these behaviours are susceptible to change due to increased competitive pressure at the feed bunk.

As feeding space becomes increasingly restricted, cows demonstrate reduced feeding time (DeVries et al., 2004; DeVries and von Keyserlingk, 2006; Huzzey et al., 2006), increased feeding rate (Olofsson, 1999; Hosseinkhani et al., 2008), and consume fewer, larger and longer meals each day (Shaver, 2002; Cook et al., 2004); greater feed bunk competition may also be associated with reduced rumination activity (Batchelder, 2000). DeVries et al. (2004) examined the effect of reducing available feed bunk space from 1.0 m/cow to 0.5 m/cow, and found that cows spent 14% less time feeding and had a 10% reduction in meal time. Increases in the rate of feed consumption are most prominent during the peak periods of feeding activity, since the reduction in available feeding space prevents the simultaneous feeding of all cows motivated by the fresh feed delivery (Olofsson, 1999; Hosseinkhani et al., 2008). Modification of the rate of intake and the length of feeding activity allows cows to maintain their daily dry matter intake (DMI); individuals may also maintain intakes by shifting their feeding activity to times of the day when fewer cows are present at the bunk (Forbes, 1995). Subordinate cows, in particular, forgo peak feeding times in favour of a later time when there is less competition for feed access (Olofsson, 1999; Rioja-Lang et al., 2009).

An interesting aspect of feeding behaviour in cows is their ability to use their nose and tongue to sort, and preferentially consume, different components of their feed (Beauchemin, 1991).

One advantage of implementing a TMR, is the ability to hinder sorting behaviour by offering a combination of all feed components, chopped and thoroughly mixed, that allows intake of a complete, balanced ration with each bite (Coppock, 1977); however, sorting behaviour remains a concern in the dairy industry. Generally, cows sort in favour of the high-energy grain particles of their diet, over the higher-fiber components (Leonardi and Armentano, 2003; 2007). DeVries et al. (2005) demonstrated an increased proportion of NDF in the remaining feed in the bunk as sorting occurred over the day, indicating a decline in the overall feed quality. In competitive feeding situations, individual cows may be forced to shift feeding visits away from peak periods following fresh feed delivery, into periods where considerable sorting has occurred, leaving an unbalanced ration (Olofsson, 1999; Leonardi and Armentano, 2003); sorted TMR may not contain the required nutrients to meet the energy demands of high-producing cows (DeVries and von Keyserlingk, 2006; Hosseinkhani et al., 2008). Since the individuals that are typically forced to access feed outside of peak periods are subordinate cows (Olofsson, 1999; DeVries et al., 2005), they are more likely to consume the sorted ration. Conversely, dominant cows that access feed during peak times may have increased consumption of the highly-fermentable carbohydrate components of the ration, and thus may be at increased risk of developing metabolic disorders such as subacute ruminal acidosis (SARA; Cook et al., 2004; Stone, 2004; DeVries et al., 2008).

Displacements from the feed bunk are a commonly observed behaviour among competitively fed cows, characterized by the initiator (actor) of the displacement, aggressively forcing the complete withdrawal of another cow (reactor) from the feed bunk through butting or pushing (DeVries et al., 2004). A higher frequency of displacements is typically observed as stocking density increases (Proudfoot et al., 2009; Collings et al., 2011), with the greatest number displayed within the peak 2 h period following delivery of fresh feed (DeVries et al., 2003; 2004;

Val-Laillet et al., 2008). Subordinate cows receive a greater number of displacements than dominant cows (Olofsson, 1999; Huzzey et al., 2006), and have also been shown to experience the greatest reduction in displacements as feeding space becomes less restricted (DeVries and von Keyserlingk, 2006). Displacements are a method of direct competition, and those cows that are unsuccessful in displacing others from the feed are forced to compete indirectly, through shifting the time of feeding visits, and by increasing the rate of feed consumption, over shorter amounts of time (Olofsson, 1999).

Competition due to increased stocking density can lead to increased idle standing time, as cows wait to gain access to an occupied feed bunk (Olofsson, 1999; DeVries and von Keyserlingk, 2006; Huzzey et al., 2006). As seen in displacement behaviour, inactive standing time is greatest during the peak periods of bunk attendance following the delivery of fresh feed (DeVries and von Keyserlingk, 2006; Huzzey et al., 2006), and it has been associated with an elevated risk of lameness (Greenough and Vermunt, 1991; Galindo and Broom, 2000). However, not all researchers have reported competition for feed access to have an effect on standing time (Collings et al., 2011), indicating that it is a highly variable behaviour between individuals (Ito et al., 2009). Social position plays a role in this variability, with subordinate cows displaying greater inactive standing times than higher-ranked cows (Olofsson, 1999; Galindo and Broom, 2000). Since each activity a cow performs throughout the day contributes to their overall daily time budget, increased standing time may be associated with reductions in other behaviours, such as lying time (Proudfoot et al., 2009) or feeding time (Olofsson, 1999). Singh et al. (1993) observed that newly introduced heifers, in a competitive, free-stall environment, displayed lying times as low as 6.25 h/d, whereas typical free-stall dairy cows in Canada display lying times between 8.7 - 13.2 h/d, with cows on overstocked (>100%) farms lying down for fewer than 12 h/d (Charlton et al., 2014).

1.2 Physiological Impact of Competition for Feed Access

To adapt to competition for feed access, cows rapidly consume feed in fewer, shorter, yet larger meals (Olofsson, 1999; Huzzey et al., 2006). Such large intakes of feed can disrupt the pH balance of the rumen (Krause and Oetzel, 2006). This behaviour, known as slug-feeding, can cause drastic pH declines following meals, leaving cows more susceptible to developing SARA (Shaver, 2002; DeVries et al., 2005). Similarly, large meals of a diet low in NDF, due to increased sorting behaviour, may result in reduced chewing behaviour, thus lowering buffering capacity of the rumen and consequently increasing the risk of SARA (Allen, 1997; Cook et al., 2004, Stone, 2004; Hosseinkhani et al., 2008). Distributing intakes of feed into smaller, more even meals throughout the day could produce a more stable and healthy rumen environment (Nocek and Braund, 1985; Shabi et al., 1999; Hart et al., 2014). A study by French and Kennelly (1990) increased the frequency of concentrate feeding from 2 to 12 ×/d, and whereas the 2 ×/d feeding elicited depressed pH levels after feeding that took several hours to rebound, feeding concentrate 12 ×/d produced almost no reduction in pH from normal levels.

Dairy cow productivity is closely linked to DMI, with a positive correlation demonstrated between DMI and total milk yield (Dado and Allen, 1994; Martin and Sauvant, 2002). Studies show that reduced competition for feed access, on farms providing more space at the feed bunk, had a positive effect on milk production (Deming et al., 2013; Sova et al., 2013). Deming et al. (2013) observed that greater availability of feed bunk space in automatic milking system (AMS) herds was associated with greater milk yield. Research by Sova et al. (2013) examined herd-level associations with feed management practices and found that for each 10 cm increase in linear feed bunk space (across a range of 30 to 60 cm/cow), there was a 0.06 percentage point increase in average group milk fat content, and a 13% reduction in average group somatic cell count. The authors speculated that cows with improved feed access displayed more consistent intakes, in smaller, more frequent meals, thereby promoting a stable rumen environment capable of greater milk fat production. In addition, the improved access to feed during the peak periods following return from milking may have increased the latency to lie down, thus reducing the potential for intramammary infection and elevated SCC (Sova et al., 2013). In other studies, more consistent intakes of feed across the day have also been found to increase milk fat content (Rottman et al., 2014) and improve milk production efficiency (Mantysaari et al., 2006).

Although cows may be able to maintain daily DMI, and thus milk production, under competition for feed access by modifying the timing of feed bunk visits, feeding rate and total feeding time (Olofsson, 1999; Hosseinkhani et al., 2008), such modifications may have negative consequences on the productivity of individual cows. Since feeding time is correlated with milk production (Shabi et al., 2005), reduced time spent feeding by competitively-fed cows could result in lower milk yields. Dominance rank is also correlated with milk production, with subordinate cows spending less time feeding and producing lower milk yields than dominant cows (Val-Laillet et al., 2008; von Keyserlingk and Weary, 2010). Indeed, subordinate cows have been shown to undergo the greatest reductions in DMI compared to dominant cows in competitive feeding situations (Olofsson, 1999; Grant and Albright, 2001; Proudfoot et al., 2009). Since dominance rank is influenced by age, body weight, and parity (Val-Laillet et al., 2008), it has also been found that primiparous cows have lower DMI and milk yields than multiparous cows (DeVries et al., 2011; Hart et al., 2014). Due to such variability in DMI and milk production at the individual cow level, reduction of competitive pressure at the feed bunk that allows improved access to feed could lead to more consistent DMI between cows, and an increase in herd productivity, as postulated by Hart et al. (2014).

Cook et al. (2004) demonstrated that lameness caused by the weakening of connections between the pedal bone and the claw wall could be attributed to more frequent weight bearing activity, such as increased standing time, a commonly observed behaviour that occurs under increased competition for feed access (Olofsson, 1999; DeVries and von Keyserlingk, 2006; Huzzey et al., 2006). Furthermore, Galindo and Broom (2000), found a greater number of cases of lameness and sole lesions among cows that spent > 45% of their time standing in a free-stall pen. Leonard et al. (1998) suggested that individuals previously involved in aggressive interactions at the feed bunk may be more prone to developing claw horn lesions than those that have not. These researchers observed that heifers had more severe claw-horn lesions 3 months following their involvement in aggressive interactions, when compared to heifers that were not involved in such interactions.

Competition with conspecifics can be highly stressful, both physiologically and psychologically. Studies of the physiological responses of cows under increased competition show a variety of changes in the level of stress-related metabolites in their system. Krawczel et al. (2012) reported an association of blood corticoid response to an ACTH challenge in competitively-fed cows, suggesting the cows experienced a stress response to the alteration of their feeding behaviour. Huzzey et al. (2012a) compared dry cows fed at 2 different stocking densities, and found higher plasma NEFA and fecal cortisol concentrations in cows with the lowest success at displacing conspecifics from the feed bunk, compared with moderately or highly successful cows. Furthermore, these researchers found a higher peak insulin response in low-success cows than higher-success cows, indicating a reduced tissue response to insulin, similar to insulin resistance. In a related study, primiparous cows had higher fecal metabolites when overstocked, while no difference was found in multiparous cows, suggesting that younger animals have more difficulty managing increased competition levels (Huzzey et al., 2012b). Changes in heart rate are also commonly monitored in response to environmental stressors (Hagen et al., 2005; Arnold et al., 2007; Gygax et al., 2008). In a study of competitively-fed dairy cows by Hetti Arachchige et al. (2014), heart rate was reduced as feeding space increased, indicating a reduction in stress response. Interestingly, heart rates of subordinate cows remained elevated over those of higher-ranked cows regardless of inter-cow feeding space, suggesting they consistently experienced a stress response when feeding in proximity to more dominant individuals (Hetti Arachchige et al., 2014). This increased stress could influence a subordinate cow's motivation to access feed when a more dominant cow occupies the bunk (Rioja-Lang et al., 2009). Competitive stress may also have an impact on reproduction; Caraviello et al. (2006) identified that the probability of pregnancy at 150 DIM increased linearly as feeding space per cow increased from 30 to 60 cm.

With an abundance of reported variation in response to competitive stress by young and low-ranked cows, it is clear that social hierarchy plays an important role in the ability of cows to adapt to competition for feed access. Social dominance provides one individual over another with the priority to approach or avoid a situation or resource (van Kreveld, 1970; Drews, 1993). Whereas the disruption of the daily routine and motivations of dominant individuals may be minimal, subordinate cows are affected to a greater extent, regularly losing or being prevented access to valuable resources (Grant and Albright, 2001). For low-ranked cows presented with competition for available feeding space, social stress may increase in response to the inability to avoid or retreat from more dominant individuals (Proudfoot and Habing, 2015). Even the perceived threat of displacement may be sufficient to elicit a stress response inhibiting further feeding activity (Morgan and Tromborg, 2007; Huzzey et al., 2012a). Research by Rioja-Lang et al. (2009) used preference testing to examine the importance of avoiding social stress imposed by more dominant cows, over feed quality. Subordinate cows were given a choice between consuming low quality feed alone, or consuming high quality feed next to a more dominant individual; results indicated that the subordinate cow preferred to feed away from the dominant individual, despite having to sacrifice feed quality. In a follow-up study, the same research group allowed subordinate cows to choose between consuming a low-palatability feed alone vs. a high-palatability feed next to a dominant cow, at different inter-cow distances (Rioja-Lang et al., 2012). When provided with smaller distances of 0.3 or 0.45 m between cows, the subordinate individual chose to feed alone; at greater distances of 0.6 or 0.75 m, the subordinate cow was willing to eat next to the dominant. These studies suggest that the stress imposed by differences in social rank is a strong motivator of altered feeding behaviours in competitive situations.

1.3 Management Factors Influencing Competition for Feed Access

Competition for feed access is an issue affecting dairy cattle in free-stall systems or other forms of loose housing, since the freedom to move around the barn and interact with conspecifics introduces competitive pressure between individuals. When fed as a group, the amount of feed consumed, as well as the rate of consumption, increases compared to individually-fed cows (Albright, 1993), and individual intakes can be highly variable between cows (Friend et al., 1977). In a natural setting, group size would be determined based on the availability of resources and would fluctuate over time (Estevez et al., 2007). In commercial dairy operations, however, cows are restricted to management groups that may not take into account the social structure of the group (Estevez et al., 2007). Groups are typically formed to streamline management practices such as feeding or milking strategy, or based on parity and production level, and may be frequently re-arranged. Continued introduction of new animals to the group may lead to social instability, increased aggression, and increased competition for resources (Grant and Albright, 2001; Estevez et al., 2007).

The design of the feeding area, specifically the available bunk space and the use of partitions between individuals, is of particular importance in determining the level of competition for feed access that cows experience (DeVries and von Keyserlingk, 2006; Hetti Arachchige et al., 2014). Availability of feed bunk space is a key determinant of the level of competition for feed access (DeVries et al., 2004), and contributes to the social stress and aggression displayed between individual cows (Morgan and Tromborg, 2007). DeVries et al., (2004), found that, in a free-stall system, doubling available linear bunk space from 0.5 to 1 m/cow resulted in 60% more space between cows, and a 57% reduction in aggressive interactions at the feed bunk. These changes allowed cows to increase the time spent feeding, particularly in the peak periods following delivery of fresh feed. Similar findings were reported by Hetti Arachchige et al. (2014), who supplemented pastured cows with a partial mixed ration on a feed pad, at 3 different space allowances. They observed that as feeding space increased, cows spent a greater amount of time feeding and were involved in fewer aggressive interactions. Both preceding studies support the idea that dominant cows are at greater advantage when access to feed is restricted (Rioja-Lang et al., 2009), since subordinate cows experience the greatest increase in feeding time, as well as the greatest reductions in aggressive interactions when more feeding space was available (DeVries and von Keyserlingk, 2006; Hetti Arachchige et al., 2014).

The feed bunk layout is also an important consideration when there is competition for feed access. Early research by Bouissou (1970) found that physical separation between the heads of feeding cows provided subordinate individuals with better access to feed: potentially due to a greater feeling of protection afforded by the physical barrier (Konggaard,1983). The two most common feed bunk types are the post-and-rail design, where there is no separation between feeding cows, and the headlock design, where a series of individual feeding positions separate the necks of adjacent cows. Huzzey et al., (2006) compared the effects of these two designs using groups of cows fed at 4 different stocking densities, between 0.21 - 0.81 m/cow (or 0.33 – 1.33 headlocks/cow). Cows on both bunk designs displayed reduced feeding times as stocking density increased, with greater reductions at each increment in stocking density. However, while these researchers found that cows using the post-and-rail system had longer feeding times and reduced idle standing time, cows experienced more displacements compared to using the headlock system. Subordinate cows in particular experienced a greater number of displacements, especially as stocking density increased, consistent with Hetti Arachchige et al. (2014).

A similar study by Endres et al. (2005) compared cows fed at post-and-rail and headlock feed bunk designs at equivalent stocking densities (0.6 m/cow or 1/ headlock/cow) and observed no differences in daily feeding time; they did, however, identify an effect during the peak period following fresh feed delivery. In peak periods, cows previously demonstrating below average feeding times for the group at the post-and-rail system, displayed feeding times similar to the group average when fed at the headlock system. This suggests that subordinate cows using the headlock system had improved access to feed during peak periods (Endres et al., 2005). Consistent with Huzzey et al. (2006), Endres et al. (2005) observed 21% fewer displacements among cows fed using the headlock system compared to the post-and-rail system.

A common aspect of these studies is that displacements are reduced when a physical barrier is provided between feeding cows, and that lower-ranked animals benefit to a greater extent. As the majority of displacements at a post-and-rail feeder are initiated from the front or side of the feeding cow (DeVries and von Keyerlingk, 2006), the difference in displacements could be due to a reduced ability to perform lateral swinging motions of the neck within the headlock system (Huzzey et al., 2006). The addition of extended feed stall barriers that separate both the heads and bodies of adjacent feeding cows may provide additional protection against this form of displacement. Herlin and Frank (2007), demonstrated that the inclusion of protective gates to concentrate feeding stations reduced displacements of feeding cows by 67%. As well, DeVries and von Keyserlingk (2006) found that displacements were reduced by approximately 55% when feed stalls were used, compared to a similar stocking density at a post-and-rail feeder. These researchers also found that cows altered the method of displacement (approaching from the rear as opposed to the front or side) when the feed stalls were used.

Restricted feed access may be due to temporal limitations, as well as bunk space and design. To reduce labour inputs and limit feed wastage, some cows may be fed for 0% refusals, known as "slick-bunk" feeding (Collings et al., 2011), which restricts the amount of time that feed is accessible throughout the day. In a study that restricted feed availability to 12 h/d for individually fed cows, there was no difference in daily DMI, yet daily feeding time was reduced and rate of feed intake was increased (Munksgaard et al., 2005), consistent with studies of spatial feed restriction (DeVries and von Keyserlingk, 2005; Hosseinkhani et al., 2008). Research by Collings et al. (2011) looked at the combined effects of both spatial and temporal feed restriction and found that the negative effects were compounded. Cows that were overstocked at a density of 2 cows:1 feed bin, combined with a time restriction of 14 h/d, spent less time feeding and had greater feeding rates than overstocked cows with ad-libitum feed availability, particularly during peak feeding times.

To overcome the spatial and temporal restrictions on feed access, researchers have examined methods of increasing the availability of fresh feed in the bunk. It is common practice on dairy farms to deliver feed 1-2 ×/d, and unless feeding from an enclosed feed bunk, dispersed feed is routinely pushed to within reach of the cows several additional times per day (known as 'push-ups'). DeVries et al. (2003) looked at the effects of increased feed push-ups in the early morning hours on attendance at the feed bunk, and found that pushing up previously delivered feed did little to stimulate increased bunk attendance. Rather than push-ups, the delivery of fresh feed stimulates the highest bunk attendance and feeding activity in dairy cows (DeVries et al., 2003; DeVries and von Keyserlingk, 2005). Increasing the frequency of fresh feed delivery may contribute to a more even distribution of feed consumption across the day (DeVries et al., 2005; Mantysaari et al., 2006), helping to maintain a more stable rumen environment (Nocek and Braund, 1985), and to reduce spikes in feed bunk attendance that may exacerbate competition for access (Mantysaari et al., 2006).

Recent advances in automated feeding technology make it possible to easily increase frequency of fresh feed delivery over the typical 1-2 ×/d (Oostra, et al., 2005). More consistent availability of fresh feed across the day may stimulate increased feeding activity (Menzi and Chase, 1994), particularly in the evening hours (Phillips and Rind, 2001; DeVries et al., 2005), and reduce sorting behaviour (Shaver, 2002; DeVries et al., 2005). A study by Oostra et al. (2005) examined the effect of increasing fresh feed delivery from 2 to 6 ×/d on the behavioural time budget of cows in an AMS. They found that increased feeding frequency promoted greater feeding activity at the feed alley and in turn reduced waiting times for the milking unit. Research by Shabi et al. (1999) determined that increasing the delivery of concentrates to cows from 2 to 4 ×/d resulted in increased DMI, reduced variation in ruminal pH, and improved efficiency of milk fat and protein production. Sova et al. (2013) observed that herds that were fed 2 ×/d compared to 1 ×/d exhibited reduced sorting behaviour, increased DMI by 1.42 kg/d/cow, and higher milk yields by 2.01 kg/d/cow. However, there is also research indicating that too frequent feed deliveries may be disruptive to feeding behaviour in cows (Phillips and Rind, 2001; Mantysaari et al., 2006). Phillips and Rind (2001) conducted 2 studies, firstly comparing cows fed daily to those fed on alternate days, and secondly comparing cows fed 1 ×/d to those fed 4 ×/d. In both studies, the authors found that when cows were fed less often, they tended to have higher DMI and had greater milk production. Similarly, Mantysaari et al. (2006) examined the feeding behaviour of individually fed cows when feed delivery frequency increased from 1 to 5 ×/d. They observed that cows fed less frequently had increased DMI, yet spent less time feeding, and increased time lying. Researchers from both studies concluded that increasing feed frequency could lead to greater disturbance of feeding behaviour and productivity. However, while cows were either fed from a feed alley (in the first study by Phillips and Rind, 2001) or from individual feed bins, neither study investigated the effects of increased frequency of feed delivery on competitively-fed cows, which are already under increased pressure when attempting to gain feed access. It is hypothesized that those cows who need to compete for access to feed may experience greater benefit from increased availability of feed than individually-fed cows.

1.4 Objectives and Hypotheses

The overall objective of this thesis was to investigate the effects, and potential mitigation, of competition for feed access on the feeding behaviour of individual dairy cows within group-housed systems. This objective was carried out through 2 independent experimental studies.

The primary objective of the first study (Chapter 2) was to determine the effect of differing levels of competition for feed access on the feeding behaviour of group-housed dairy cows. A secondary objective was to determine the impact of competition on variability in feeding and behaviour patterns, and productivity between individuals within the group. It was hypothesized that as competition increased, cows would consume their feed faster and in larger meals, and that individuals within the group would experience greater variability in their patterning of feed consumption, behaviour, and productivity.

In the second study (Chapter 3), the objective was to determine whether increased feeding stimuli could mitigate the effect of competition on individual cows within a group. It was hypothesized that, under competitive feeding conditions, a higher frequency of feed delivery would provide more individuals the opportunity to access feed during peak periods of feed consumption than at a lower frequency of feed delivery. Secondly, it was predicted that there would be less variability in feeding patterns, and the resulting behaviour and productivity, between individual cows at a higher feed delivery frequency than at a lower feed delivery frequency.

CHAPTER 2. Variability in behaviour between dairy cows fed under differing levels of competition

2.1 INTRODUCTION

Dairy cows experience the greatest motivation to feed following the delivery of fresh feed and, to a lesser extent, upon return from milking (DeVries and von Keyserlingk, 2005; King et al., 2016). However, when space at the feed bunk is limited, particularly at these times of high bunk attendance, individual cows must compete for feed access. Competition for resources, such as feed, leads to greater social pressure (Nielsen, 1999) and results in altered feeding behaviour, such as reduced feeding time (Huzzey et al., 2006; Proudfoot et al., 2009), increased feeding rate (Olofsson, 1999; Hosseinkhani et al., 2008), and greater idle standing time (Huzzey et al., 2006). Higher frequencies of displacements from the feeding area have also been demonstrated under increased competition for feed access, particularly for subordinate cows (Huzzey et al., 2006; Val-Laillet et al., 2008; Proudfoot et al., 2009). These alterations of feeding behaviour in competitive environments may influence intake and meal patterns, resulting in health problems such as increased lameness (Cook et al., 2004) and subacute ruminal acidosis (Shaver, 2002). The productivity of individual cows may also be affected by changes in feeding behaviour, as milk production has been correlated with feeding time and DMI (Dado and Allen, 1994; Shabi et al., 2005).

Subordinate cows have demonstrated a greater stress-response to feeding in the company of higher ranked neighbouring cows (Hetti Arachchige et al., 2014), and to sacrifice feed quality to avoid feeding in proximity to a more dominant individual (Rioja-Lang et al., 2009). This indicates that feeding conditions can impose great social stress on subordinate cows, which under competitive pressure, have been observed to deviate from the preferred peak feeding times associated with fresh feed delivery (Olofsson, 1999). In these situations, individuals may subsequently consume a diet that is different from that intended, as feed sorting will result in altered feed composition further from feed delivery times (Leonardi and Armentano, 2003). Hosseinkhani et al. (2008) studied the effects of feed bunk competition on feed sorting by close-up prepartum cows and found a tendency for competition to affect the sorting of medium particles, with competitively fed cows displaying less sorting of medium particles than non-competitively fed cows shortly after feed delivery. However, those researchers compared only non-competitively to competitively fed cows and did not consider to what extent the degree of competition could affect sorting behaviour. In addition, Hosseinkhani et al. (2008) looked at close-up cows fed a diet with a higher proportion of forage compared to a lactating cow diet; such a diet would potentially be less easily sorted than a lower forage, lactating cow ration (DeVries et al., 2007).

A common factor in most studies of feeding competition is that subordinate cows are particularly affected by increased levels of competition (DeVries et al., 2004; Huzzey et al., 2006; Val-Laillet et al., 2008). Depending on grouping strategy, individual cows within group-housed systems can differ based on their age, parity, stage of lactation, production level, and body weight (BW), all of which may influence their relative social position and contribute to their success in competitive interactions. Poor success in gaining feed access in competitive situations can act as a source of physiological stress with negative consequences for an individual cow's welfare (Huzzey et al., 2012b; Hetti Arachchige et al., 2014). While these past studies have discussed differences between dominant and subordinate cows, they have not investigated how individual variability among all cows within the group may affect their respective feed intakes, meal patterns, and time allocated to other behaviours (e.g. ruminating, and lying down).

The primary objective of this study was to investigate the effect of differing levels of competition for feed access on the feeding patterns, behaviour, and productivity of group-housed dairy cows. The secondary objective was to determine the impact of competition on variability in feeding and behaviour patterns, and productivity between individuals within the group. It was hypothesized that as competition increased: 1) cows would consume their feed faster and in larger meals, and 2) individuals within the group would experience greater variability in their feed consumption and behaviour patterns.

2.2 MATERIALS AND METHODS

2.2.1 Animals and Housing

Eighteen lactating Holstein dairy cows, including 5 primiparous and 13 multiparous (average parity = 3.4 ± 1.3), were chosen from the research herd at the University of Guelph, Kemptville Campus Dairy Education and Innovation Center. At enrollment into the study, subject animals were 77 ± 20 DIM, with an average milk production of 46 ± 7 kg/d, and BW of 721 ± 85 kg. Health status of each cow was evaluated before selection and monitored throughout the trial; no cows were identified that experienced health concerns requiring removal from the study during the transition period or early lactation. Each cow participated in the study for a total of 33 d. Cows were housed in groups of 6 animals, in a free-stall pen with 6 automated feed bins (Insentec RIC, Marknesse, The Netherlands), and 6 stalls equipped with waterbeds (DCC Waterbeds, Advanced Comfort Technology Inc., Reedsburg, WI, USA), bedded with wood shavings as needed. Manure was scraped from the stalls to within reach of automatic alley scrapers during milking times. Cows had ad-libitum access to water from two bowls within the pen. Cows were milked 3 times daily at 0800, 1400, and 2000 h; at each milking cows were manually brought to a holding pen for individual milking by an AMS (Lely Astronaut A3 Next, Lely Industries N.V., Maassluis, The Netherlands) to simulate conventional milking systems. No supplemental feed was supplied by the AMS. Once weekly, cows were treated with preventative hoof spray (HealMax Spray, Agrochem Farm and Dairy Products, Saratoga Springs, NY, USA). The use of cows and experimental procedures complied with the guidelines of the Canadian Council on Animal Care (CCAC, 2009) and were approved by the University of Guelph Animal Care Committee (Animal Use Protocol #3245).

2.2.2 Experimental Design

The study was conducted using 3 groups of 6 individuals. Within each group, cows were assigned to 2 sub-groups of 3 individuals, balanced for DIM, parity, and production. Sub-groups of cows were exposed in a modified Latin-square design to each of 3 different competition levels: 1) high competition (**High**; cows fed at a ratio of 3 cows: 1 feed bin), 2) moderate competition (**Moderate**; 3 cows: 2 feed bins), and 3) low competition (**Low**; 3 cows: 3 feed bins). Cows were exposed, in random order, to each treatment for a period of 10 d. Sample size and power analyses were used to calculate the number of replicates (sub-groups) needed (Morris, 1999) to detect a 15% level of observed difference for the primary outcome variables, including feeding behaviour, DMI, and sorting. Estimates of variation for these variables were based on previously reported values (Hosseinkhani et al., 2008; Hart et al., 2013; 2014).

Each group of 6 cows was moved into the research pen and introduced to the feed bins 3 d prior to the start of trial. The feed bins were programmed to allow access to only specified cows, and recorded their feed intakes and behaviour, as validated by Chapinal et al. (2007). During this time, each sub-group of 3 cows successfully learned to access feed from only their designated bins. The feed bins of each sub-group were then assigned their respective treatments beginning at 1400 h on the first day of each treatment period. The first 5 d served as adaptation to the treatment, and data was recorded for the last 5 d (d 6 – 10). Recording began each day at 1400 h and continued until 1359 h the following day. Treatments were switched, in random order, at the end of each recording period, and the above-mentioned procedures were repeated.

2.2.3 Feeding Procedure

Cows were fed a TMR according to the NRC (2001) nutrient requirements of a dairy cow producing a mean milk yield of 43 kg/d (Table 2.1). The TMR was prepared in a mixer wagon (Jaylor 4425, Jaylor Fabricating, Orton, ON, Canada) and delivered once daily into a feed cart (Rovibec 530, Ste-Monique Co., Nicolet, QC, Canada). Supplemental grain pellets were weighed manually on a scale (Model 2020, Mettler-Toledo Inc., Mississauga, ON, Canada) prior to being mixed into the TMR for 4 min by the feed cart. Fresh feed was provided 3 ×/d: at 0800, 1400, and 2000 h. Freshly mixed feed was first delivered each day at 1400 h (**F1**), after daily emptying of the feed bins, therefore, 1400 h was designated the start of the day for data recording purposes. Approximately 1/3 - 1/2 of the daily feed allotment was supplied at this first feeding, with the remainder divided between the second (2000 h; **F2**) and third (0800 h; **F3**) feedings. Each day, newly mixed feed was delivered directly to the feed bins at F1, with the remainder stored in covered containers until delivery at each subsequent feeding. To allow equal opportunity to access the fresh feed, cows were denied access to the feed bins from the start of each milking until the last cow exited the AMS (~1 h). Additionally, feed bins were closed for 30 min prior to F1 (from 1330 to 1359 h) each day, while the previous days' refusals were sampled and the bins were cleaned out. The total amount of feed offered was adjusted to target approximately 10% daily refusals per cow.

2.2.4 Behavioural Data Collection

Data collected from the Insentec system provided the time each feeding visit occurred, the visit duration, and the amount of feed consumed per visit. For each recording period, these data were used to calculate daily DMI (kg/d), daily feeding time (min/d), and average feeding rate (kg DM/min) of each cow. The DMI, feeding time, and feeding rate were also analyzed across treatments for the first hour following each feed delivery and milking time, since this has been previously identified as the period of peak feed bunk attendance and DMI (DeVries et al., 2003a; DeVries and von Keyserlingk, 2005; King et al., 2016).

Meals were determined by combining individual feeding visits according to the methods described by DeVries et al. (2003b). Meal criteria (defined as the minimum time interval between meals) were determined for each cow during each period using the MIX 3.1.3 software (MacDonald and Green, 1988), by fitting normal distributions to the frequency of $\log_{10}$ transformed intervals of time between feeding visits, as collected from the Insentec system. Meal frequency (no./d) was determined by summarizing the number of intervals between feeding visits that exceeded the individual meal criterion of each cow. Meal length (min/meal) was calculated as the time between the start of the first feeding visit and the end of the last feeding visit before the meal criterion was surpassed. Meal size (kg DM/meal) was calculated as DMI divided by meal frequency.

Replacements were defined, as per Huzzey et al. (2014), as instances when the actor (initiator) of an aggressive interaction at a feed bin was the next to occupy the same feed bin, once the reactor (feeding cow) had exited. The daily number of times a cow was involved in a replacement from the feed bin was determined using electronically recorded feeding behaviour from the Insentec system, according to the methods validated by Huzzey et al. (2014). The frequency of replacements was identified as when ≤ 26 sec had elapsed between the exit of one cow from a feed bin and the entrance of another. The number of times each cow was involved as either the actor or reactor in a replacement were summarized, and a replacement success index (SI) was determined as a measure of individual success in competitive interactions. The SI was calculated as the number of times each cow was the actor of a replacement, divided by the number of times as both the actor and reactor (Galindo and Broom, 2000; Val-Laillet et al., 2008). Using this SI, each cow was categorized by a rank of Low, Medium or High competitive success, according to the methods described by Huzzey et al. (2012a); cows with an SI < 0.4 were ranked as Low, an SI ≥ 0.4 and < 0.6 were ranked as Medium, and an SI ≥ 0.6 were ranked as High.

Standing and lying behavioural data were recorded using data loggers (HOBO Pendant G Logger, Onset Computer Corporation, Pocasset, MA, USA), as validated by Ledgerwood et al. (2010). Data loggers were affixed to the rear hock of each cow using veterinary bandaging tape (Vetrap Bandaging Tape, 3M, London, ON, Canada) before the start of d 6 and removed following the end of d 10 in each period. Leg orientation data were recorded at 1 min intervals and used to compute standing and lying duration (min/d), lying bout frequency (bouts/d), and lying bout length (min/bout).

Rumination behaviour was recorded electronically using automatic rumination detection loggers (Lely Qwes-HR collars, Lely Industries N.V., Maassluis, The Netherlands), as validated by Schirmann et al. (2009). Loggers were attached to a collar and lay on the left side of each cows' neck, where they recorded sounds of regurgitation and rumination with a microphone. These data were processed, summarized in 2 h intervals, and stored in the memory of the logger for up to 22 h before being automatically uploaded via a reader located inside the AMS unit. The resulting rumination time data were downloaded following the completion of each recording period; these data were then summarized for each cow, by day and 2 h interval per day.

2.2.5 Feed Sampling and Analyses

Feed samples were collected during the 5 d of each recording period. On d 6 and 7, 1 composite sample of fresh offered feed from the bins of each sub-group was taken at each feeding for dry matter (DM) determination. On d 8 to 10, a composite sample of each of the offered and refused feed was taken from the bins of each sub-group, at each feeding, to determine DM and differences in sorting. At F2 and F3, new feed was added to each bin and mixed thoroughly with any remaining orts prior to sampling the offered feed. Samples of TMR components were collected once weekly to be analyzed for DM, chemical composition, and particle size. All feed samples were frozen at -14ºC upon collection until further analysis.

Each sample for sorting determination was separated using a 3-screen Penn State Particle Separator (**PSPS**; Kononoff et al., 2003) into long (> 19 mm), medium (< 19 > 8 mm), short (< 8 > 1.18 mm), and fine (< 1.18 mm) particles. The subsequent fractions, in addition to the whole samples used for DM determination, were oven-dried at 55ºC for 48 h. All dried samples of TMR feed components and fresh TMR (whole samples and PSPS fractions) were ground (Wiley Mill, Arthur H. Thomas Co., Philadelphia, PA, USA) and passed through a 1 mm screen; ground samples were shipped to Cumberland Valley Analytical Services Inc. (Maugansville, MD, USA) for DM (135°C; AOAC, 2000; method 930.15), ash (535°C; AOAC, 2000; method 942.05), ADF (AOAC, 2000; method 973.18), and NDF with heat-stable α-amylase and sodium sulfite (Van Soest et al., 1991) analyses. The chemical composition of the TMR is found in Table 2.1, while particle size distribution and nutrient content by particle size fraction are found in Table 2.2.

Feed sorting was determined by dividing the DM amount of each particle fraction actually consumed by the predicted DM amount consumed for the same fraction, and expressing it as a percentage (Leonardi and Armentano, 2003). The results of the PSPS analysis were used to determine the actual and predicted DM consumed by each sub-group. The actual DM consumed was calculated as the DM proportion of each particle fraction of refused feed subtracted from the DM proportion of each particle fraction in the offered feed; the predicted DM consumed was calculated as the proportion of total DMI for each particle fraction. Resulting values equal to 100% indicated no sorting of the fraction, while values > 100% indicated sorting in favour of that fraction (actual consumption was greater than predicted), and values < 100% indicated sorting against that fraction (actual consumption was less than predicted); the greater the deviation from 100%, the greater the amount of sorting, either for or against a particular particle size fraction.

2.2.6 Milk Production and Components

Milk yield data were collected daily by the AMS and extracted for d 6 - 10 in each period, while milk quality was recorded on d 8 and 10. The Lely AMS Shuttle Sampling Device (Lely Industries N.V., Maassluis, The Netherlands) was used to sample milk from each cow at each milking on those days. All milk samples on d 8 and 10, separate for each milking, were sent to a DHI testing laboratory (CanWest DHI, Guelph, ON, CAN) for component analysis (fat, protein, and MUN) by a Fourier Transform Infrared Spectrometer (FTIR) full spectrum analyzer (Milkoscan FT+ and Milkoscan 6000, Foss, Hillerød, Denmark). These data were averaged across milkings to create one value per cow per sampling day.

For each day that milk samples were collected, 4% fat-corrected milk yield (4% FCM; kg/d) was calculated as 0.4 × milk yield (kg/d) + 15.0 × fat yield (kg/d) (NRC, 2001), and energy-corrected milk yield (ECM; kg/d) was calculated as (0.327 × kg of milk) + (12.95 × kg of fat) +

(7.2 × kg of protein) (Tyrrell and Reid, 1965). The efficiency of milk production was calculated as kilograms of milk, 4% FCM yield, and ECM yield per kg of DMI per cow.

2.2.7 Statistical Analyses

All analyses were performed using the SAS 9.4 software (SAS Institute Inc., 2013), with significance declared at $P \leq 0.05$, and tendencies reported if $0.05 < P < 0.10$. Interactions were only considered if they met the level of $P \leq 0.05$. Data were tested for normality prior to analysis using the UNIVARIATE procedure, and the assumptions of normality were met for all variables. Data were summarized by sub-group and period (the 5 recording days of each treatment); sub-groups were considered experimental units as the treatments were applied at that level. These data were then analyzed in a general linear mixed model. The MIXED procedure was used, with the fixed effects of treatment, period, and treatment × period interaction; the random effects were group, and sub-group within group. Degrees of freedom were estimated using the Kenward-Rogers adjustment in the MODEL statement. To find the best fit to the data, contrast statements were included to fit both the linear and quadratic response to treatments; all values reported are least squares means. Additionally, to test our hypothesis that competition for feed access would increase within-group variability, the daily standard deviation of each sub-group was calculated for each measure and averaged across each period. The resulting data were analyzed using the above-mentioned model.

As rank of competitive success was determined at the individual cow level, the effect of rank on feeding time, feeding rate, and DMI by treatment was summarized by cow and treatment and then tested using the MIXED model described previously, and including the additional fixed effects of rank, and the interaction of rank and treatment. The effects of individual cow BW and parity were also considered in this model. As BW and parity were correlated, only BW was included in the model; this variable was removed from the model, and not further reported, when it was not significant.

To test for the occurrence of feed sorting on each treatment, the sorting activity was summarized by sub-group and period for each particle fraction at each feeding and tested for a difference from 100 using a t-test. Differences in sorting by treatment and feeding were compared using a repeated measures mixed model, treating feeding as a repeated measure. The fixed effects were treatment, feeding (F1, F2, and F3), period, and the interactions of treatment × feeding, and treatment × period. The random effect was group, and the subject of the repeated statement was sub-group within group. The variance-covariance matrix structure used was compound symmetry, chosen on the basis of best fit according to Schwarz's Bayesian information criterion. Contrast statements were utilized to determine whether there was a linear or quadratic response to treatment effects. The Kenward-Rogers adjustment for degrees of freedom was included in the MODEL statement, and all values were reported as least squares means. If interactions of treatment × feeding were detected, the data were then analyzed by feeding, using the first-described model to determine the effect of treatment.

2.3 RESULTS

Feeding time decreased in a quadratic manner as the level of feeding competition increased (Table 2.3), with the least time spent feeding under High competition. As no difference in DMI was found between treatments, there was a similar quadratic response in feeding rate as competition level increased, with the lowest rate of feed consumption under Low competition.

In the hour immediately following each fresh feed delivery and milking, feeding time (Figure 2.1a) showed a quadratic response to increasing competition following the first 2 feedings (F1: SE =

2.15, $P_{quadratic}$= 0.005; F2: SE = 1.85, $P_{quadratic}$ = 0.01), yet no significant difference was seen following F3 (SE = 2.29, $P \geq 0.11$). Following the first 2 feed deliveries of the day, feeding time was much reduced under the High competition treatment compared to both the Low and Moderate treatments. For the same peak periods, feeding rate (Figure 2.1b) demonstrated an opposite quadratic effect of increased competition, with High competition eliciting the highest rate of feed consumption following F1 (SE = 0.04, $P_{quadratic}$ = 0.03) and F2 (SE = 0.02, $P_{quadratic}$ = 0.03), and demonstrating a tendency for higher rate following F3 (SE = 0.02, $P_{quadratic}$ = 0.07). Similar to the daily summarized data, the opposing responses of feeding time and feeding rate resulted in no detected effect of competition level on the DMI in the hour following each feed delivery and milking (Figure 2.1c).

Quadratic associations were found between competition for feed access and meal patterns (Table 2.3). Meal criteria, meal length, and non-feeding time within meals results were similar at Low and Moderate competition, while they were greater at the High competition level. This was particularly evident for the non-feeding time, which under High competition was approximately twice as long as that of both the Low and Moderate competition levels. There was also a tendency for a quadratic effect on meal frequency and meal size, with fewer and larger meals found under High competition than both Low and Moderate. No effect of treatment on the time interval between meals was detected.

There was no effect of increased levels of competition detected on the daily frequency of replacements; however, analysis of the hour following each feed delivery revealed a tendency for reduced replacements under Low competition after F1 (Low = 0.7; Moderate = 1.5; High = 1.4 replacements/1 hr post-feeding, SE = 0.24, P_{linear} = 0.07). No effect of treatment on the frequency of replacements following F2 and F3 was detected ($P \geq 0.62$). The analysis of intakes by rank indicated an effect on feeding time (P = 0.03), where High ranking cows had greater feeding times than cows with Low or Medium ranks of competitive success (data not shown). Neither feeding rate nor DMI was associated with rank.

Competition level had a quadratic effect on lying time, with a mean reduction of 0.7 h/d (42 min/d) under High competition compared to both Low and Moderate (Table 2.3). There was no effect of treatment detected on the frequency of lying bouts or lying bout length; nor did we detect an effect of competition level on daily rumination time.

There was a treatment × feeding interaction for sorting of both long (> 19 mm) and medium particles (> 8, < 19 mm; Table 2.4). The interaction revealed that sorting of long particles varied in a quadratic manner ($P_{quadratic}$ = 0.02) by treatment at F3; under Low competition cows sorted in favour of long particles, while under High competition cows sorted against long particles (Table 2.4). There was a tendency for a quadratic effect ($P_{quadratic}$ = 0.09) of competition on the sorting of medium particles at F3; cows sorted in favour of medium particles under High competition and did not sort for or against these particles on the other treatments (Table 2.4). Differences in the sorting of short and fine particles between treatments were not detected, however, cows primarily sorted against these particles across all treatments and feedings. The extent of sorting varied by feeding, with the greatest sorting against short and fine particles occurring after F1 and F3, respectively.

Competition level did not influence total milk yield, however, there was a tendency for a quadratic effect on 4% FCM and ECM; these were lowest at High competition (Table 2.5). A quadratic response was also found on milk protein yield, which was lower under High competition than both Low and Moderate. There was a tendency for a quadratic increase in MUN with greater competition, while no effects of competition level on milk composition and efficiency of production were detected.

Analyses revealed a linear increase in within-group variation in feeding time, as well as a quadratic increase in variation in feeding rate with higher competition (Table 2.6). As at the sub-group level, there was no detected effect of competition on within-group variability in DMI. Due to quadratic effects, the variability observed in meal patterns was much greater under the High competition treatment than under Low and Moderate in each of meal criteria, meal length, and non-feeding time within meals. No effect of increased competition was detected on within-group variability in meal frequency, meal size, and the interval between meals. There was a tendency for a quadratic effect on variability in lying time, with cows under High competition demonstrating greater within-group variability than when under Low and Moderate. No effect of competition level was found on within-group variability in lying bout frequency, bout length, daily rumination time, or frequency of daily replacements.

Milk data analyses (Table 2.7) indicated that with increasing competition for feed access there was a linear increase in the within-group variability in milk yield, 4% FCM, and ECM. There was a quadratic effect on the variability in milk fat percentage and the milk protein component yield (kg/d), with both demonstrating reduced variability at Low competition compared to Moderate and High. Additionally, there was a tendency for a linear increase in the variability in milk fat component yield (kg/d) as competition level increased. There was also a tendency for a quadratic effect of competition for feed access on variability in efficiency of milk production (kg milk/kg DMI), which was greatest under High competition.

2.4 DISCUSSION

The elevated levels of feeding competition tested in this study represent both average and extreme conditions and, as such, did not follow a linear pattern; the Low and Moderate competition treatments corresponded to 100 and 150% stocking densities, respectively, at the feed bunk, while High represented a 300% stocking density. These levels of competition make linear relationships between competition and feeding behaviour unlikely, thus it was expected that we would find primarily quadratic relationships for the majority of the variables investigated in this study.

In support of our hypothesis, at the highest level of competition cows spent the least amount of time feeding, yet at the highest rate of consumption. This behavioural pattern was demonstrated both on a daily basis, as well as during the periods of peak feeding activity following the first 2 feed deliveries. Researchers have previously found that increasing competition through greater feed bunk stocking density leads to reduced daily feeding times (DeVries et al., 2004; Huzzey et al., 2006). Across treatments, cows that were more successful in gaining access to the feed bin (i.e. higher rank of competitive success) were able to spend a longer time feeding. These correspond to the dominant animals within the group, as cows of high dominance rank have been shown to spend a significantly longer proportion of time at the feed bunk than subordinate cows (Grant and Albright, 2001; Val-Laillet et al., 2008). Olofsson (1999) compared the effects of competition at levels of 1 or 4 cows/feeding station, and found decreased feeding times and increased feeding rates under the higher competition level; this effect was more pronounced in subordinate cows, which tended to alter their feeding behaviour to a greater extent than dominant cows. Increasing feeding rate allows individuals to indirectly compete for feed (Giraldeau and Caraco, 2000), which may be beneficial for lower-ranked cows that are unable to compete through displacing others from the feed bunk. Such a discrepancy between dominant and subordinate cows is likely the cause of the greater within-group variability in both feeding time and rate of feed intake as competition increased. This supported our hypothesis that individuals within the group would experience greater variability in feed consumption patterns, and suggests that with greater pressure at the feed bunk, some cows are better able to manage the effects of competition than others.

The ability of dairy cows to modify their feed intake patterns by eating faster, over shorter periods of time, allows them to compensate for increased social pressure at the feed bunk. This was demonstrated in the current study, as both daily and peak period DMI remained constant across all competition levels. Similarly, Hosseinkhani et al. (2008) found increased feeding rates, yet no effect of competition on daily DMI. In their study, DMI was lower for competitively fed cows in the hours surrounding feedings, yet higher through the remainder of the day, allowing equivalent net DMI between both competitively and non-competitively fed cows. It should be noted that increasing feed consumption rate to maintain DMI may negatively affect rumen health. Rapid ingestion of larger meals results in declining rumen pH (Allen, 1997); additionally, research has shown that salivation rate is higher when feed is consumed more slowly (Maekawa et al., 2002; Beauchemin et al., 2008). Using estimates of salivation rate from Maekawa et al. (2002), for cows fed a ration of similar forage content, the increased feeding rate observed in the current study (of 20 g DM/min) would result in approximately 16.4 L/d less saliva produced as the competition level increased from Low to Moderate, and an equivalent reduction from Moderate to High competition. This is in comparison to an estimated 44-56 L/d of total saliva production (Maekawa et al., 2002). Since saliva is an important factor in maintaining the buffering capacity of the rumen, and in limiting the magnitude of pH decline while feeding (Allen, 1997; Beauchemin, 2007), such a reduction in saliva production could increase the risk of developing ruminal acidosis. Rumination activity is also known to affect saliva production, however, there was no apparent effect of increased competition for feed access on daily, or within-group variability, in rumination time.

Despite the faster feeding rate and shorter feeding times displayed by cows, meal criteria, and meal length were longest under High competition. This was attributed to the greatly elevated non-feeding time within meals, which indicates that cows were waiting to gain access to occupied feed bins. Proudfoot et al. (2009) similarly found that increased meal length was due to greater non-feeding time within meals among primiparous transition cows. These researchers found that non-feeding time within meals increased by 46% between their non-competitive (1:1), and competitive (2:1) treatment levels; however, this corresponds most closely to a comparison of our Low (1:1) and Moderate (1.5:1) competition treatment levels, where we found an increase of only 8%. Our lesser change in non-feeding time was likely driven by the higher nutrient intakes of cows closer to peak lactation compared to transition cows, enhancing their motivation to compete for feed access, and resulting in less time spent waiting within meals. When we compared the Low (1:1) to High (3:1) competition levels in the current study, non-feeding time within meals increased by 103%. This suggests that lactating cows were able to compensate for a moderate level of competition for feed access by altering their feeding behaviour, but as that competition increased, cows became less able to compete in such a manner, and were, therefore, forced to increase their idle standing time. This supports previous research that demonstrated greater idle standing time in the feed area with increased stocking density at the feed bunk (Huzzey et al., 2006). Prolonged time standing on hard surfaces has been associated with increased risk of lameness due to claw horn lesions (Greenough and Vermunt, 1991; Cook et al., 2004), and could be especially problematic for subordinate cows that experience the greatest increases in daily standing times, particularly surrounding peak feeding periods (Galindo and Broom, 2000; DeVries and von Keyserlingk, 2006).

With changes to feeding time and length of meals, there should be a corresponding effect on the time allotted to other behaviours in the cows' daily time budget. The tendency for reduced meal frequency accounts for some of this time, and together with the tendency for increased meal size under High competition, is similar to a study by Hosseinkhani et al. (2008) which found fewer, longer and larger meals in competitively-fed transition cows. Management practices that promote such intake patterns may put cows at increased risk of subacute ruminal acidosis and laminitis (Shaver, 2002; Krause and Oetzel, 2006). Additionally, in the current study, the cows' time budget was affected by a 42 min reduction in daily lying time under High competition. Within-group variation in lying time also demonstrated a slight curvilinear increase indicating a tendency towards more variation in lying time under High competition. When resources are restricted, lying time is a high priority behaviour that is shown to take precedence over feeding and social contact (Munksgaard et al., 2005); however, even though cows were able to compensate for increased competition through higher feeding rate and reduced feeding time, the time spent waiting to access feed under High competition remained sufficient to require a reduction in lying time, despite its importance to the daily time budget.

In support of our second hypothesis, greater within-group variability in meal patterns was observed; meal criteria, meal length, and non-feeding time within meals all demonstrated more variability under High competition compared to the lower levels, reflecting the same curvilinear response as at the group level. Proudfoot et al. (2009) found parity to play a role in the differences in meal patterns under competition. Those researchers observed that primiparous transition cows fed competitively tended to have longer meals in the first week after calving than those fed without competition; yet multiparous cows showed no differences in meal length for the same periods. Further research into the effect of parity under increased levels of competition could help to explain the differing ability of individual cows to cope with increased competitive pressure at the feed bunk.

Surprisingly, cows primarily sorted the TMR neither for nor against long particles, sorted in favour of medium particles, and against short and fine particles. These findings are contrary to previously reported data indicating that cows typically sort against larger and in favour of smaller particles (Leonardi and Armentano, 2003; DeVries et al., 2007; Hosseinkhani et al., 2008). The third feeding of the day, under High competition, was the only feeding where sorting against long particles did occur; cows compensated for this selective refusal by increasing their consumption of medium particles. The results of the current study, however, are not unprecedented; DeVries et al. (2008) similarly found cows to sort in favour of medium particles, and against long, short and fine particles. These researchers attributed this anomalous finding to cows selecting for the grain supplement pellet present in the medium particle fraction, and to the settling or loss of fine particles to the floor as cows push and sort the TMR in the bunk. In the current study, medium particles were the most abundant component of the experimental diet (Table 2.2), which could explain the increased selection for that fraction. A study of feed sorting in tie-stall cows by Miller-Cushon and DeVries (2010) also found increased sorting in favour of medium particles and against short particles when feeding a comparable ration composed of > 50% medium particles on a DM basis. These authors suggested the greater availability of highly palatable, high moisture corn within the medium size fraction, may have motivated this selective consumption.

Competition level had only a minor effect on the frequency of replacements, which were reduced for the hour following the first feeding under Low competition; yet there was no effect on the frequency of daily replacements from the feed bins, which is contrary to the results of most studies focused on competition for feed access (Olofsson, 1999; Huzzey et al., 2006; Hetti Arachchige et al., 2014). However, displacements were recorded in those studies; a common method that uses video recordings to observe when one cow forcefully takes the place of another feeding cow. The current study identified replacements, according to the methods described by Huzzey et al. (2014), which utilized the time between sequential feeding visits, as recorded by the automated feed bins. Replacements were recorded as instances when a feeding cow was superseded by another within 26 sec or less; this method has been validated by Huzzey et al. (2014) and shown to be highly correlated (r = 0.94) with displacements as an indicator of competitive success. Potentially, the cows used in our study, which were fed in sub-groups of 3 individuals at a time, were of a sufficiently small group size to easily determine their relative social positions within the group. Since dominance behaviours and the establishment of social rank are learned behaviours that can persist over long periods (Bielharz and Zeeb, 1982), it is possible that there were fewer attempts to access the feed bins when a known dominant individual was feeding; thus, reducing the opportunities for replacements to occur. This is consistent with the findings of Rioja-Lang et al. (2009), that demonstrated subordinate cows chose to eat lower-quality feed alone rather than in proximity to a dominant individual; furthermore, those researchers found that even when not feeding, subordinate cows spent the majority of their time (83%) on the unoccupied side of the test arena, rather than in the middle or on the side occupied by the dominant cow. Research has shown that as the number of individuals within a group increases, it becomes more difficult for cows to recognize others and their respective social positions (Grant and Albright, 2001); therefore, were group sizes to increase, replacements may become more frequent.

Minor changes to milk production and composition were noted at different levels of competition, including slight decreases in 4% FCM and ECM, and increases in MUN under High competition; the greatest change was decreased protein yield under High competition. In a review of 10 years of milk production studies, by Lee et al. (2014), factors contributing to milk quality were evaluated; it was determined that the most influential factor in milk protein and fat yield was DMI. In the current study, there was no change in daily DMI, yet individual fluctuations in intake patterns throughout the day to maintain DMI under varying competition levels could account for changes in production. Additionally, there was a great deal of within-group variability in milk yield, composition, component yield, and efficiency, which indicates that the impact of competition on milk production differs greatly between individuals. Future studies of the long-term effects on milk production may provide a better understanding of the individual impacts of restricted feed access as a result of feed bunk competition.

2.5 CONCLUSIONS

Under higher levels of competition for feed access, cows demonstrated increased feeding rates and decreased feeding times that allowed them to maintain daily DMI. The elevated competition also altered meal patterns, resulting in the consumption of feed in fewer, larger meals that were longer in duration. As well, there was greater variability in these feeding patterns among individuals as competition for feed access increased. This research suggests that providing cows with equal opportunities to access feed promotes healthy feeding behaviour patterns, more consistent feed intake, and reduces the variation in feeding behaviour between individual cows within a group.

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Table 2.1 Ration ingredients and chemical composition (mean ± SD) of the fresh experimental diet

Composition	Diet
Ingredient, % DM	
Corn silage[1]	25.0 %
Haylage #1[2]	13.0 %
Haylage #2[3]	16.9 %
High moisture corn	14.2 %
Protein concentrate pellet[4]	11.3 %
Grain supplement pellet[5]	19.6 %
Chemical composition[6]	
DM, %	53.1 ± 1.58
OM, % of DM	92.1 ± 0.25
CP, % of DM	18.3 ± 0.30
ADF, % of DM	22.8 ± 1.40
NDF, % of DM	34.9 ± 1.12
NFC, % of DM	38.9 ± 1.16
Ca, % of DM	1.0 ± 0.06
P, % of DM	0.5 ± 0.01
NE_L, Mcal/kg of DM	1.6 ± 0.02

[1]Corn silage had a DM of 41.1 ± 4.54% and chemical composition (DM basis) 7.2 ± 0.31% CP, 26.2 ± 1.15% ADF, and 42.3 ± 1.48% NDF.
[2]Haylage 1 = Red clover (95%) and orchard grass (5%) haylage had a DM of 36.4 ± 1.55% and chemical composition (DM basis) 22.7 ± 0.56% CP, 37.3 ± 1.77% ADF, and 45.1 ± 1.46% NDF.
[3]Haylage 2 = Red clover (75%) and timothy/orchard grass (25%) haylage had a DM of 46.3 ± 2.92% and chemical composition (DM basis) 19.7 ± 1.06% CP, 38.5 ± 1.55% ADF, and 47.4 ± 2.71% NDF.
[4]Supplied by Dundas Feed & Seed Ltd. (Winchester, Ontario, Canada) including the ingredients (as is): 35-40% corn distillers, 18-33% soybean meal, 8-24% canola, 6.8% calcium carbonate, 1.5-7.5% feather meal, 2.4% salt, 2.0% sodium bicarbonate, 0-3% tallow, 0.8% dicalcium phosphate, 0.4% magnesium oxide, 0.144% trace minerals, and 0.046% vitamins.
[5]Supplied by Dundas Feed & Seed Ltd (Winchester, Ontario, Canada) including the Ingredients: 20-40% wheat shorts, 16-34% soybean meal, 12-32% corn, 4-14% corn distillers grains, 0-10% oat by-product, 3% molasses, 2.0% dry fat, 0.6% calcium carbonate, 0.9% dicalcium phosphate, 0.3% choline chloride, 0.4% salt, 0.0084% vitamins, 0.0569% trace minerals, 1.25% pellet binder, and 0.125% flavor/attractant.
[6]Values were obtained from chemical analysis of TMR samples. OM = 100 - % ash. NFC = 100 – (% CP + % NDF + % fat + % ash). NEL was calculated based on NRC (2001) equations.

Table 2.2 Particle size distribution[1] (mean ± SD), and nutrient content (mean ± SD) by particle size of the fresh experimental diet

Item	Diet
% DM retained on screen	
Long	5.5 ± 1.76
Medium	40.3 ± 3.33
Short	38.3 ± 2.73
Fine	15.9 ± 1.72
NDF, % of screen DM	
Long	56.1 ± 1.36
Medium	36.7 ± 1.15
Short	32.2 ± 1.50
Fine	22.2 ± 1.10
CP, % of screen DM	
Long	11.7 ± 1.33
Medium	15.9 ± 0.50
Short	19.3 ± 1.08
Fine	24.0 ± 1.21

[1]Particle size determined by the Penn State Particle Separator, which has a 19 mm screen (long), 8 mm screen (medium), 1.18 mm screen (short), and a pan (fine).

Table 2.3 Effect of 3 levels of competition for feed access on the feeding behaviour, rumination time, and lying behaviour of groups of lactating Holstein dairy cows[1]

	Treatment[2]					
	Low	Moderate	High	SE[3]	P_{linear}[4]	$P_{quadratic}$[5]
Feeding time, min/d	202.6	194.9	183.6	8.84	0.006	0.008
Feeding rate, kg DM/min	0.16	0.18	0.20	0.01	0.003	0.007
DMI, kg/d	29.3	29.0	29.1	0.67	0.51	0.82
Meal criterion, min	38.3	36.2	58.6	5.88	0.005	0.002
Meal frequency, no./d	7.9	8.0	7.5	0.58	0.12	0.06
Interval between meals, min	160.1	159.4	171.4	16.32	0.18	0.12
Meal size, kg DM/meal	3.9	3.9	4.3	0.48	0.12	0.06
Meal length, min/meal	37.0	36.6	47.3	5.05	0.03	0.02
Non-feeding time within meals, min/meal	10.0	10.8	20.3	3.24	0.004	0.003
Replacement frequency, no./d	2.7	3.6	4.1	0.64	0.15	0.25
Rumination, min/d	514.1	513.9	511.6	8.27	0.74	0.71
Lying time, h/d	10.2	10.2	9.5	0.51	0.09	0.05
Lying bout frequency, no./d	10.5	10.9	10.3	1.01	0.76	0.47
Bout length (min/bout)	63.7	62.5	61.8	6.35	0.60	0.68

[1]Data were averaged over 5 d for 6 sub-groups (each containing 3 cows) on each treatment.
[2]Competition level treatments: Low = 3 cows: 3 feed bins, Moderate = 3 cows: 2 feed bins, and High = 3 cows: 1 feed bin.
[3]Standard error of the mean.
[4]P_{linear} = linear response to treatment.
[5]$P_{quadratic}$ = curvilinear response to treatment.

Table 2.4 Effect of 3 competition levels on the sorting (%)[1] of long, medium, short, and fine particle sizes at each feeding of the day, for groups of lactating Holstein dairy cows[2]

Particle size fraction at each feeding[3]	Treatment[4]			SE[5]	Effects		
					Treatment	Feeding	T × F[6]
	Low	Moderate	High		*P*	*P*	*P*
Long				4.25	0.02	0.77	0.006
Feeding 1	100.5	99.6	101.5				
Feeding 2	101.8	105.2	101.2				
Feeding 3	113.6*	103.7	85.0*				
Medium				0.85	0.46	0.04	0.04
Feeding 1	103.1*	103.5*	102.6*				
Feeding 2	102.3*	101.8*	101.3				
Feeding 3	102.8	102.1	106.0*				
Short				0.65	0.88	0.08	0.98
Feeding 1	97.9*	97.3*	97.6*				
Feeding 2	98.8*	98.6*	99.0				
Feeding 3	98.4	98.6	98.7				
Fine				1.47	0.47	0.01	0.51
Feeding 1	93.7*	94.7*	96.2*				
Feeding 2	96.2*	96.7*	97.8				
Feeding 3	92.2*	95.0*	91.7*				

[1]Sorting % for each fraction = (actual DMI/predicted DMI) × 100. Sorting values = 100% indicate no sorting, < 100% indicate selective refusals (sorting against), and > 100% indicate preferential consumption (sorting for). * Indicates sorting was different from 100% ($P \leq 0.05$).
[2]Data were averaged over 5 d for 6 sub-groups (each containing 3 cows) on each treatment.
[3]A 3-screen Penn State Particle Separator was used to separate samples into 4 particle size fractions: Long (> 19 mm), Medium (< 19 mm, > 8mm), Short (< 8 mm, > 1.8 mm), and Fine (< 1.8 mm). Cows were fed 3 ×/d at 1400 h (Feeding 1), 2000 h (Feeding 2), and 0800 h (Feeding 3).
[4]Competition level treatments: Low = 3 cows: 3 feed bins, Moderate = 3 cows: 2 feed bins, and High = 3 cows: 1 feed bin.
[5]Standard error of the mean.
[6]T × F = interaction of Treatment and Feeding.

Table 2.5 Effect of 3 competition levels on milk production and composition for groups of lactating Holstein dairy cows[1]

	Treatment[2]			SE[3]	P_{linear}[4]	$P_{quadratic}$[5]
	Low	Moderate	High			
Milk yield, kg/d						
Milk	46.1	46.4	45.5	0.47	0.36	0.18
4% FCM	45.9	47.1	45.2	0.85	0.37	0.09
ECM	48.9	50.1	47.9	0.92	0.27	0.06
Milk composition, %						
Fat	4.02	4.09	4.07	0.09	0.49	0.78
Protein	3.08	3.06	3.06	0.08	0.42	0.60
Milk component yield, kg/d						
Fat	1.84	1.90	1.80	0.05	0.45	0.16
Protein	1.41	1.42	1.36	0.05	0.04	0.01
Efficiency of milk production, kg/kg						
Milk/DMI	1.58	1.61	1.58	0.03	0.98	0.53
4% FCM/DMI	1.58	1.63	1.57	0.05	0.74	0.25
ECM/DMI	1.68	1.73	1.66	0.05	0.61	0.20
MUN, mg/dL	13.7	13.8	14.0	1.45	0.05	0.06

[1]Data were averaged over 2 d for 6 sub-groups (each containing 3 cows) on each treatment.
[2]Competition level treatments: Low = 3 cows: 3 feed bins, Moderate = 3 cows: 2 feed bins, and High = 3 cows: 1 feed bin.
[3]Standard error of the mean.
[4]P_{linear} = linear response to treatment.
[5]$P_{quadratic}$ = curvilinear response to treatment.

Table 2.6 Effect of 3 different competition levels on within-group variability[1] in feeding behaviour, rumination time, and lying behaviour of groups of lactating Holstein dairy cows

	Treatment[2]			SE[3]	P_{linear}[4]	$P_{quadratic}$[5]
	Low	Moderate	High			
Feeding time, min/d	20.6	28.4	28.9	2.86	0.05	0.18
Feeding rate, kg/min	0.03	0.05	0.07	0.01	0.02	0.03
DMI, kg/d	4.6	4.7	4.4	0.71	0.46	0.32
Meal criterion, min	15.4	16.0	37.4	4.88	0.01	0.006
Meal frequency, no./d	1.7	1.9	2.0	0.31	0.21	0.34
Interval between meals, min	32.6	36.0	42.5	12.84	0.13	0.14
Meal size, kg DM/meal	1.1	1.2	1.5	0.33	0.25	0.24
Meal length, min/meal	12.0	13.9	29.0	6.02	0.02	0.02
Non-feeding time within meals, min/meal	6.4	8.3	21.5	5.02	0.02	0.01
Replacement frequency, no./d	2.2	1.7	2.5	0.62	0.68	0.33
Rumination, min/d	71.6	78.9	72.2	8.74	0.95	0.67
Lying time, h/d	1.7	1.5	2.0	0.18	0.21	0.07
Lying bout frequency, no./d	2.9	3.4	3.7	0.37	0.18	0.27
Bout length (min/bout)	21.6	18.3	24.0	4.90	0.43	0.15

[1]Calculated as the daily standard deviation of each group averaged over 5 d for 6 sub-groups (each containing 3 cows) on each treatment.
[2]Competition level treatments: Low = 3 cows: 3 feed bins, Moderate = 3 cows: 2 feed bins, and High = 3 cows: 1 feed bin.
[3]Standard error of the mean.
[4]P_{linear} = linear response to treatment.
[5]$P_{quadratic}$ = curvilinear response to treatment.

Table 2.7 Effect of 3 different competition levels on within-group variability[1] in milk production and composition for groups of lactating Holstein dairy cows

	Treatment[2]			SE[3]	P_{linear}[4]	$P_{quadratic}$[5]
	Low	Moderate	High			
Milk Yield, kg/d						
Milk	5.9	7.0	7.1	1.26	0.02	0.10
4% FCM	6.5	7.9	7.8	1.51	0.04	0.19
ECM	6.7	8.2	8.2	1.56	0.02	0.12
Milk Composition, %						
Fat	0.33	0.44	0.53	0.08	0.03	0.05
Protein	0.13	0.15	0.16	0.03	0.14	0.21
Milk Component Yield, kg/d						
Fat	0.28	0.35	0.36	0.10	0.06	0.17
Protein	0.17	0.22	0.22	0.04	0.004	0.05
Efficiency of Milk Production, kg/kg						
Milk/DMI	0.18	0.16	0.21	0.02	0.20	0.08
4% FCM/DMI	0.14	0.15	0.17	0.02	0.31	0.27
ECM/DMI	0.15	0.15	0.18	0.02	0.33	0.28
MUN, mg/dL	1.6	1.4	1.3	0.37	0.51	0.62

[1]Calculated as the daily standard deviation of each group averaged over 2 d for 6 sub-groups (each containing 3 cows) on each treatment.
[2]Competition level treatments: Low = 3 cows: 3 feed bins, Moderate = 3 cows: 2 feed bins, and High = 3 cows: 1 feed bin.
[3]Standard error of the mean.
[4]P_{linear} = linear response to treatment.
[5]$P_{quadratic}$ = curvilinear response to treatment.

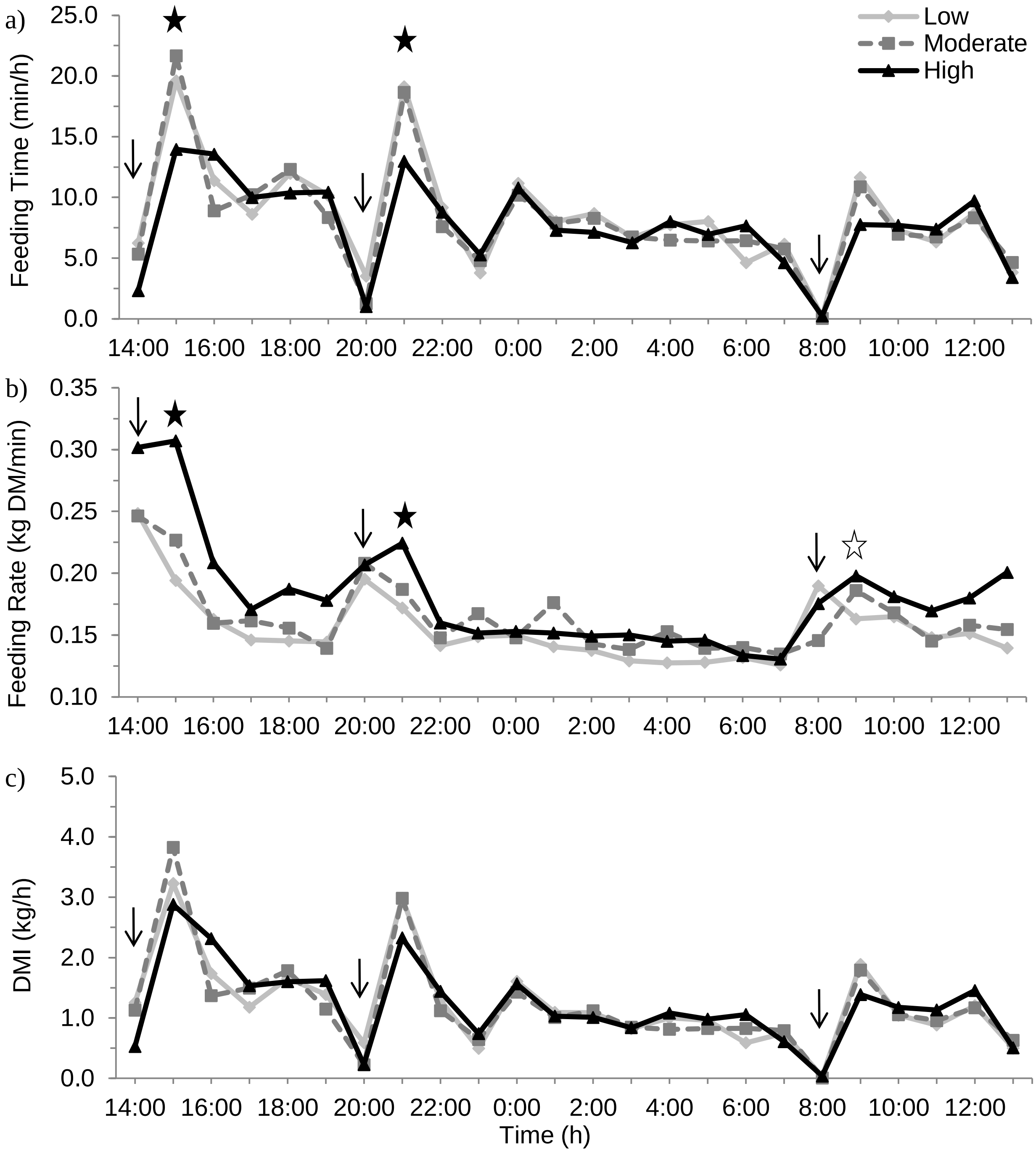

Figure 2.1 Average **a)** feeding time (min/h; SE = 1.35), **b)** feeding rate (kg DM/min; SE = 0.02), and **c)** dry matter intake (DMI, kg/h; SE = 0.21) by hour of the day for lactating Holstein dairy cows fed under Low (3 cows: 3 feed bins), Moderate (3 cows: 2 feed bins), and High (3 cows: 1 feed bin) competition treatments. Cows were milked and delivered feed 3×/d at 1400, 2000, and 0800 h (denoted by ↓). Recording began at the first fresh feeding after daily emptying of the feed bins. Data were averaged over 5 d for 6 sub-groups (each containing 3 cows) on each treatment. Filled stars indicate hours demonstrating differences ($P \leq 0.05$) between treatments, and open stars indicate tendencies for differences ($0.05 < P < 0.10$).

CHAPTER 3. Mitigation of behavioural variability between competitively-fed dairy cows through increased feed delivery frequency

3.1 INTRODUCTION

Feeding a TMR 1-2 times daily is common practice on many farms, yet since the delivery of fresh feed has been shown to have the greatest influence in stimulating feeding activity in dairy cattle (DeVries and von Keyserlingk, 2005; King et al., 2016), there has been a great deal of research into the effects of greater frequency of feed delivery. Greater and more evenly distributed feeding activity throughout the day (Phillips and Rind, 2001; DeVries et al., 2005) as well as decreased sorting of feed (DeVries et al., 2005) have both been demonstrated at increased frequency of feed delivery. Since the provision of fresh feed throughout the day is a contributing factor to a healthy rumen environment (Nocek and Braund, 1985), more consistent availability of TMR could aid in the prevention of SARA (Shaver, 2002; Krause and Oetzel, 2006) and promote greater milk production efficiency (Mantysaari et al., 2006) and improved milk fat production (Gibson, 1984).

Researchers have yet to establish how increased feed delivery frequency affects the behaviour of dairy cows in a competitive feeding environment. Competition for feed access can lead cows to modify their feeding behaviour, including reduced feeding time, increased rate of feed intake, increased meal size, and increased idle standing time, (Olofsson, 1999; Huzzey et al., 2006; Hosseinkhani et al. 2008); all of which may elevate the risk of health problems such as lameness and SARA (Cook et al., 2004). Subordinate cows, in particular, have been shown to adjust their feeding times away from peak periods associated with fresh feed delivery, to avoid the social stress and agonistic behaviour resulting from competition for feed access (Olofsson, 1999; Rioja-Lang et al., 2009). This potentially, leads those cows to consume an unbalanced ration, of poorer nutritional quality, due to the preferential selection of feed in the bunk throughout the day (Leonardi and Armentano, 2007; Hosseinkhani et al., 2008). More frequent feed delivery may reduce such variability between individual cows, as it is the animals that experience shorter feeding times under less frequent feed delivery that are observed to increase their feed consumption activity during peak periods, with more frequent feed deliveries (DeVries et al., 2005).

The objective of this study was, thus, to determine whether increased feeding stimuli could mitigate the effect of competition on individual cows within a group. It was hypothesized that, under competitive feeding situations: 1) at higher frequency of TMR delivery, more individuals would have the opportunity to access feed during peak periods of feed consumption than at a lower frequency of TMR delivery, and 2) there would be less variability in feeding patterns, and the resulting behaviour and productivity, between individual cows at a higher TMR delivery frequency than at a lower TMR delivery frequency.

3.2 MATERIALS AND METHODS

3.2.1 Animals and Housing

Sixteen lactating Holstein dairy cows, consisting of 4 first lactation, 5 second lactation, and 7 third lactation or greater (parity = 4 ± 0.8), were selected from the University of Guelph, Kemptville Campus Dairy Education and Innovation Centre herd. Selected individuals had an average DIM of 72 ± 35 d, daily production of 42 ± 6 kg/d and BW of 692 ± 73 kg at entry to the study. Before selection, the health status of each cow was evaluated and no cows were identified that experienced health concerns during the transition period or early lactation.

Cows were housed in groups of 8 in a free-stall pen with a stocking density of 1 stall/cow; stalls were equipped with waterbeds (DCC Waterbeds, Advanced Comfort Technology Inc., Reedsburg, WI, USA) and bedded with wood shavings as needed. Manure was scraped from stalls manually to within range of the alley scrapers at milking times. Two water bowls within the pen provided cows with ad-libitum access to water. Cows were milked 3 times daily at 0715, 1430, and 2000 h. For milking, cows were brought manually to a holding pen and milked individually and sequentially using an AMS (Lely Astronaut A3 Next, Lely Industries N.V., Maassluis, The Netherlands) to represent conventional milking practices. The cows did not receive supplemental feed from the AMS; TMR (Table 3.1) was provided through automated feed bins (Insentec RIC, Marknesse, The Netherlands) that monitored the intakes and timing of feed visits for each individual animal.

Cows were managed according to the standard operating procedures of the research facility. Once weekly, cows' feet were treated with a preventative hoof spray (10% solution of Hoofsure, Provita Eurotech Limited, Omagh, Northern Ireland). The use of cows and experimental procedures complied with the guidelines of the Canadian Council on Animal Care (2009), and were approved by the University of Guelph Animal Care Committee (Animal Use Protocol #3245).

3.2.2 Experimental Design

The study utilized 8 pairs of cows (16 cows divided into 2 groups of 8) in a 2 × 2 crossover design. Sample size and power analyses were used to calculate the number of replicates (pairs) needed (Morris, 1999) to detect a 12.5% level of observed difference for the primary outcome variables, including feeding behaviour, DMI, and sorting. Estimates of variation for these variables were based on previously reported values (Hosseinkhani et al., 2008; Hart et al., 2013; 2014). In each group, individual cows were categorized by parity as either **Young** (≤ 2^{nd} lactation) or **Mature** (≥ 3^{rd} lactation) and assigned to one of 4 pairs, balanced for DIM and production, and paired to maximize their difference in parity, thus maximizing the effects of competition, as parity is associated with dominance rank (Val-Laillet et al., 2008). Mean BW of Young cows was 655 ± 58 kg, and for Mature cows was 738 ± 66 kg. Seven of the 8 pairs consisted of a Young cow, matched with a Mature cow. Due to an insufficient number of cows in their 3rd lactation or greater, 1 pair (out of 8) consisted of a 1st lactation cow (Young) matched with a 2nd lactation cow (Mature). In two 10-d periods, pairs of cows were exposed in random order to each of 2 treatments: 2 ×/d TMR delivery (**Low)** or 6 ×/d TMR delivery (**High**). Treatments were assigned alternately to 4 feed bins, with the order reversed between groups. All cows were fed competitively in a ratio of 2 cows:1 feed bin (i.e. 1 pair of cows per feed bin). Low frequency feed deliveries occurred at 1545 and 0830 h, and High frequency feed deliveries occurred at those times, plus 4 additional times distributed at 2 h intervals between milkings: 1745, 2100, 1030, and 1230 h (Figure 3.1).

Three days prior to the start of the study, each pair was introduced to their assigned feed bin, which was programmed to allow access to only the designated pair of cows. Treatments were assigned to each pair beginning at the first feeding (1545 h) on the first day of each period, and the cows were allowed 5 d of adaptation before recording began. Data was collected from d 6 - 10 of each treatment period beginning daily at 1545 h, and ending at 1544 h the following day.

3.2.3 Feeding Procedure

Cows were fed a TMR that met the nutrient requirements, according to the NRC (2001), of a cow producing a mean milk yield of 45 kg/d (Table 3.1). Changes in forage availability over time necessitated the use of 2 experimental diets (similar in nutrient composition; Table 3.1) throughout the course of the study: TMR 1 was fed from the start of the trial until the end of the first group of cows; TMR 2 was fed starting from the beginning of the second group of cows until the completion of the study. The total amount of feed offered was adjusted daily to target approximately 10% refusals per bin. Once daily, at approximately 1100 h, TMR was prepared in a mixer wagon (Jaylor 4425, Jaylor Fabricating, Orton, ON, Canada), and transferred to a feed cart (WIC RTM-11, WIC Inc., Wickham, QC, Canada). Supplemental grain pellet was manually weighed on a scale (Model 2020, Mettler-Toledo Inc., Mississauga, ON, Canada), added to the TMR in the feed cart, and mixed for approximately 4 min. Sufficient feed for the first feeding was distributed to the bins, and the remainder stored in covered containers to be delivered at subsequent feedings. All cows were denied access to the bins during milking times (Figure 3.1) to ensure all individuals had equal opportunity to access feed.

3.2.4 Behavioural Data Collection

Feed bins recorded the time of entry, time of exit, and amount of feed consumed during each visit. These data were used to calculate the average rate of consumption, daily DMI, and daily feeding time of each cow. According to the methods of DeVries et al. (2003b), individual feeding visits were combined into meals using the MIX 3.1.3 software (MacDonald and Green, 1988) to determine meal criteria (the minimum time interval between meals) for all cows. A meal criterion for each cow during each treatment period was identified by fitting normal distributions to the frequency of $\log_{10}$ transformed intervals of time between feeding visits, as recorded by the Insentec system. Meal frequency (no./d) for each cow was determined by summarizing the number of intervals between feeding events that exceeded their meal criterion. Meal length (min/meal) was calculated as the time between the start of the first feeding visit, until the end of the last visit within the meal criterion. Meal size (kg DM/meal) was calculated as DMI divided by meal frequency. The length and size of the first meals following all feed deliveries were calculated by summarizing the time spent eating, and the total DMI for the first meal after each feed delivery for each cow, averaged across the 5 d recording period.

The frequency of replacements from the feed bins was recorded according to the methods validated by Huzzey et al. (2014). Data on feeding visits collected by the Insentec system were used to determine when one cow (the actor of the replacement) took the place of another (the reactor of the replacement) at the feed bin within 26 s or less of the reactor's exit from the bin; this action was defined as a replacement. This method of determining replacements is highly correlated (r = 0.94) with the common method of measuring displacements from the feed bin (Huzzey et al., 2014). The daily number of replacements for each cow, as either the actor or the reactor, were summarized and used to calculate an index of success (SI) in competitive interactions at the feed bin; for each cow, the number of times they were the actor in a replacement was divided by the number of times they were both the actor and the reactor (Galindo and Broom, 2000; Val-Laillet et al., 2008). An SI value between 0 (low competitive success) and 1 (high competitive success) was obtained for each cow, for each treatment period.

Standing and lying behavioural data were recorded with data loggers (HOBO Pendant G Logger, Onset Computer Corporation, Pocasset, MA, USA), as validated by Ledgerwood et al., (2010). Data loggers were secured to the rear hock of individual cows with Vetrap Bandaging Tape (3M, London, ON, Canada) prior to the start of each recording period (d 6) and removed after 1545 h on the last day of each recording period (d 10). Measurements were taken at 1 min intervals and leg orientation data was used to compute lying time (h/d), lying bout frequency (no./d), and bout length (min/bout).

Rumination behaviour was electronically monitored using automatic rumination detection loggers (Lely Qwes-HR collars), as validated by Schirmann et al. (2009). Rumination time (RT) data were processed, summarized in 2 h intervals, and stored for up to 22 h in the logger's memory; a reader positioned inside the AMS automatically uploaded the stored data at each cow's visit to the milking unit. At the completion of each treatment period, RT data were downloaded from the reader and summarized by day and 2 h interval/d for each cow. Rumination per kg of DMI per cow was calculated by dividing the daily RT for each cow by their daily DMI.

3.2.5 Feed Sampling and Analyses

Feed samples were collected during the final 5 d of each period. Two samples of fresh feed were collected daily at the first feeding (1545 h) to determine DM and sorting. One refusal sample from each pair (4/d) was collected at the end of each recording day (1430 h) to determine differences in sorting. Component samples were also collected once weekly to be analyzed for DM, chemical content, and particle size. Upon collection, each sample was frozen at -15ºC, awaiting further analysis.

All samples were oven-dried at 55ºC for 48 hours; those samples used to determine sorting were separated using a 3-screen (19, 8, 1.8 mm) Penn State Particle Separator (**PSPS**; Kononoff et al., 2003) prior to being dried. Subsequent fractions, as well as whole DM samples, and TMR component samples were ground through a 1 mm screen (Wiley Mill, Arthur H. Thomas Co., Philadelphia, PA, USA), in advance of their shipment to Cumberland Valley Analytical Services Inc. (Maugansville, MD, USA) for DM (135°C; AOAC, 2000; method 930.15), ash (535°C; AOAC, 2000; method 942.05), ADF and NDF with heat-stable α-amylase and sodium sulfite (Van Soest et al., 1991) analyses. Particle size distribution and nutrient composition by particle size fraction are identified in Table 3.2.

Feed sorting was calculated as the proportion of each fraction actually consumed divided by the proportion that cow was predicted to consume, expressed as a percentage. Actual DM consumed was determined from the results of the PSPS analysis as the percentage DM of refused feed, subtracted from the percentage DM of offered feed for each fraction. Predicted DM consumed was determined as the percentage of total DMI for each particle fraction. The amount of sorting was represented by 3 different categories: a value of 100% indicated no sorting, a value > 100% indicated sorting in favour of a particular fraction (actual consumption was greater than predicted), and a value < 100% indicated sorting against the specified fraction (actual consumption was less than predicted). The greater the difference from 100%, the more the feed was sorted, either for or against that particle size fraction.

3.2.6 Milk Production and Components

Milk yield was recorded by the AMS for the last 5 d of each treatment period, while milk composition was recorded by sampling milk on d 8 and 10; the Lely AMS Shuttle Sampling Device was used to collect a milk sample from each cow at each milking on those days. Resulting milk samples, separate for each cow at each milking, were sent to the DHI testing laborory (CanWest DHI, Guelph, ON, CAN) for component analysis (fat, protein, and MUN) using an FTIR full spectrum analyzer (Milkoscan FT+ and Milkoscan 6000, Foss, Hillerød, Denmark). One value per cow on each sampling day was obtained by calculating the average across milkings.

Milk composition samples were used to determine the 4% fat-corrected milk yield (4% FCM; kg/d), calculated as 0.4 × milk yield (kg/d) + 15.0 × fat yield (kg/d) (NRC, 2001), and energy-corrected milk yield (ECM; kg/d), calculated as (0.327 × kg of milk) + (12.95 × kg of fat) + (7.2 × kg of protein) (Tyrrell and Reid, 1965). Efficiency of milk production was calculated as kilograms of milk, 4% FCM yield, and ECM yield per kg of DMI per cow.

3.2.7 Statistical Analyses

All analyses were conducted using SAS v. 9.4 software (SAS Institute, Cary, NC, 2013), with significance declared at $P \leq 0.05$, and trends reported if $0.05 < P < 0.10$. Interactions were only entertained if they met a significance level of $P \leq 0.05$. Data were tested for normality prior to analysis using the UNIVARIATE procedure, and all data met the assumptions of normality. Treatments were applied at the pair level, therefore, pair was considered the experimental unit. Data were summarized by pair and treatment for all outcome variables, and compared using a general linear mixed model. The MIXED procedure was used to test for treatment differences. The fixed effects were treatment, period, and the interactions of treatment × period; the random effects were group, and pair within group. The Kenward-Rogers adjustment for degrees of freedom was included in the model and all values are reported as least squares means. Since diet was confounded with group, the effect of group was initially included in the model as a fixed effect. However, group was determined to be not significant, and thus was included as a random effect. Variability between pairs was determined by calculating the absolute difference within each pair, and averaging over the 5-d recording period to provide one value per pair. These values were compared using the previously described model, with only group, and pair within group as random effects.

To determine the occurrence of sorting within treatments, the summarized data for each particle size, was tested for a difference from 100 using t-tests. Differences in sorting were analyzed using the previously described MIXED procedure model.

To test the prediction that individual cows within each pair would be differently affected by treatment, we ran a second MIXED procedure model with the data summarized at the cow level. The fixed effects were treatment, period, parity (Young vs. Mature), and the interactions of treatment × period, and treatment × parity, with the Kenward-Rogers adjustment for degrees of freedom. Random effects were group, pair within group, and cow within pair and group. No interactions were found between treatment and parity, therefore, results of those analyses are not reported. This model was also used to assess the impact of SI on intake patterns (feeding time, feeding rate, and DMI), with the additional fixed effects of index, and the interaction of treatment × index.

3.3 RESULTS

No effect of treatment on DMI, feeding time, or feeding rate was detected (Table 3.3). A tendency for feed delivery frequency to affect RT was identified, with cows fed 6 ×/d ruminating approximately 25 min/d longer than those fed only 2 ×/d. Additionally, there was a tendency towards greater variability in RT between pairs under higher frequency of feed delivery (Low = 38.0, High = 50.0 min/d; SED = 5.57; $P = 0.08$). Meal patterns were largely unaffected by treatment (Table 3.3); however, there were discernible differences in the first meal following fresh feed deliveries. Cows had lower feeding time ($P < 0.001$; Figure 3.2a) and DMI ($P < 0.001$; Figure 3.2b) during the first meal after feed delivery when fed 6 ×/d compared to when they were fed 2 ×/d. No effect of treatment on the variability of feeding time (28.1 min/d; SED = 8.85; $P = 0.68$), feeding rate (0.04 kg/min; SED = 0.005; $P = 0.88$), or DMI (3.88 kg/d; SED = 0.93; $P = 0.21$) within pairs was detected.

Cows sorted the TMR to a similar extent ($P \geq 0.24$) regardless of the frequency of feed delivery. On average, cows did not sort for or against long particles (98.0 ± 1.5%; $P \geq 0.11$), sorted in favour of medium particles (104.1 ± 0.53%; $P < 0.001$), and sorted against ($P < 0.001$) short (97.9 ± 0.45%) and fine (94.8 ± 0.90%) particles.

When feeding patterns were compared between Young and Mature cows, there was a discernible effect of parity on feeding rate and DMI, both of which were greater for Mature than Young cows (Table 3.3); however, no effect of parity was found on feeding time. An effect of parity on meal patterns indicated that meal criteria, meal size, and the interval between meals were all greater for Mature cows, while meal frequency was lower for Mature cows. No effect of parity was detected for either meal length, or non-feeding time within meals. Yet, a parity effect on the first meal after fresh feed delivery was identified; average DMI for the first meals after feed deliveries was lower for Young than Mature cows (Young = 3.65; Mature = 4.44 kg DM/meal; SED = 0.34; $P = 0.03$; Figure 3.2b). Young cows demonstrated greater RT compared to Mature cows (Table 3.3); additionally, there was an effect of parity on RT/kg DMI, with Young cows ruminating 3.9 min longer than Mature cows for every kg of DM consumed (Young = 21.9, Mature = 18.1 min/kg DMI; SED = 1.28; $P = 0.02$).

No effect of the frequency of feed delivery was detected on the daily replacement frequency (Table 3.3). Neither was there a difference detected in the variability in daily replacement frequency between pairs (absolute difference of 0.9 replacements/d; SED = 0.97; $P = 0.82$). However, there was an effect of SI on feeding patterns, with cows that were more successful in competitive interactions at the feed bins spending a greater amount of time feeding ($P = 0.007$), and having greater DMI ($P = 0.01$) than less successful individuals (data not shown); no effect of SI on feeding rate was detected ($P = 0.15$).

An effect of feed delivery frequency was detected on the length of lying bouts (Table 3.3), indicating that lying bouts for cows fed 6 ×/d were an average of 3.7 min longer than when cows were fed 2 ×/d. There was no effect detected on the daily number of lying bouts or total lying time. However, lying time and lying bout length were affected by parity, with Mature cows lying down longer and demonstrating longer lying bouts than Young cows (Table 3.3); yet no effect of parity was observed in the daily lying bout frequency. Greater variability in lying time (2.0 h/d; SED = 0.52; $P = 0.96$), lying bout frequency (3.2 bouts/d; SED = 1.39; $P = 0.29$) or lying bout length (16 min/bout; SED = 5.08; $P = 0.94$) were not detected between pairs at different frequencies of feed delivery.

Whereas milk production and components appeared unaffected by the frequency of feed delivery, effects of parity were detected (Table 3.4). Total milk yield, 4% FCM, and ECM were greater for Mature cows than Young cows. Fat yield, protein yield, and MUN were also higher for Mature cows. Greater variability within pairs of cows was observed at Low frequency of feed delivery for 4% FCM, ECM, and protein yields (Table 3.5); there tended to be more variability in fat yield within pairs under Low frequency. All other milk production variables indicated no effect of treatment.

3.4 DISCUSSION

Under competitive feeding conditions, dairy cattle have been shown to maintain daily DMI by increasing their rate of feed consumption (Olofsson, 1999; Hosseinkhani et al., 2008) and reducing their total feeding time (Huzzey et al., 2006; Proudfoot et al., 2009); behaviours which could have negative consequences for the health of the animal (Shaver, 2002; Cook et al., 2004). However, in the current study, increasing from the typical 2 ×/d to a higher 6 ×/d frequency of TMR delivery demonstrated no measureable difference in feeding behaviours for cows fed competitively. While daily feeding times numerically increased under High frequency, the difference was not significant; similarly, differences in average feeding rate and DMI were not detected when cows were fed at either Low or High frequency. These results are consistent with previous research that found no increase in DMI with higher frequency of TMR delivery (Robinson and Sniffen, 1985; Kudrna and Republic, 2003; DeVries et al., 2005), and those that found feeding rate to be unaffected by greater feed frequency (Hart et al., 2014). However, there are conflicting results in the literature with regards to TMR delivery frequency. In some studies, cows on lower frequencies of feed delivery exhibited greater DMI (Nocek and Braund, 1985;

Phillips and Rind, 2001) while in others, cows on higher frequencies of feed delivery had greater DMI (Hart et al., 2014). Additionally, greater feeding time has been demonstrated under increased feed delivery frequency in some studies (Mantysaari et al., 2006; DeVries et al., 2005), while others show reduced feeding times (Phillips and Rind, 2001).

Whereas these previous studies examined the effects of feeding frequency on cows fed without competition, the current study is unique in that all cows were fed competitively (2 cows:1 feed bin). Dominance relationships between individual cows are learned through past interactions and can persist for long periods of time (Bielharz and Zeeb, 1982); therefore, it is possible that the consistent competitive pressure at the feed bin during both the Low and High treatments maintained the cows' motivation to alter their feeding behaviours, regardless of the frequency of TMR delivery. In the current study, pairs consisted of a Young and a Mature cow to maximize the effect of competition; yet, dominance relationships within a herd can be very complex and do not always follow a linear pattern whereby one cow is dominant over all others (Val-Laillet et al., 2008). Thus, it is recommended that future research examine the impact of feed delivery frequency on larger, more socially complex groups of cows, experiencing high levels of competition for feed access.

Differences in feeding behaviour were observed between the individual cows within pairs. Mature cows demonstrated greater daily DMI than Young cows, and consumed feed faster, in fewer yet larger meals. The difference in DMI is likely attributable to both the greater body size and production level of the Mature cows. Previous research has similarly found that multiparous cows at peak production consume larger meals at a faster rate than peak-production primiparous cows (Dado and Allen, 1994). Since social position among herdmates is associated with age, BW, and seniority in the herd (Dickson et al., 1970), it would be expected that younger, subordinate cows would display higher feeding rates when subjected to competitive pressure from herdmates, as demonstrated by previous research (Olofsson, 1999). However, cows categorized as Young in the current study included both first and second lactation animals, which could have influenced this outcome.

While there were no differences detected in the number of daily replacements, or the variability in replacements between treatments, competition for access to feed creates social pressure between individual cows (Nielsen, 1999), resulting in aggressive behaviour at the bunk (DeVries et al., 2004; Morgan and Tromborg, 2007). The SI calculated in the current study indicated that as a cow's success in competitive interactions increased, they were able to spend a greater amount of time feeding and achieve greater DMI. This supports previous research by Val-Laillet et al. (2008), who found that cows with high success in competitive interactions spent a greater proportion of their time at the feed bunk than less successful cows.

Previous research has shown that cows selectively consume the high-energy components of the TMR across the day (DeVries et al., 2005), generally sorting in favour of smaller particles, and against larger forage particles (Leonardi and Armentano, 2003; DeVries et al., 2007; Hosseinkhani et al., 2008). This could result in an altered composition of the feed available later in the day, as demonstrated by DeVries et al. (2005), who found that the NDF content of the remaining feed increased throughout the day. Whereas, those researchers observed the level of sorting to be reduced with TMR delivery frequency of 2 and 4 ×/d, as compared to 1 ×/d, cows in the current study did not sort differently between Low and High frequencies. This is not unexpected when considering that cows exhibited similar feeding rates and time spent feeding between treatments.

Similar to the patterning of feed intakes, no differences in meal patterns across the day were detected between different frequencies of feed delivery. However, examination of the average first meal after each fresh feed delivery did reveal that when cows were fed 6 ×/d, the first meal was shorter in duration and smaller in size than when fed 2 ×/d; this behaviour was evident across both Young and Mature cows. It should be noted that the time immediately following fresh feed delivery is of particular interest when studying competitively-fed cows, as these are periods of peak feeding activity, when the majority of cows are stimulated to feed, and thus the competition for feed bunk access is greatest (DeVries et al., 2003a; DeVries and von Keyserlingk, 2005). These results suggest that implementing feeding management practices such as increased delivery frequency, whereby cows maintain daily DMI while exhibiting shorter and smaller meals during peak periods of feed consumption, could improve access to the bunk during times of high bunk attendance, thereby providing more opportunities for individual cows to consume fresh, unsorted TMR.

Continuous availability of fresh feed, and the consumption of smaller meals throughout the day could be beneficial to competitively fed cows as a method of maintaining a stable rumen environment (Nocek and Braund, 1985), and maintaining rumen function by reducing slug-feeding behaviour, characterized by the rapid intake of large amounts of feed (Shaver, 2002). Slug-feeding is a common issue with competitively-fed cows, since as previously noted, they modify their feeding behaviour to compensate for competitive pressure by increasing feeding rate and decreasing feeding time (Olofsson, 1999; Huzzey et al., 2006). However, following the consumption of large quantities of TMR, there is a decline in rumen pH, which increases the risk of developing SARA and laminitis (Shaver, 2002). As changes in the rumen environment were not monitored in the current study, further research is required to draw conclusions regarding the effects of higher feed delivery frequency on rumen health. We did find, however, that at the higher frequency of TMR delivery, RT tended to increase. This could have a positive impact on rumen health, as chewing stimulates saliva production, an important factor in sustaining rumen buffering capacity, and moderating fluctuations in pH (Erdman, 1988). This is consistent with research from Shabi et al. (1999), who found that when the feeding frequency of lactating cows was increased from 2 to 4 ×/d, there was a decrease in the diurnal fluctuation in ruminal pH. As the frequency of feed delivery in the current study increased, so too did the variability in RT among individuals within pairs, suggesting that all cows did not exhibit similar increases in RT; Young cows experienced a numerically greater increase in RT between Low and High delivery frequency compared to Mature cows. Rumination behaviour may be reduced under competition for feed access (Batchelder, 2000). Thus, the greater increase in RT experienced by Young cows under increased feed delivery frequency could potentially indicate a measure of relief from the social pressure imposed by competition with more dominant Mature cows for access to feed. As well, Mature cows demonstrated higher DMI, but ruminated less for every kg of DM consumed; therefore, accounting for the higher overall RT of Young cows.

Lying behaviour is relatively consistent within dairy cows, who tend to modify other behaviours to conserve lying time (Cook et al., 2004; Munksgaard et al., 2005). We observed that when cows were delivered feed at a High frequency they increased each lying bout by 3.7 min, however, since there was no difference in the total number of daily lying bouts, this had no discernible effect on overall lying time. These findings are contrary to those of DeVries et al. (2005) who found cows exhibited shorter and more frequent bouts of lying when feed delivery was increased from 2 to 4 ×/d. Potentially, the increased competitive pressure at the feed bins in the current study was encouraging cows to spend more time lying during each bout, as some overstocked cows have been observed to lie down rather than feed during peak periods (Batchelder, 2000). Mature cows had higher daily lying times than Young cows due to longer bouts of lying behaviour. This is understandable if you consider Young cows to be subordinate individuals, which have been demonstrated to have reduced lying times compared to more dominant cows (Galindo and Broom, 2000).

Consistent with previous research by Hart et al. (2014), we observed no effect of the frequency of feed delivery on milk yields, components, or efficiency. There was notable variation between individual cows within pairs in terms of their milk production. Since production capacity is known to be a major contributing element in the response of a cow to changes in feeding frequency (Grant and Albright, 1995), and physical size is a limiting factor in DMI, and thus production level, it is likely that the difference in BW between Mature and Young cows influenced this variability in milk production. It is interesting to note that there was less variability between individuals within pairs in 4% FCM, ECM, and component yields under High feeding frequency. This may be explained, in part, by the numerical increase in milk production observed in the Young cows under the High frequency of feed delivery. Subordinate cows are most negatively impacted by increased competition for feed access (DeVries et al., 2004; Huzzey et al., 2006), but experience the greatest reductions in displacements from the feeding area when fed more often (DeVries et al., 2005). Therefore, it is possible, in the current study, that providing TMR more often allowed the Young cows improved access to feed when they were motivated to, enabling them to also ruminate more, and thus reduce the difference in milk production between them and the Mature cows.

3.5 CONCLUSIONS

The results of this study suggest that increased frequency of fresh TMR delivery to competitively-fed cows could improve access to the feed bunk during periods of peak consumption throughout the day. Allowing cows to consume smaller amounts of TMR over shorter periods of time, while maintaining daily DMI, would increase access to the feed bunk, and provide opportunity for more cows to feed during peak periods following feed delivery. The results also indicate that parity plays a potentially larger role than the frequency of feed delivery on the feeding behaviour of a cow under competitive pressure, and therefore should be taken into consideration when managing groups of competitively-fed cows.

3.6 ACKNOWLEDGEMENTS

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Table 3.1 Ration ingredients and chemical composition (mean ± SD) of the fresh experimental diets

Composition	TMR 1[1]	TMR 2[1]
Ingredient, % DM		
Corn silage[2]	23.5%	23.5%
Haylage[3]	37.7%	28.9%
High moisture corn	13.8%	14.8%
Protein concentrate pellet[4]	11.5%	14.2%
Grain supplement pellet[5]	13.4%	18.6%
Chemical composition[6]		
DM, %	59.5± 6.35	57.9 ± 1.03
OM, % of DM	91.4 ± 0.04	91.2 ± 0.16
CP, % of DM	18.0 ± 0.35	18.2 ± 0.14
ADF, % of DM	24.1 ± 1.77	22.9 ± 4.03
NDF, % of DM	35.3 ± 1.27	35.6 ± 5.37
NFC, % of DM	38.2 ± 1.56	37.4 ± 5.66
Ca, % of DM	1.1 ± 0.01	1.1 ± 0.01
P, % of DM	0.57 ± 0.01	0.61 ± 0.0
NE_L, Mcal/kg of DM	1.6 ± 0.02	1.6 ± 0.03

[1]Changes in forage availability necessitated the use of 2 experimental diets. TMR 1 was fed to the first group of 8 study cows and TMR 2 was fed to the second group of 8.
[2]Corn silage in TMR 1 had a DM of 38.9 ± 4.5% and chemical composition (DM basis) of 8.4% CP, 26.7% ADF, and 44.2% NDF. Corn silage in TMR 2 had a DM of 39.7 ± 1.3% and chemical composition (DM basis) 8.4% CP, 25% ADF, and 42.5% NDF.
[3]Haylage consisted of red clover (75%), and timothy/orchard grass (25%). TMR 1 had a DM of 57.2 ± 17.4% and chemical composition (DM basis) of 18.3% CP, 39.2% ADF, and 50.1% NDF; TMR 2 had a DM of 70.9 ± 4.7% and chemical composition (DM basis) of 17% CP, 41.1% ADF, and 51.7% NDF.
[4]Supplied by Dundas Feed & Seed Ltd. (Winchester, Ontario, Canada) including the ingredients (as is): 35 to 40% corn distillers, 18 to 33% soybean meal, 8 to 24% canola, 6.8% calcium carbonate, 1.5-7.5% feather meal, 2.4% salt, 2.0% sodium bicarbonate, 0-3% tallow, 0.8% dicalcium phosphate, 0.4% magnesium oxide, 0.144% trace minerals, and 0.046% vitamins.
[5]Supplied by Dundas Feed & Seed Ltd (Winchester, Ontario, Canada) including the Ingredients: 20 to 40% wheat shorts, 16 to 34% soybean meal, 12 to 32% corn, 4 to 14% corn distillers grains, 0 to 10% oat by-product, 3% molasses, 2.0% dry fat, 0.6% calcium carbonate, 0.9% dicalcium phosphate, 0.3% choline chloride, 0.4% salt, 0.0084% vitamins, 0.0569% trace minerals, 1.25% pellet binder, and 0.125% flavor/attractant.
[6]Values were obtained from chemical analysis of TMR samples. OM = 100 - %ash. NFC = 100 – (%CP + %NDF + %fat + %ash). NE_L was calculated based on NRC (2001) equations.

Table 3.2 Particle size distribution[1] (mean ± SD), and nutrient content (mean ± SD) by particle size of the fresh experimental diets

Item	TMR 1[2]	TMR 2[2]
% DM retained on screen		
Long	3.5 ± 0.83	4.9 ± 1.04
Medium	38.8 ± 2.76	43.6 ± 2.34
Short	38.9 ± 2.71	34.2 ± 1.17
Fine	18.8 ± 1.26	17.4 ± 1.95
NDF, % of screen DM		
Long	59.9 ± 0.64	55.0 ± 1.27
Medium	38.4 ± 0.64	37.1 ± 0.07
Short	36.1 ± 2.12	33.6 ± 0.57
Fine	26.4 ± 1.56	22.7 ± 0.49
CP, % of screen DM		
Long	8.7 ± 0.07	10.1 ± 0.78
Medium	14.9 ± 0.21	15.4 ± 0.57
Short	17.8 ± 0.00	18.4 ± 0.49
Fine	25.0 ± 0.78	26.2 ± 0.14

[1]Particle size determined by the Penn State Particle Separator, which has a 19 mm screen (long), 8 mm screen (medium), 1.18 mm screen (short), and a pan (fine).
[2]Changes in forage availability necessitated the use of 2 experimental diets. TMR 1 was fed to the first group of 8 study cows and TMR 2 was fed to the second group of 8.

Table 3.3 Effect of frequency of feed delivery on the feeding behaviour, rumination time, and lying behaviour of 8 pairs of competitively-fed, lactating Holstein dairy cows[1]

	Treatment[2]							
	Low		High		Treatment Effect		Parity Effect	
	Young	Mature	Young	Mature	SED[3]	*P*	SED[3]	*P*
Feeding time, min/d	181.4	173.1	190.3	176.0	6.22	0.39	12.02	0.33
Feeding rate, kg/min	0.17	0.19	0.15	0.18	0.014	0.22	0.014	0.02
DMI, kg/d	25.4	28.5	25.8	28.7	0.51	0.55	1.38	0.04
Meal criterion, min	21.9	32.9	27.1	36.3	3.03	0.20	6.01	0.03
Meal frequency, no./d	8.7	7.4	8.5	7.5	0.48	0.96	0.71	0.03
Interval between meals, min	148.2	184.3	145.0	172.2	11.94	0.55	17.45	0.02
Meal size, kg DM/meal	3.2	4.3	3.2	4.1	0.19	0.68	0.32	<0.001
Meal length, min/meal	27.1	28.6	28.2	29.3	1.69	0.61	3.02	0.57
Non-feeding time within meals, min/meal	33.0	26.5	33.9	33.5	6.52	0.57	8.97	0.60
Rumination, min/d	521.1	497.8	552.2	516.6	11.32	0.06	9.40	<0.001
Replacement Frequency, no./d	1.8	2.2	1.6	1.7	0.34	0.37	0.52	0.64
Lying time, h/d	8.3	9.4	8.3	9.4	0.32	0.66	0.76	0.05
Lying bout frequency, no./d	11.7	10.6	9.8	10.3	0.60	0.24	1.52	0.75
Lying bout length, min/bout	46.1	58.6	52.2	59.9	1.00	0.03	6.80	0.05

[1]Data are averaged over 5 d for 8 pairs of cows (n=16) on each treatment.
[2]Frequency of fresh feed delivery: Low = 2 ×/d at 1545, and 0830 h; High = 6 ×/d at 1545, 1745, 2100, 0830, 1030, and 1230 h. Cows on each treatment were categorized as Young (parity ≤ 2) or Mature (parity ≥ 3).
[3]Standard error of the difference.

Table 3.4 Effect of frequency of feed delivery on milk production and composition for 8 pairs of competitively-fed, lactating Holstein dairy cows[1]

	Treatment[2]				Treatment Effect		Parity Effect	
	Low		High					
	Young	Mature	Young	Mature	SED[3]	*P*	SED[3]	*P*
Milk Yield, kg/d								
Milk	38.8	45.7	40.0	45.6	0.45	0.27	2.21	0.01
4% FCM	38.5	44.2	39.6	43.6	0.26	0.81	2.60	0.06
ECM	41.0	46.8	41.9	46.4	0.79	0.86	2.77	0.06
Milk Composition, %								
Fat	3.85	3.84	3.84	3.75	0.074	0.55	0.19	0.77
Protein	2.95	2.93	2.93	2.95	0.028	0.85	0.08	0.98
Milk Component Yield, kg/d								
Fat	1.53	1.74	1.56	1.69	0.048	0.91	0.12	0.14
Protein	1.17	1.33	1.18	1.34	0.026	0.81	0.09	0.08
Efficiency of Milk Production, kg/kg								
Milk/DMI	1.54	1.64	1.58	1.63	0.506	0.55	0.084	0.37
4% FCM/DMI	1.52	1.58	1.55	1.56	0.033	0.90	0.078	0.57
ECM/DMI	1.62	1.68	1.64	1.66	0.050	0.90	0.082	0.59
MUN, mg/dL	14.9	16.3	14.8	15.5	0.49	0.42	0.71	0.11

[1]Data are averaged over 5 d for 8 pairs of cows (n=16) on each treatment.
[2]Frequency of fresh feed delivery: Low = 2 ×/d at 1545, and 0830 h; High = 6 ×/d at 1545, 1745, 2100, 0830, 1030, and 1230 h. Cows on each treatment were categorized as Young (parity ≤ 2) or Mature (parity ≥ 3).
[3]Standard error of the difference.

Table 3.5 Effect of frequency of feed delivery on variability[1] in milk production and composition for 8 pairs of competitively-fed, lactating Holstein dairy cows

	Treatment[2]			
	Low	High	SED[3]	*P*
Milk Yield, kg/d				
Milk	8.3	7.1	0.98	0.25
4% FCM	9.2	6.9	0.76	0.02
ECM	10.1	7.1	0.62	0.003
Milk Composition, %				
Fat	0.44	0.37	0.12	0.58
Protein	0.19	0.21	0.062	0.82
Milk Component Yield, kg/d				
Fat	0.39	0.28	0.047	0.06
Protein	0.32	0.19	0.030	0.005
MUN, mg/dL	1.66	1.45	0.53	0.70

[1]Absolute difference within each of 8 pairs of cows (n = 16), averaged over 5 d.
[2]Frequency of fresh feed delivery: Low = 2 ×/d at 1545, and 0830 h; High = 6 ×/d at 1545, 1745, 2100, 0830, 1030, and 1230 h.
[3]Standard error of the difference.

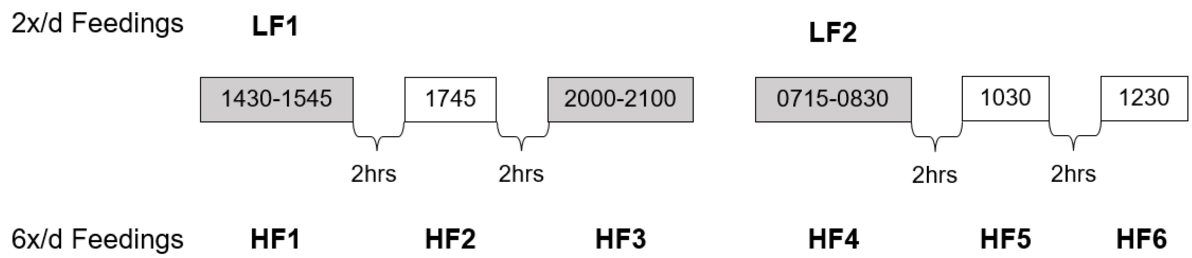

Figure 3.1 Feed delivery times for cows on the Low frequency (LF; 2 ×/d delivery), and High frequency (HF; 6 ×/d delivery) treatments. Shaded boxes indicate time away for milking, identical between treatments.

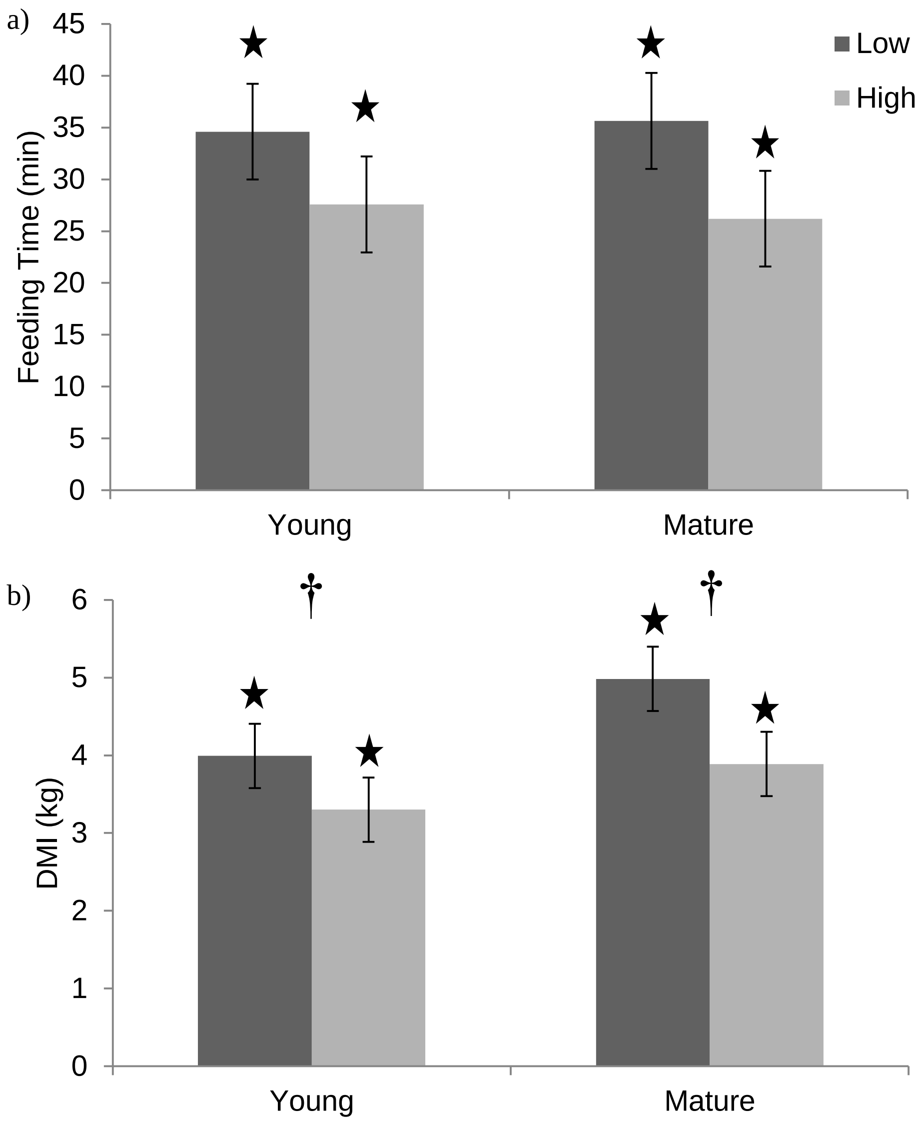

Figure 3.2 Average **a)** feeding time (min; mean ± SE), and **b)** dry matter intake (kg; mean ± SE), for the first meal following all feed deliveries for Young (parity ≤ 2) and Mature (parity ≥ 3) cows fed at a Low (2 ×/d at 1545, and 0830 h) or High (6 ×/d at 1545, 1745, 2100, 0830, 1030, and 1230 h) frequency. All cows were fed competitively in a ratio of 2 cows: 1 feed bin. Data was averaged over 5 d for 8 pairs of lactating Holstein cows (n = 16) on each treatment. Filled stars indicate significant differences ($P \leq 0.05$) between treatments, and significant differences between parities are denoted by †.

CHAPTER 4. GENERAL DISCUSSION

4.1 Important Findings

Understanding the response to competitive feeding environments is an important factor in maintaining the health and welfare of dairy cows. In the first study (Chapter 2), the goal was to examine how the feeding behaviour of group-housed, lactating dairy cows responded to increasing levels of competition for feed access. It was hypothesized that at increased levels of feed competition, cows would modify their behaviour to consume feed faster and in larger meals. The curvilinear responses in feeding rate, feeding time, and meal patterns, as competition for feed access was elevated from a low (3 cows fed from 3 feed bins) to an extreme level (3 cows fed from 1 feed bin), support this hypothesis. On a daily-basis, cows consumed their feed at the fastest rate and for the shortest period of time when fed at the highest tested level of feed competition. These modifications of feeding behaviour allowed cows to maintain similar levels of DMI under all levels of feed competition. Meals consumed by cows when they were under the highest level of competition for feed access were approximately 10.5 min longer, and tended to be larger and less frequent. This pattern of rapid consumption of large infrequent meals, known as slug-feeding, has been shown to produce large fluctuations in rumen pH, thus increasing the risk of cows developing SARA (Shaver, 2002; DeVries et al., 2005; Krause and Oetzel, 2006). Additionally, the time spent not actively engaged in consuming feed during meals was doubled when competition for feed access was greatest. This may potentially lead to another health concern, as increased standing time has been identified as a risk factor for lameness (Greenough and Vermunt, 1991; Cook et al., 2004). The similar DMI, as a product of increased feeding rate and decreased feeding time, was mirrored during most peak feeding periods, in the 1 h post-feed delivery.

It was further hypothesized in Chapter 2 that individual cows within the group would exhibit greater variability in their feeding patterns as competition for feed access increased. This hypothesis was largely supported by the results of this study. Greater variability in feeding time, feeding rate, meal patterns, and milk production were identified between individuals within each group when the highest level of feeding competition was imposed, suggesting that as competition for feed increases, all cows are not able to compensate equally for the greater competitive pressure. Such increased variation may be due to differences in the relative social position between individuals within the group, supported by our finding that high-ranking cows within the group spent more time feeding than lower-ranked cows; however, this pattern was not maintained across feeding rate or DMI.

After examining the effects of differing levels of competition for feed access on variability in feeding patterns, we sought to investigate the use of increased feeding stimuli as a method of mitigating any negative effects of said competition. In the second study (Chapter 3), it was hypothesized that by increasing the frequency of feed delivery from a low level (2×/d) to a higher level (6×/d), competitively-fed cows would have greater opportunity to access feed during peak periods. This hypothesis was supported by the feeding behaviour observed during the first meal following each fresh feed delivery. While daily DMI remained consistent, the first meals were, on average, shorter and smaller in size when cows were fed at the higher frequency compared to the lower frequency. The first meals post-feeding coincided with peak periods when the majority of cows were feeding together and the competition for access to feed is typically at its highest level (DeVries et al., 2003a; DeVries and von Keyserlingk, 2005; King et al., 2016). Such a feeding pattern would allow for a greater turnover of cows at the feed bunk, and thus would provide more opportunities for all individuals to access fresh feed. Despite this change in feeding behaviour during peak times of feeding activity, the overall daily feeding measures of feeding time, feeding rate, DMI, sorting, number of replacements, and meal patterns did not differ with increased frequency of feed delivery.

It was further hypothesized in the second study (Chapter 3) that individual, competitively-fed cows would demonstrate reduced variability in feeding behaviour when fed at a higher frequency than at a lower frequency of feed delivery. This hypothesis was partially supported by the tendency for greater rumination time at high frequency of feed delivery, and the greater variability within pairs for certain measures of milk production at low frequency. Parity, however, had a greater impact on differences between individual cows. Mature cows (parity $\geq$ 3) demonstrated increased DMI, increased feeding rate, reduced meal frequency, and increased meal size compared to Young cows (parity $\leq$ 2) when experiencing competition for feed access. Success rate in competitive interactions also played a role in feeding patterns, with the more successful cows spending greater time feeding and achieving higher DMI.

4.2 Future Research

Whereas previous studies of the effects of feed bunk competition (Olofsson, 1999; Huzzey et al., 2006; Collings et al., 2011), as well as Chapters 2 and 3, imposed competitive feeding conditions for short periods of time, a dairy cow in a commercial operation may experience competitive pressure for months at a time, or throughout its lifetime. Further research into how competition for feed access affects dairy cow feeding behaviour, and consequently their health, productivity, and welfare, should focus on the long-term effects of such an environment. One factor that may benefit from a longer period of study is milk production. A low level of variability in milk production was observed as the feed competition increased in Chapter 2, and as the frequency of feed delivery increased in Chapter 3. However, 10-d treatment periods, may not accurately capture the effect of competition for those cows experiencing sustained competitive conditions. Thus long-term studies could provide greater knowledge into the effects of competition on the milk production of the herd as a whole.

Long-term studies would also allow investigation of the physiological effects of competition. The consumption of larger, less frequent meals due to increased competition results in large fluctuations in pH throughout the day, which may increase the risk of developing SARA (Shaver 2002; Krause and Oetzel, 2006). However, in the studies described in Chapters 2 and 3, no physiological measures of the rumen environment were taken; thus it is difficult to draw conclusions regarding what effect increased feed competition or frequency of feed delivery may have on rumen function in competitively-fed cows. Over a longer-term study, measurements of rumen pH following peak feeding periods or fresh feed deliveries could provide a better understanding of the impacts of variations in feeding behaviour.

Similarly, future research could examine whether the physiological stress level of individual competitively-fed cows reflects the variation in feeding behaviour, and whether increasing the frequency of feed delivery is an effective method of reducing that stress. It has been suggested that long-term exposure to stressful stimuli may contribute to reproductive problems, reduced immune responses, and abnormal growth or development (Moberg, 2000). Previous studies have utilized heart rate monitors (Hagen et al., 2005; Gygax et al., 2008; Hetti Arachchige et al., 2014), glucose tolerance tests, and ACTH challenges (Huzzey et al., 2012b) to measure the physiological stress induced by competitive feeding environments. The use of any of these methods to monitor the stress response of dairy cows experiencing sustained feeding competition could help identify potentially harmful effects.

A question arising from the studies described in Chapters 2 and 3 is whether the small group sizes tested (i.e. 2 or 3 cows/group) influenced the response of individual cows to increased levels of competition. In larger herds or groups of dairy cows, the social structure between individuals is highly complex, and individual cows may be unfamiliar with all conspecifics (Estevez et al., 2007). We suggested that familiarity between individuals in our small groups may have influenced attempts by individuals to replace others from the feed bin, resulting in the similar number of replacements observed as competition increased in Chapter 2, and as the frequency of feed delivery increased in Chapter 3. Further research into the effects of competition on a larger group, or in a commercial herd with frequent re-grouping of animals, may demonstrate a greater response by individual cows.

Since not all cows within a group or pair display a simple linear hierarchy, whereby one individual is dominant over all others (Bielharz and Zeeb, 1982; Val-Laillet et al., 2008), this adds another consideration to studies of competitive feeding behaviour. In the current studies in Chapters 2 and 3, success in competitive interactions at the feed bin was used to identify a rank or index for individual cows within the group, and to explore differences in social position. However, future research may benefit from conducting preliminary studies that specifically identify dominant and subordinate individuals, thus ensuring that experimental groups or pairs represent individuals from all social ranks.

Given the numerically higher feeding times observed under the 6 ×/d feeding treatment, it is possible that exaggerating the difference between the frequencies of feed delivery could influence the resultant feeding patterns. In the second study (Chapter 3), our selection of feed delivery times was limited by the size of the feed bins, which required filling a minimum of 2 times daily to meet the intake requirements of 2 lactating cows. Had this not been the case, a single daily feeding for each pair of cows, compared to feeding 6 ×/d or more, may have been sufficient to identify changes in daily feeding behaviour. Although this would represent a dramatic change from the typical feeding management practices on commercial dairy operations, automatic feeding technology is currently available and capable of providing numerous feedings throughout the day without an excessive increase in labour.

Similar to such studies as Olofsson (1999), who compared non-competitively-fed cows to those fed at 400% competition, the current study also compared low and moderate levels of competition (100 and 150%), with a greatly exaggerated competition level of 300%. As indicated by the curvilinear response in feeding patterns demonstrated in Chapter 2, there is a notable change in the response of dairy cows between the 150 and 300% levels of competition for feed access. Further long-term examination of the effects of feed competition on the variability in feeding behaviour between these levels could provide a better understanding of the point at which individuals become unable to compensate through behavioural modification, and at what level the onset of potential health problems occurs.

4.3 Implications

With the dairy industry facing increased pressure from consumers, who are expecting dairy products to be produced from dairy cows cared for at a high standard of welfare, it is more important than ever for producers to be conscious of how their feeding management practices can maintain productivity, while promoting a low-stress environment for their animals.

Results of this thesis demonstrate that avoiding competition at the feed bunk will limit variation in feeding behaviour between individuals within a group. This is an important consideration for producers, as increased variability could make meeting the optimal production requirements of individual cows more difficult when managing their feeding at a group level. Furthermore, competitive pressure at the feed bunk may encourage poor feeding behaviour patterns (i.e. 'slug-feeding') and longer standing times that put undue stress on individual cows, thus increasing their risk of developing detrimental and costly conditions, such as lameness and SARA.

My thesis research also indicates that, in competitive feeding situations, access to feed during peak periods may be improved by increasing the frequency of fresh feed delivery. This could be particularly beneficial for lower parity cows that are more likely to be the subordinate individuals within the group. The observed differences in parity under a consistent level of competition for feed access also emphasize the importance for producers to account for parity when creating a grouping strategy, particularly under situations where cows face competition for feed access.

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