The behaviour and health of dairy lambs reared artificially with and without early access to meal

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Abstract

Many large-scale dairy sheep producers use lamb-rearing systems and provide lambs with milk replacer (MR) *ad libitum* and grain-based meal to accelerate rumen development to support early weaning methods. Lambs are raised inside for three weeks before being relocated to a pasture paddock and weaned off MR, followed by weaning off meal 3-4 weeks later onto a pasture-only diet. The potential to replace the early provision of meal with early access to good quality pasture before weaning has not been evaluated and may have effects on the development of feeding behaviour. Studies on feeding behaviour in lambs have focused on differences between restricted and *ad libitum* quantities of MR, with little research on differences in use of solid feed before weaning. Sixty East Friesian crossbred ewe lambs aged 3-4 days were randomly allocated to one of two treatment groups; MR *ad libitum* with access to meal (M) or MR *ad libitum* without meal (NM). Both groups had access to pasture at the beginning of week 4, and were abruptly weaned off MR at week 6 and gradually weaned off meal (M lambs only) beginning in the middle of week 8 until the end of week 10. It was hypothesised that; (1) while lambs were being reared inside, M lambs would initiate rumination earlier due to their early access to meal. (2) There would be no difference in the milk feeding behaviour between lambs on the two diets. (3) There would be no difference in the health of the lambs and lastly (4), once outside, M lambs would spend more time grazing and subsequently ruminating as a result of their earlier rumen development. All lamb behaviours were visually recorded during weeks 2, 3, 5, 7, 10 and 12 (nine hours/week). Milk feeding behaviour traits were automatically recorded hourly through the automatic MR dispenser while being reared inside for 23 days. Health scores were recorded twice daily and total days health incidences were recorded. Meal access accelerated onset of rumination, while NM lambs spent more time consuming wood shavings during week 3 ($P<0.001$). Once outside, NM lambs spent more time grazing during weeks 5 ($P<0.05$), 7 and 12 ($P<0.001$), and increased rumination time compared to M lambs by week 12 ($P<0.001$). Lambs with meal access on average had a greater number of rewarded meals (meals in which lambs consumed more than 1 ml), with a greater intake of MR per meal than lambs without meal access ($P<0.001$). There were no mortalities of lambs fed either diet. Loose faeces (mild scours), pink eye and navel infections were observed in both M and NM lambs. These findings may allow refinement of lamb-rearing practices by adjustments to the provision of meal to lambs since no adverse behavioural or health effects were observed in lambs without meal access.

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Chapter one: Introduction

The sheep dairy industry in New Zealand

Slowly but surely, the dairy sheep industry in New Zealand is growing, with several large-scale farms currently operating (Peterson and Pritchard, 2015). The New Zealand sheep dairy industry was originally founded in the late 1990s after early research was conducted into the potential of sheep dairy farms ability to operate (Geenty and Davison, 1982; Smith and Geenty, 1983) followed by the importation of the high-milk-producing East Friesian breed (Allison, 1996). However, soon after, the industry collapsed, due to the lack of processing facilities. Only a couple of farm operations remain from that early industry, but over the last decade, interest has developed, leading to a new generation of dairy sheep farmers. The growing movement towards alternative, healthy dairy products such as goat and even vegetable milks (almond) has allowed for the new growth and establishment of sheep dairy in New Zealand. The industry has an estimated turnover of $15 million in 2015 (Peterson and Pritchard, 2016), with the projected potential to grow into a substantially greater industry which can compete with the overseas markets (Griffiths, 2015).

There are currently three large farm operations and several small- to medium-sized operations are operating in New Zealand with flock sizes ranging from 40 to 10,000 milking ewes (Peterson and Prichard, 2015; 2016). A range of sheep dairy breeds is currently utilised; East Friesian crosses, Awassi, Coopworth, Dorset and crosses of these breeds. Recently, the Lacaune breed has been imported from France. The first officially recognised New Zealand sheep milking breed is the ‘Dairymeade’ from the Kingsmeade operation, which were bred from East Friesian adapted to New Zealand conditions over the last 20 years (Lopez-Villalobos et al. 2017). These new developments in the industry have enabled a slow and steady growth of the dairy sheep industry to where it is now. The change in people’s food preferences and the development and demand from overseas markets should allow for continued growth and development of the sheep dairy industry.

Artificial rearing of lambs

The large-scale sheep dairy operations employ artificial-rearing of lambs, a more intensive rearing method compared to the traditional New Zealand sheep operations in which the lambs are reared by the dam. It is common to artificially rear dairy lambs in Europe and America (McKusick et al. 2001; Bimczok et al. 2005; David et al. 2014; Burgett 2015; Earleywine 2015; McKinzey and McKinzey 2016). It is common in New Zealand for sheep farmers to bottle feed orphans or lambs from large litters (Davies and Owens, 1967; Lane et al. 1986). Large-scale artificial-rearing systems that prepare the lamb for the New Zealand farming systems have not been used in New Zealand until the recent development of the sheep dairy industry. This practice of artificial rearing and removing lambs early after birth has been utilised to maximise milk production as 25% of the ewe's total milk production occurs within the first month of lactation (McKusick, et al. 2001).

There has been limited research literature about artificial rearing of lambs in New Zealand, due to it being largely uneconomical for conventional sheep farms to do so (Smith and Geenty, 1983). McMillian et al. (2014) and King et al. (2015) characterised two lamb rearing methods in New Zealand. On the Kingsmeade farm, single-bearing ewes begin milking once daily around one week after lambing with the lamb at foot, while multiple-bearing ewes begin milking after weaning. The age at weaning was unspecified (King et al. 2015) but was estimated to be five to six weeks of age, with some lambs up to eight to nine weeks of age (McCoard, personal communication, 2017). Antara Ag Farm, which supplies Blue River Dairy removes lambs before 30 days of age (McMillian et al. 2014) and some after four days (S. Peterson, personal communications, 2017). Bull and Binnie (2006) evaluated a lamb-rearing method to reduce abomasal bloat in lambs reared artificially using "soured" cold milk replacer *ad libitum* and meal *ad libitum* which resulted in lower abomasal bloat and higher survival rates compared to lambs with normal milk replacer Smith and Geenty (1983) provided data on a cost-effective method of artificially rearing lambs on diets consisting of high (320 g DM/lamb/day) or low ration of (180 g DM/lamb/day) ewe milk replacer and weaning onto good-quality pasture. While this was a cost-effective method, lambs didn't achieve live weights of 40-45 kg until 15 months of age. In the current farm system for meat sheep, lambs attain live weights of 40-45 kg by 6-8 months of age to breed ewes as hoggets (Kenyon and Webby, 2007). Knight et al. (1993) examined the effects of milking and rearing regimens on lamb performance, survival and milk yields. Ewes and there lambs were allocated to one of four treatments; 1) a control group of ewes who were milked twice daily and had there lambs artificially reared, 2) ewes milked once a day and had there lambs artificially reared, 3) Ewes with access to their lambs at night, and 4) ewes with access to their lambs during the day. These treatments led to three groups of lambs, 1) artificially reared, 2) day-suckling and 3) night-suckling. The lambs reared artificially had continuous access to milk replacer and pellets, while lambs in the other treatments had pellets when removed from their dam. The lambs reared artificially had lower growth rates than those in the other two groups of lambs (140 g/day *vs.* 230-250 g/day) and were older at weaning, but had similar mortality rates (28% *vs.* 30%).

Currently some of the large-scale dairy sheep operations in New Zealand are removing lambs around 3-4 days of age, after they have had sufficient time to consume colostrum from their dam. The lambs are then moved into a rearing shed in group pens and provided with warm milk replacer (MR) *ad libitum* using artificial teats connected to automatic milk-feeding machines, accompanied by a grain-based starter meal. The objective of this system was to accelerate growth and rumen development to support early weaning off milk by 5-6 weeks of age onto good-quality pasture (Baldwin et al. 2004), to minimise the costs of rearing without compromising the welfare of the lambs.

The problem

The use of artificial rearing of lambs provides an alternative to natural rearing systems. On dairy sheep farms artificial rearing increases the survival of lambs (David et al. 2015), and facilitates increased harvesting of milk for specialty products rather than for lamb consumption. Artificial rearing supports the growth and development of good-quality lambs for later use as replacements (milk production and production of future lambs) or for meat production (Emsen et al. 2004). However, artificial rearing is associated with high costs due to the use of milk replacer and meal, and infrastructure is required for housing and feeding, and is labour intensive. Minimising the costs associated with artificial-rearing systems without compromising welfare, growth and lamb quality should be explored to support the profitability of on-farm operations.

The gap in knowledge

A plethora of research associated with lamb rearing internationally has been published during the past 20+ years covering areas such as lamb-rearing methods (McKusick et al. 2001; Rodriguez et al. 2007), growth and nutrition (Chai et al. 2017; Danso et al. 2016; Rodriguez et al. 2007), welfare (behaviour, growth, environmental effects, immune response) (Napolitano et al. 2008; Orgeur et al. 1998), and behaviour (David et al. 2014; Karaagac et al. 2005; Savas et al. 2001). However, there has been a lack of literature surrounding the feeding behaviour of artificially reared dairy lambs during the transitions from a liquid diet onto a pasture-only diet. Feeding behaviour develops at a young age, with feeding regimens and management systems being influential (Miller-Cushon and DeVries, 2015). Understanding the early development of feeding behaviour and how it is effected by the dietary and management transitions is important to support welfare and performance outcomes. While there has been a large amount of research conducted to examine the feeding behaviour of artificially reared dairy calves' milk feeding behaviour (Appleby et al. 2001; Jasper and Weary, 2002; Jensen, 2003; Ballou et al. 2013; Khan et al. 2007; Khan et al. 2014) only a hand-full of papers have been published on lambs behaviour (Bechet et al. 1989; Emsen et al. 2004; Bimczok et al. 2005; David et al. 2014). Several papers have characterised the health problems associated with young naturally and artificially reared lambs (Bull and Binnie, 2006; Crawford, 2013; Maroney et al. 2015). The characterisation of the welfare particularly health issues associated with artificial rearing of dairy lambs in New Zealand has not been presented and would be beneficial to the emerging sheep dairy industry. There is the potential to record and describe the developments and changes of feeding behaviour in artificially reared dairy lambs as they change from a milk diet onto a solid-feed diet of pasture in a New Zealand context with and without access to meal.

This review of literature will encompass artificial rearing of lambs, the welfare of neonatal lambs and health implications of artificial-rearing methods. The development of the gastrointestinal tract of ruminants and its association with the development of feeding behaviour as they transition from a liquid to a solid feed diet will be discussed. Due to the paucity of research in sheep, comparisons will be made with dairy calves.

Chapter Two: Literature Review

Lamb rearing

Although lambs are ruminants, they are born as pre-ruminants and must go through several transitions before becoming a true ruminant (Baldwin et al. 2004). After birth, they change feed dependency from the intra-uterine environment with nutrients provided *via* the placenta to the extra-uterine environment where the newborn becomes dependent on milk from the dam. Naturally reared lambs begin to nibble and mouth pasture as young as three days of age but don't begin to ingest measurable quantities of pasture until three weeks of age (Owens and Davies, 1967; Lane et al. 2000), when a slow and gradual transition from a liquid to solid diet begins (Guilloteau et al. 2009). In conventional meat production, and some dairy sheep farming operations, lambs can suckle the dam and are gradually weaned off milk over periods from ranging from several weeks to three to four months of age depending on the farming operation (McKusick et al. 2001; Kenyon and Webby, 2007). On the other hand, in more-intensive systems where artificial rearing is utilised on dairy farms, lambs are removed from the dam at 2-4 days of age (allowing time to enable consumption of sufficient colostrum) and moved into an artificial-rearing facility.

On conventional farms, lambs go through one major transition from milk to pasture weaning at around two to three months of age while lambs being artificial reared have several transitions. The early removal from the dam and settling into a rearing facility with other lambs involves change in environment, social structure. In addition, there is a change in diet from ewes milk to milk replacer, and change from a natural to an artificial teat. As lambs age, they begin to consume starter feed (e.g., a grain-based meal and/or roughage). Many large sheep dairy farms incorporate early weaning programs to reduce costs associated with MR and meal (Emsen et al. 2004). The lamb will be either abruptly or gradually be weaned off MR, followed by weaning off meal, and depending on the country, will be transitioned onto TMR or a 100% pasture, as is the case in New Zealand systems. To ensure successful transition from liquid to solid feed the lamb must rapidly develop (metabolically and physically) at a young age to minimise potential liveweight losses, hunger and stress that occurs if lambs are not accustomed to the solid feed provided when weaned (Baldwin et al. 2004; Khan et al. 2016). This requires sufficient development of the rumen and associated organs (notably the liver and gastrointestinal tract) prior to early weaning to facilitate rumination and establishing early solid feed intake to meet nutritional requirements once milk replacer is removed. In addition, it is important for the welfare of the animal, that during the transition from liquid to solid feed, weight loss and weaning distress commonly associated with weaning transitions are minimised (Weary et al. 2008).

The welfare of dairy lambs artificially reared

Animal welfare is a science used to understand the experiences that animals go through in relation to their environments, and how they cope. These experiences can be assessed and classified to be poor, good or excellent (Stafford, 2013). With a growing public concern for animals to have basic requirements such as good health, nutrition, 'natural' environments, freedom from pain or fear, and the ability to express their normal behaviours, animal welfare is becoming more important for farm decision making. Animal welfare has different aspects which can be categorized into five components, based on the 'five domains model of animal welfare' (Mellor and Beausoleil, 2015). These components are; nutrition, health, behaviour and environment (physical affective states) and mental (physiological affective states). The five domains model of animal welfare can be used as a device to evaluate and grade animal welfare based on negative and positive states and their interactions on the animals' experiences (Mellor and Beausoleil, 2015). The assessment of animal welfare can be done in several ways. The changes in physiological (pathology, physiology, etc.), physical (health, production, growth) and behaviour responses (abnormal, motivation, deviations from 'normal') (Broom and Fraser, 2007), to differing environments, treatments. Changes in an animal's state, such as health, can lead to changes in behaviour and physiological functions of the animal (Stafford, 2013).

The issue of animal welfare affects the economics, ethical and legal aspects, and public expectations of New Zealand. The development and growth of new farm production systems such as dairy sheep, will result in new welfare issues for animals. The lambs of sheep dairy operations are commonly artificially reared, which of itself is not necessarily a problem but the raising of thousands of lambs in a single operation presents potential problems in relation to welfare. Much of the public perception we see today is supportive for providing more than just the basic requirements for animals to survive, such as providing opportunities for positive emotions and positive welfare.

Dairy lambs are of a significant importance to sheep dairy systems as replacements (ewes and rams) and or for meat production. Currently in New Zealand's extensive pastoral production system, lambs are reared with their dam, remaining with them until 2-3 months of age when they are weaned. The welfare of lambs at foot (reared with their dam), has seen a large body of research conducted and evaluated over the years, both internationally (Dwyer et al. 2015; Dwyer, 2009; Dwyer et al. 2003) and within a New Zealand context (Stafford, 2013). Due to the small number of sheep dairy farms in New Zealand, there is little information on the welfare of artificially reared dairy lambs. Previous research has been conducted using artificially reared meat lambs within New Zealand (Bull and Binnie, 2006). The focus of this literature review will be on health and behaviour of dairy lambs reared artificially in New Zealand and due to the paucity of research, comparisons will be made to dairy calves.

During the first couple of days of life, lambs are in the most vulnerable state and are susceptible to death from starvation, exposure (hypothermia), miss-mothering (poor maternal-young bond), and infectious diseases (Dwyer et al. 2015). They must stand and suckle from the dam to obtain colostrum. Colostrum contains immunoglobulins, hormones, growth factors, nutrients for survival (Nowak and Poindron et al. 2006; Banchero et al. 2015). A mutual bond forms between the lamb and their dam within the first day of life (Dwyer et al. 2015). The onset of this bond is due to hormonal changes during birth modifying the maternal responsiveness of the ewe towards her lamb(s) (Nowak and Poindron et al. 2006). In extensive management systems, this bond is imperative to the survival of lambs as the ewe will not allow the lamb to suckle if they aren't bonded.

Lambs that are artificially reared move from an extensive rearing system with their dam to a new environment with other lambs. They also undergo a change in diet from ewe milk to milk replacer and change in social interactions, which can affect the lamb's welfare, such as, health, immune function, behaviour and overall survival (Napolitano et al. 2008). It is important for lambs that they are able to express their normal behaviours (suckling, play, rumination), the environment is adequate (comfortable, warm), diet is sufficient for normal growth (acceptable formulation of milk replacer) and performance, they are free from diseases, infections and other health problems (Dwyer, 2003). Poor health is associated with poor welfare, and such, young mammals like lambs are vulnerable, they must be taken care of sufficiently within the constraints of the production system they are in.

Health of lambs reared artificially

Neonatal ruminants are vulnerable to morbidity and mortality (Stafford, 2013), that can lead to losses of production, profitability of the farm and influence their welfare (Dwyer et al. 2015). They are particularly susceptible to starvation, hypothermia and mis-mothering soon after birth with up to 50% of all pre-weaning lamb mortality occurring during the first 24 hours of life (Nowak et al. 2000).

Once lambs are moved into rearing sheds, mortality rates can be greater than that of conventionally reared lambs (Schouten, 2004; Napolitano et al. 2008). David et al. (2014) used 94 Romane lambs and had a mortality rate of 12% and Emsen et al. (2004) reported a 15% mortality rate for 20 Awassi lambs. In a New Zealand study, two farms in the South Island that employ artificial rearing methods had 29% and 33% mortality rates (Schouten, 2004). Much of the mortality rates in lambs reared artificially are due to health issues. Hepola, (2003) reported that group-reared calves are at greater risk of health problems due to the sharing of teats on automatic feeding dispensers.

The main health problems associated with artificial rearing of lambs are scours (diarrhoea), respiratory problems (commonly pneumonia), bloat, coccidiosis, navel infections, with other issues such as pink eye and lameness (Large, 1965; Binns et al. 2002; Bull and Binnie, 2006; Crawford, 2013; González et al. 2016).

Scours commonly occurs in young ruminants (Walker and Faichney, 1964; Large, 1965; Leaver and Yarrow, 1972; Davis and Owens, 1987; Jasper and Weary, 2002). Several studies of dairy calves have reported no differences in days with scours or incidence when fed MR *ad libitum vs.* restricted (Appleby et al. 2001; Jasper and Weary, 2002; Borderas et al. 2009), while others have reported that calves fed higher quantities of MR had more days with scours (Quidley, 2006). There are two types of scours; nutritional and infectious (Kehoe, 2014). Infectious scours result from an infection with organisms such as E. *coli*, *Salmonella*, or *Cryptosporidium* which lead to poor absorption of nutrients and water in the intestines causing watery, runny and discoloured faeces that can have blood (Cho and Yoon, 2014). Nutritional scours are the result of interactions of lamb susceptibility, stress, nutrition (change in diet, milk quantities) and environmental factors that result in light-yellow runny faeces, but does not affect lambs behaviour (Kehoe, 2014). Lambs with nutritional scours can improve without treatment, but can be more susceptible to infectious scours (Large, 1965). If scours are left untreated or unnoticed, it can result in lamb mortality.

Respiratory problems have been highlighted as a severe issue impacting lamb health (Crawford, 2013). Infections and or inhalation of dust particles or feed (solid or liquid) can cause irritation of the upper or lower respiratory tract of lambs leading to poor liveweight gain and greater mortalities (Scott, 2011). Lambs with respiratory problems are characterised by poor posture, lethargic, coughing/wheezing, struggling to breathe and discharge from their nose (Plummer, Plummer and Still, 2012). Many respiratory problems of lambs reared artificially or lambs reared in large groups have been attributed to poor ventilation (Gökçe and Erdoğan, 2008) and high stocking densities (Gonzalez et al. 2016).

Bull and Binnie (2006) highlighted abomasal bloat as a concern for lambs artificially reared within the first two to four weeks of life when MR is offered in restricted or *ad libitum* quantities. The accumulation of gas within the stomach following feeding causes pain and discomfort and can lead to death left if untreated (Navarre et al. 2012). While lameness can be a problem for extensively managed sheep, and to an extent lambs (Sevi et al. 2009), it seems less common in lambs artificially reared.

Indoor rearing and housing systems for lambs have benefits when it comes to monitoring health and identifying potential problems earlier than in extensively raised lambs. Due to lambs being in pens with many others. However, it is easy for pathogens and infections to spread quickly (Dwyer et al. 2015). Daily monitoring is essential to early detection of any health problem that lambs may be experiencing. Hygiene and ventilation are key to minimising the potential outbreak of disease and illness within an indoor housing system (Roekel, 2012). Indoor systems can have a greater number of infectious diseases if not correctly managed (Dwyer et al. 2015). It has been highlighted that less-routinely cleaned and/or changed bedding within indoor systems can create an environment where pathogens can easily spread (Binns et al. 2002). Similarly, rearing calves in pens with a high stocking density can lead to the spread of disease through close contact and due to many calves sharing the same automatic milk dispensing teat (Hepola, 2003).

Weaning transitions of lambs artificially reared

Lambs that are artificially reared go through a series of major diet and environmental weaning transitions. These include: 1) Weaning from ewe's milk to MR; 2) Weaning off MR to solid feed, and depending on the rearing system; 3) Weaning off meal onto pasture; 4) Moving from being outside with the dam into an indoor housing system or being born inside and eventually moving outside. These weaning transitions involve the progression of their diets, social interactions and environment. These transitions can lead to nutritional and emotional stress (Jasper et al. 2008; Napolitano et al. 2008; Weary, 2008).

Soon after parturition, like other mammals, the ewe and lamb begin to form a mutual bond (mother-young bond) with the newborn lamb by sniffing, cleaning, and eventually encouraging the lamb to suckle from the teat (Flower and Weary, 2003; Napolitano et al. 2008). Lambs establish a strong rewarding attachment when suckling the dam, strengthening their bond (Nowak et al. 1997). The removal of the lamb at around two to four days of age disrupts the bond and abruptly weans the lamb off their mother's milk. The lambs are moved to a new physical environment and must transition on to a MR (Napolitano et al. 2008). It has been shown that blood cortisol concentrations can be higher than those of ewe-reared lambs (Napolitano et al. 2003), while others have shown that there is little effect (Sevi et al. 1999; Napolitano et al. 2002). Group rearing of young ruminants can reduce the stress associated with removal from the mother and weaning (reviewed by Costa et al. 2016), increase positive social interactions (Zito et al. 1977; Jensen et al. 1998; Chua et al. 2002; Napolitano et al. 2003).

In many artificial-rearing methods, lambs and calves can be abruptly weaned off MR onto solid food (Bimczok et al. 2005). Many dairy-calf rearing methods are moving towards gradual weaning or 'step down' methods as starter intake is improved with less weight lost due to growth checks (Khan et al. 2007; Jasper et al. 2008; Sweeney et al. 2010). Lambs must be consuming adequate quantities of solid feed before weaning, to minimise the effects of early milk weaning (Weary, 2008; Khan et al. 2016). The quantity of MR offered can affect their performance during weaning, with restricted MR quantities leading to greater solid feed intake but lower growth rates, while when MR is offered *ad libitum,* less solid feed is consumed but results in greater growth rates (Byrne et al. 2017). Naturally reared lambs continue to consume their mother's milk until two to three months of age and are gradually weaned (Kenyon and Webby, 2007). Early weaning methods result in the young ruminants becoming emotionally and physiologically stressed and can result in growth checks due to insufficient nutrient intake to maintain the continued growth rates (Jasper et al. 2008; Weary, 2008; Napolitano et al. 2008). Group rearing of calves compared to single housed calves can lead to increases in starter feed intake, reducing the effects of growth checks (De Paula Vieira et al. 2010). Similarly, weaning at later ages may reduce the negative effects of weaning (Roth et al. 2008; Eckert et al. 2015) and gradually weaning compared to abrupt weaning and reduce growth checks (Terré, et al. 2007; Khan et al. 2016). Neonates have preferences towards milk due to their young age and their inability to consume solid feed (Weary, 2008).

Lambs reared artificially in New Zealand transition from starter feed onto pasture where another growth check can occur (Jensen et al. 2017). Weaning lambs on to leafy, good quality pasture can reduce the effects of weaning and help with post-weaning growth (Jagusch et al. 1979). While the provision of meal or concentrate can increase growth rates after milk-weaning, larger quantities of concentrate have been shown to reduce the time spent grazing (Vendramini et al. 2006).

Conventional methods of providing milk replacer *ad libitum* and abrupt weaning can result in high levels of stress and larger growth checks compared to 'step down' (gradual) weaning methods, as starter feed intake increases (Jasper and Weary, 2002; Khan et al. 2007). In New Zealand, the use of meal (starter feed), may provide smoother transitions on to pasture when weaned off MR. The establishment of sufficient solid feed intake before weaning will help lessen and/or mitigate any potential problems associated with weaning.

Gastrointestinal development and function

Pre-ruminant to ruminant

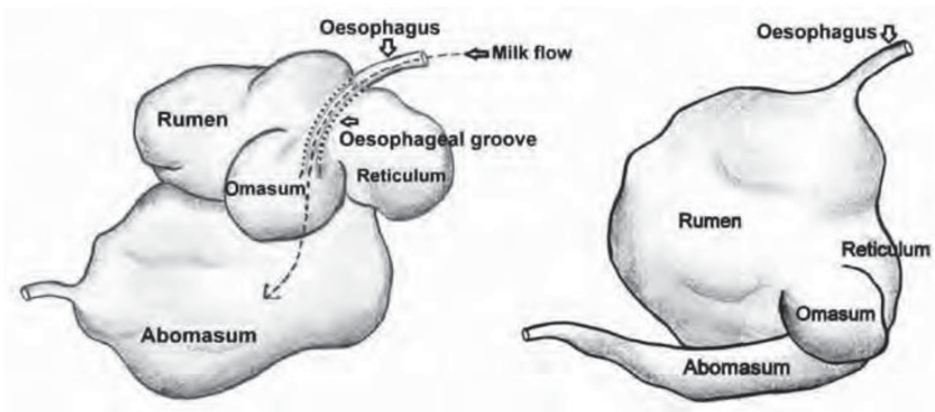
At birth, the structure of the gastro-intestinal tract (GIT) is well developed and has the ability to digest milk via cellular processes and enzymatic activity (Guilloteau et al. 2009). The abomasum is the largest compartment of the ruminant stomach at birth (Membrive, 2016).

Within three weeks of life, the abomasum decreases relative to total body weight (BW). The rumen and small intestine increase in mass rapidly after birth to reach just over 2.5% of total body weight becoming the largest organ making up nearly 80% of the total stomach mass (Figure 1), (Baldwin and Jesse, 1992; Guilloteau et al. 2009). The four-chambered stomach of a ruminants consists of the rumen, reticulum, omasum and abomasum, each having a different purpose for digestion (Membrive, 2016). The reticulum is responsible for maintaining large feed particles for storage so they don't flow into the next chambers of the stomach before regurgitation, re-chewing and digestion has occurred in the rumen. The rumen is the largest compartment of the rumen stomach and is responsible for the fermentation of the ingested feed via the microbial organisms that inhabit the stomach and has a pH around 6.5 to 7. The omasum is connected to the rumen and the abomasum, it acts as a filter for the water within the digesta due to its large surface area and slows down the flow of digesta into the abomasum. The last compartment is the abomasum, which is considered the true stomach and resembles the monogastric stomach. Unlike the other compartments, it has a low pH (pH 3 to 4) that enzymes and acids are secreted for the digestion of proteins (Membrive, 2016).

While the new born is a pre-ruminant and its ability to digest solid feed is minimal to none and it must rely solely on milk for the first several weeks of life to meet the nutrient demand for growth and maintenance (Arnold et al. 1979; Gonyou and Stookey, 1987; Baldwin et al. 2004). When young ruminants consume milk either by suckling from a teat (real or artificial) or consume milk from a bucket, it initiates the closure of the oesophageal groove. The closure results in milk bypassing the rumen/reticulum and flowing directly into the abomasum (Ørskov et al. 1970). The abomasum, small intestine, and pancreas are responsible for the successful digestion and absorption of the nutrients within the colostrum and milk via three main enzyme activities; chymosin, elastase II, and lactase, respectively (Guilloteau et al. 2009).

Lambs rely on milk during the early weeks of life, but must transition onto solid feed before milk weaning which involves the physical and metabolic development of the rumen before rumination can occur. The ruminant stomach's digestive capacity and growth can have a large impact on the animal's performance. The rumen grows rapidly after birth, but at birth the rumen is a non-functional underdeveloped sac. It must grow in size (mass) and surface area, establish a microbial ecosystem, initiate fermentation processes and increase rumen motility (Khan et al. 2016). This coincides with the development of solid-feeding behaviour and rumination, and adjustments associated with the hepatic metabolism and intestinal tissues of the gut (Baldwin et al. 2004; Khan et al. 2011b; Khan et al. 2016).

Figure 1 The development in stomach compartments of a ruminant as it grows from a pre-ruminant to adult ruminant (FAO, 2011).



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The rumen mass, volume and surface area, papillae length, size and number must grow sufficiently (Baldwin, 2000). The size of the rumen has been shown to be affected by the ingestion of solid feed, with early access to solid feed increasing growth (Khan et al. 2016), while a lack of solid feed hinders the growth (Baldwin, 2000). The rumen papillae are important in absorption, and must grow in length to increase the surface area for absorption. They are responsible for the absorption of volatile fatty acids (VFA), which the ruminant uses as its main energy source once weaned off milk completely. The papillae length and growth is influenced by the presence and absorption of short chain fatty acids (SCFA; also known as VFA) within the rumen (Heinrichs, 2005). Butyrate is the most stimulatory followed by acetate and then propionate, with a continuous presence of VFA helping to maintain growth and function of papillae within the rumen (Warner et al. 1956). Inert materials (plastic materials and wood shavings) have been shown to increase the rumen size, but had little effect on the papillae length in calves (Smith, 1961).

Solid feed is also necessary to stimulate rumen development and rumination activity in the neonatal ruminant (Zitnan et al. 1993; Baldwin, 2000; Baldwin et al. 2004; Forbes, 2007; Khan et al. 2016). As the pre-ruminant ages, it begins to start mouthing/nibbling at solid feed. This may consist of bedding material and/or hay or forage, and/or other solid feed that they are given access to (Phillips, 2004; Forbes, 2007). The ingested material or food flows into the reticulum/rumen and helps with the microbial population that is later responsible for ruminal fermentation (Baldwin, 2000; Baldwin et al. 2004).

When neonatal ruminants are fed exclusively on MR, their rumen development is hindered, with reduced capacity, papillary differentiation, muscularity, keratinization, and an overall lower rumen weight (Warner et al. 1956; Smith et al. 1961; Tamate et al. 1962). Lane et al. (2000) reported lambs fed exclusively MR from birth to 84 days of life had reduced growth of the papillae length and width, compared to lambs fed MR and weaned onto a starter feed from 49 to 77 days of age. Lambs offered MR exclusively, however, had a greater number of papillae. Baldwin et al. (2000) reported that lambs fed MR and a pelleted lamb's starter either *ad libitum* or restricted, had greater rumen mass (muscle and epithelium) compared to lambs which were fed exclusively on MR or MR and oral VFA infusions. Although lambs with VFA infusions had greater rumen development than those with MR, it was not enough to induce normal rumen development. Thus, for successful rumen development, early access to solid feed is key to stimulating growth of the rumen. Access to solid feed at an older age (e.g., 35 days old) may result in the rumen taking longer to develop and subsequently hinder lamb growth if weaned early (e.g., 5 to 6 weeks of age).

The type of solid feed provided to neonatal ruminants is an important factor influencing rumen growth and development (Khan et al. 2016). Concentrates such as maize or mixed meal stimulate a high rate of papillae differentiation and growth (Heinrichs, 2005; Laarman et al. 2011). On the other hand, forages and feeds such as fresh or dried grass with large particle size, stimulate rumen mass growth (Khan et al. 2011b), weight and volume rather than papillae differentiation and growth (Beharka et al. 1998; Zitnan et al. 1998; Norouzian and Valizadeh, 2014; Khan et al. 2016). Concentrates are more favourable in developing the rumen due to the greater increase in papillae growth leading to greater absorption of VFA. The provision of forages with concentrates has been shown to improve rumen pH while supporting a healthy rumen environment and may increase the rate of rumen passage allowing greater intake (Castells et al. 2013). Early dairy-calf rearing systems provided a concentrate, to promote growth and rumen papillae differentiation, VFA production and microbial colonization (Sander et al. 1959; Monotoro et al. 2013). While concentrates cause higher growth rates and differing ruminal development, the provision of forages, such as hay or grasses, can promote muscular development of the rumen (Khan et al. 2016; Norouzian et al. 2011; Norouzian and Valiadeh, 2014), creating a more-natural rearing process (Phillips, 2004). Recent literature has shown the importance of providing forages, concentrates or a mixture of both promote rumen development, health (Castells et al. 2012), growth, and a smoother transition to a solid food only diet (Overvest et al. 2016). Khan et al. (2011b) found that feeding hay to calves that were offered large volumes or MR, promoted solid feed intake and improved rumen development compared to calves fed only a starter feed.

Once solid feed intake increases, the salivary glands increase production, to provide a buffer for normal rumen function. Forages require a larger production of saliva to help with the longer period of mastication and rumination compared to concentrates which are easily digested and which require less saliva. Increasing the proportion of forage in the diet has been shown to increase rumination time (Phillips, 2004), and potentially the saliva production, which is responsible for acting as a buffer for maintaining the rumen pH (Castells, 2013).

Along with the rumen, the intestines and the liver undergo similar growth, development and change in metabolic activity within the first weeks of life. During neonatal life, the intestines undergo rapid growth and proliferation to support the transition to a milk diet immediately after birth to enable absorption of nutrients when feed chyme flows in from the abomasum. The activity of the intestinal tissue enables the absorption of nutrients from colostrum and milk during the pre-ruminant stage. This activity continues with the change in diet from liquid to solid feed, with the flow of nutrients from the post-fermented feed bolus that flows through the intestines being absorbed (Baldwin et al. 2004). The intestine sees a decrease in glucose and fatty acids with an increase in SCFA, ketones, amino acids and microbial protein sources. The glucose and fatty acids don't reach the intestine as the microbial colony utilises these energy sources for VFA production, thus reducing glucose absorption (Baldwin and Jesse, 1992). Beta-hydroxybutyrate (BHBA) is produced from butyrate via ketogenesis in the ruminal epithelium when solid feed intake increases and is pronounced at weaning when BHBA production has been reported to increase up to six-fold (Baldwin and Jesse, 1992). The ketogenic capacity of the rumen, is not influenced by the diet presented, but develops as lambs age (Lane et al. 2002).

The liver begins to increase in oxygen demand during the change from milk (glucose and fatty acids) to solid feed (VFA). With the reduction in glucose absorption, the liver is responsible for the higher production of glucose from the products absorbed (Membrive, 2016).

Ruminal fermentation activity

The rumen microbial colony is responsible for breaking down the structural carbohydrates (cellulose, hemi-cellulose and pectin) which undergo anaerobic fermentation breaking down the structural polysaccharides into glucose. There are several classes of rumen microorganisms (bacteria, protozoa, and fungi) responsible for degradation of feedstuff in the rumen. The main microorganisms are; cellulolytic (breaking down cellulose), hemi-cellulolytic (breaking down hemi-cellulose), pectinolytic (breaking down pectin), amylolytic (digesting starch and sugars), with others responsible for lipids digestion (lipolytic), ammonia-producing bacteria and methanogens. The microbial communities in the rumen are influenced by the type of solid feed provided; a concentrate diet results in a higher concentration of amylolytic bacteria, while forages increase the population of cellulolytic bacteria (Khan et al. 2016). Cellulolytic bacteria are important for the fermentation of forages and grasses, particularly important if lambs are being weaned off starter feed onto pasture at an early age.

The microorganisms utilise the glucose from fermentation within the rumen to produce VFA. The three main VFA, acetate, butyrate and propionate, are utilised by ruminants for energy and make up 50-70% of total energy use (Bergman, 1990). Acetate is the most produced VFA followed by propionate and butyrate. Lambs which are fed exclusively on MR have lower concentrations of VFA compared to lambs weaned onto solid feed (Lane et al. 1986; Lane et al. 2000).

VFA are absorbed through the rumen epithelia and make their way from the blood into the liver. Each major VFA provides energy for the ruminant. The majority of the butyrate leaves the rumen as BHBA and is utilised by the body's tissues for energy. Propionate is used by the liver as the main substrate for the gluconeogenesis pathway for the ruminant's glucose production. When the diet transitions from milk to solid feed, almost all glucose is utilised in the rumen by the microbial organisms, thus propionate production is important for hepatic glucose production. Acetate is utilised by tissues to produce Acetyl CoA which is used in the TCA cycle, glycolysis, glycogenesis and amino acid synthesis (Heinrichs, 2006; Forbes, 2007).

During fermentation processes, a large quantity of gas is produced by the microorganisms, with 70% being carbon dioxide (CO_2) and around 30% methane (CH_4), this makes its way to the top of the rumen above the digesta and is removed via belching (Aschenbach et al. 2011).

The pH homeostasis is an important factor in maintaining rumen health (Owens et al. 1998). The microorganism biodiversity and the end products being produced by the microorganisms and are directly affected by the diet offered to the ruminant (Khan et al. 2016). Diets high in carbohydrates, such as concentrates, allow for less fermentation losses while increasing the fermentation rate, resulting in a high proportion of fermented end products. These end products can result in a decrease in the rumen pH < 6 (Beharka et al. 1998; Aschenbach et al. 2011) inhibiting cellulolytic bacteria activity (Russel and Wilson 1996; Russel and Rychlik 2001) and can produce acidosis (Owens et al. 1998). On the other hand, forages are higher in structural carbohydrates requiring greater fermentation and digestion than a diet high in concentrates. Forage digestion leads to a higher proportion of acetate than butyrate and propionate without affecting the rumen environment and pH (Khan et al. 2011a; Castells et al. 2013).

Mould et al. (1983) reported that an increase in the concentrate (barley) to forage (hay) ratio (25%, 50%, 75% and 100%) as well as a change in the concentrate form (whole, pelleted, ground) resulted in the pH of the rumen declining. Above 50% concentrate in the diet reduced the pH below 6.5, and with the inclusion rate of 75%, the pH was reduced to below 6. The smaller particle size of a diet makes it more readily digestible when ingested as it does not require a great amount of chewing or rumination compared to diets with larger particles (Waghorn and Reid, 1983). This can affect the pH of the rumen, with small particle sizes producing a more acidic pH than coarser particles within a diet (Greenwood et al. 1997). A decrease in the rumen pH from ground diets have been reported to affect the presence of bacteria, with a pH lower than 6 inhibiting the activity of cellulolytic bacteria and their numbers, while a higher number of amylolytic bacteria are observed compared to unground or coarse diets (Mould et al. 1983; Beharka et al. 1998).

Feeding behaviour

Introduction

The feeding behaviour of animals has been extensively studied since the early 1950s (Munro, 1953). Since then, there has been advancements in the understanding of the mechanisms that control feed intake and what influences the feeding behaviour of ruminants. The feeding behaviour of ruminants, like many other species, can be affected by many different factors, including the nutritional requirements of the animal (Dulphy et al. 1980), physical and nutritional characteristics of feeds (Baumont, 1996; Baumont et al. 2000; Cosgrove and Edwards, 2007; De Araújo Camilo et al., 2012; Miller-Cushon and DeVries, 2015; Simeonov et al., 2015) the type and size of feeds (Baldwin, 2000; Vendramini et al. 2006), housing dynamics (Chua et al. 2002; De Paula Vieira et al. 2010; Filho et al., 2014; Costa et al. 2014; 2015; 2016), diet choices (Kenney and Black, 1984; Miller-Cushon and DeVries, 2011; Filho et al., 2016), birth weight (Yilidrim et al., 2013) and social interactions and facilitation (Leme et al 2013). Understanding the development of feeding behaviour from birth to adulthood, the role of management and weaning transitions of performance of feeding behaviour and how this may affect the lamb's health and performance. It is important for future management systems and for the optimisation of artificial lamb-rearing systems to include the utilisation of all offspring.

Feed intake is regulated by hunger and satiety (Miller-Cushon & DeVries, 2015). The regulation of intake is related to short-term control of feeding behaviour by hormonal ques via homeostatic regulation within the body to satisfy energy and nutrient demands by the animal's body. Animals that are fed indoors or in feedlots have scheduled meals rather than having to search for the food themselves. Thus, meals are distributed within set periods, while animals which are grazed in pastoral systems search for preferred patches of feed to graze. The meals are initiated by hunger and diminish due to rumen fill, fermentation products and absorbed nutrients resulting in satiety. Following satiety, long periods of relaxation occur, and for ruminants, periods of rumination (Forbes, 2007).

Artificially reared lambs, like dairy calves, are removed from the mother within the first 2-4 days of life. This is common practice on cow dairy farms (Miller-Cushon and DeVries, 2015), and similarly is occurring on large-scale sheep dairy farms. The farmer controls how the lamb feeds, when and what it consumes, based on the management practices. This can lead little opportunity for the feeding behaviour to develop without influences from management decisions.

Feeding behaviour is important to understand, particularly for artificially reared neonatal ruminants. At a young age, neonatal ruminants go through several transitions (environmental and nutritional) when learning is fast paced, and initial learning can be influenced leading to developments in their feeding behaviour patterns at an older age. Secondly, animals are very vulnerable when young. They must cope through these transitions when their behaviour plays an important role in their development (e.g., rumination and foraging). The inability to successfully transition onto solid feed or to express their natural behaviours can hinder their performance (Khan et al. 2016) and impair their welfare.

Milk feeding behaviour and development

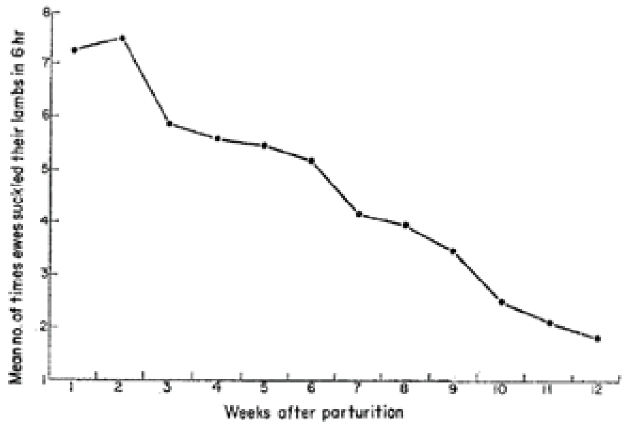
Artificial lamb-rearing systems are becoming more regularly utilised within the dairy sheep industry (Bimczok et al. 2005). These artificial rearing systems have similar aspects to the ways in which dairy calves are raised (management, dietary changes and transitions). Early methods of artificial-rearing systems allowed lambs to ingest sufficient colostrum intake (via the ewe or artificial source) (Large, 1965), then provide milk replacer with varying concentrations of milk solids (cows, ewe and synthetic milk replacers) (Cunningham et al. 1961), temperatures (Large and Penning, 1967) and different apparatuses e.g., buckets, buckets with teats, bottles with teats or milk bars (Cunningham et al. 1961; Kilgour and Dalton, 1983). These systems have developed and have become further intensified with semi- and/or automatic milk-feeding machines allocating milk replacer in restricted or *ad libitum* quantities (Emsem et al. 2003; Bimczok et al. 2005; David et al. 2014) with varying weaning methods (McKusick et al. 2001). Automatically recorded feeding behaviour has been used for indicating ill health in calves due to changes in their normal feeding patterns (e.g., lower intake), (Weary et al. 2009; Borderas et al. 2009a; reviewed by Rushen et al. 2012).

Lambs suckling behaviour is first influenced by an innate behaviour to locate and begin suckling and from teats as well as the assistance of the dam helping the lamb (Kilgour and Dalton, 1983). Lambs learn to suckle with the help from the dam within the first 12 hours of life and over the first few weeks, a strong motivation to suckle from the dam develops (Margerison et al. 2003). A circadian rhythm of feeding develops, with the largest meals occurring at dawn and dusk with smaller bouts throughout the day (Munro, 1956).

When lambs are removed from the dam and moved into a rearing system, they must quickly adjust to their new environment and learn to use the automatic milk-dispensing apparatuses, otherwise growth rates can become impaired or there is the potential for starvation (Dwyer, et al. 2003). Lambs should be carefully supervised until they are adequately suckling from an artificial teat. It can be difficult to teach each lamb to suckle with each individual lambs ability to suckle being different (Fraser, 1987). Lambs suckling artificial teats begin to express a similar pattern of feeding to that of lambs-at-foot once they have adjusted to the milk feeding apparatuses, allowing for their feeding behaviour to be monitored. The frequency of suckling bouts varies among lambs, the greatest number of suckling bouts occurring during the first three weeks, with a steady natural decline as lambs age (Figure 2).

Early observations of lambs suckling ewes by Ewbank, (1964) showed that, on average, single lambs had 30 suckling bouts per day during the first week of life, declining to 10 suckling bouts per day at 10 weeks of life, with twins suckling more frequently over the first four weeks.

Figure 2 Changes in suckling frequency as lambs age from weeks one to week twelve after parturition (Fletcher 1971).



The suckling frequency can vary for lambs depending on birth rank (singles, twins and triplets), with singles having a higher frequency than twins or triplets (Hess, 1974). Penning et al. (1973) reported that naturally suckling lambs suckled the ewe around 40 times per day.

Lambs reared artificially were reported to suckle 8 to 12 times per day when fed milk replacer *ad libitum via* artificial teats from an automated milk feeder (David et al. 2014). Bimczok et al. (2005) reported the effects of three types of feeding systems (milk replacer *ad libitum* (n=80), restricted milk replacer (n=65) using artificial teats for both, and bucket fed (n=60) on lamb's growth. The feeding behaviour of 'restricted' fed lambs resulted in increased MR quantities from 0.4 L a day at five days of age to 2.4 L a day at 35 days of age). The average number of visits per day to the feeder (suckling frequency) was 38.4, with 21% of these suckling bouts rewarded and 79% unrewarded. Rewarded suckling bouts are when lambs consume MR compared to an unrewarded bout during which little to no MR is consumed. The rewarded visits lasted significantly longer than the unrewarded visits (41.8 ± 53.28 *vs.* 33.6 ± 67.1 seconds). The milk suckling speed for restricted fed lambs was 289±83 ml/minute with an average intake of 129±118 ml per suckling bout (Bimczok et al., 2005). This has been observed in dairy calves restricted-fed (MR offered at 10% of body weight), they had more non-nutritive and non-rewarding suckling bouts and lower intakes of milk replacer than did dairy calves fed milk replacer *ad libitum* (Appleby et al. 2001; Jasper and Weary, 2002; Borderas et al. 2009a). The large number of unrewarded suckling bouts may be an indication of hunger (de Paula Vieira et al. 2008). Restricted-fed calves commonly consumed their allocated amount of milk within a quick timeframe (de Paula Vieira et al. 2008), while lambs and calves fed milk *ad libitum* are observed to consume large meals during several periods of the day and night (Jasper and Weary, 2002; David et al. 2014). The restricted feeding methods result in young ruminants that may experience hunger for prolonged periods of time compared to their *ad libitum* counterparts (Rosenberger et al. 2017).

The average calf has 4-10 suckling bouts per day depending on age (Lidfors and Jensen, 1988; de Passillé, 2001; Miller-Cushon and DeVries, 2015). In both calves and lambs, suckling frequency declines in association with the decline in milk production during lactation. Using Romane lambs, David, et al. (2014) investigated the feeding behaviour of artificially-reared lambs, considering their pattern of milk consumption, and the effects on feeding management between 5-28 days of age using automatic feeders with one teat for 8-15 lambs. There was a decrease in the number and duration of a suckling bout that lambs had per day over the trial along with an increase in milk ingested per meal showing lambs' milk consumption efficiency increases with age.

Van Welie et al. (2016) found no significant difference in mean suckling duration among singles, twins and triplets for both morning and afternoon behavioural recordings (36.3, 33.7 and 31.2 seconds in the morning *vs.* 65.9, 61.7 and 43.1 seconds in the afternoon). Lighter-born lambs usually have a poorer suckling drive compared to heavier-born lambs resulting in smaller meal sizes (Ewbank and Rogers, 1967; Hess, 1974). It has also been found, that calves have the largest meals in the morning when fed on automatic feeders (Appleby et al. 2001). During the first two to three weeks of life there is an increase in the duration of suckling when the lambs are having small meals in frequent bouts throughout the day. As they age and grow, they are able to ingest larger meals and reduce the frequency that they need to suckle. At the same time, the development of solid feed intake occurs and lambs begin to consume solid feed around 2-3 weeks of age (Munro, 1956; Khan et al. 2011a).

David et al. (2014), observed the feeding behaviour of female and male lambs between 4-28 days of age, with milk replacer *ad libitum*. Overall there was a sex, age, growth and behavioural difference over time affecting the lambs feeding behaviour. A total of 37529 unique visits were recorded to the automatic feeders from a total of 94 lambs, with an average of 399.24 unique visits to the feeder per lamb, and an average 17.34 visits per day. Of these visits 76% were rewarded with meals and 27% unrewarded. The average time spent at the teat suckling for unrewarded visits was lower than for rewarded visits (76 v. 159 s). Although females visited the teats more and initiated more meals per day than did male lambs, their milk intake was lower. Intake increased from 114 ml per meal on day 5 to 230 ml on day 28. The lambs were not observed to suckle preferentially at given periods during the day. This is in accordance with the findings of Borderas et al. (2009a) that showed that calves fed *ad libitum* distributed their visits to the feeder throughout the day.

For artificial rearing of lambs, further research should be conducted to evaluate the effects of stocking density on feeding patterns and rumination in large groups of lambs. While milk feeding has been demonstrated to be attainable with 15 lambs per automatic dispenser teat (David et al. 2014). If the lambs do not have sufficient space for each of them to consume solid feed at the same time, this may affect intake rates and growth.

Competition

Competition for milk consumption occurs in both natural and artificial-rearing systems. Triplet-bearing ewes have trouble feeding all three lambs leading to competition for suckling time and consumption with the more vigorous being the more dominant one(s) (Peterson et al. 2006). This can result in more unrewarded meals but is associated with earlier herbage intake (Peterson et al. 2006). Similarly, among artificially reared calves and lambs, restricted feeding methods of providing small quantities throughout the day, usually during the morning and then again at night, results in a high rate of unrewarded suckling bouts and lower live weights in comparison to milk replacer *ad libitum* (Jasper and Weary, 2002; Bimczok et al. 2005; De Paula Vieira et al. 2008). Feeding larger quantities of MR can result in greater growth rates and has been associated with better health and welfare status (Khan et al. 2007; Bach et al. 2013). Recent literature has shown that calves are now fed large quantities of milk rather than restricted feeding (de Passillé, 2011). With lambs reared artificially, it has been shown that 15 lambs per teat can be attainable (Bimczok et al. 2005), which is much higher ratio compared to dairy calves (von Keyserlingk et al. 2004). This difference may be due to the lower quantities consumed per suckling bout for lambs, and/or lambs have not been observed expressing non-nutritive suckling which is commonly seen in dairy calves (de Passillé, 2001).

Transitioning from liquid to solid feed

Promoting solid feed intake is important for the young ruminant's ability to successful transition onto a solely solid feed diet with sufficient rumen development (Norouzian et al. 2011). Under natural systems, young ruminants begin to graze pasture early in life as young as 3 days of age. Around three weeks of age they begin to consume noticeable quantities. In the presence of their dam, this behaviour is observed earlier, as the young mimic their dam (Phillips and Youssef, 2003). As lambs begin to graze, they spend only small periods of time grazing, but as they age, they increase grazing time (Munro, 1956; Owens, 1969; Joyce and Rattray, 1970; Peterson et al. 2006). As milk intake declines, and following weaning, lambs will spend up to 12 hours a day grazing (Dulphy, et al. 1982). Bechet et al. (1987) demonstrated that a decline in the provision of milk led to a greater amount of time spent grazing lambs-at-foot and lambs artificially reared.

Joyce and Rattray (1970) examined the intake of milk and grass by lambs from birth until weaning. Most lambs were observed eating herbage by the 3rd or 4th week of age which may have been influenced by the quantity of milk. Lambs artificially reared on low milk rations consumed more herbage then those with high milk rations. There was an increase in time spent grazing as lambs age (Joyce and Rattray, 1970; Peterson et al. 2006). All lambs were observed consuming herbage, by three weeks of age, with several low-milk-ration lambs consuming herbage in week two.

Penning et al. (1973) found that offering larger quantities of milk replacer (180 g/DM *vs.* 248 g/DM *vs.* 343 g/DM) to lambs was inversely related to a decrease in concentrate intake and was further lower when weaning age was considered. Penning and Gibb (1979) found that milk intake for lambs was negatively correlated with herbage intake and positively correlated with growth rate. Lambs within treatments grazed on pasture (P) had higher herbage intakes than lambs within the treatment that were fed cut and carry herbage *ad libitum*. Penning and Treacher (1975) reported that lambs that were reared with 180 g/DM of milk replacer and weaned at 21 days of age consumed more concentrate DM from day 1 to the slaughter date (at 40 kg live weight) compared to lambs with higher milk quantities (248 and 343g/DM) and later weaning dates (29 and 40 days). Concentrate intake was influenced by milk replacer intake, with lower concentrate intakes recorded for larger quantities of milk allocated. These results regarding reduced concentrate intake were also seen by Khan et al. (2011b) in calves.

Solid feed intake and the development of feeding behaviour

Estimates of grazing and feeding behaviour of sheep can be used as an important tool for both diet evaluation and animal health and can be used to inform ruminant feeding management to enhance productive performance (Gonyou, 1984; Vavra and Ganskopp, 1998). Among lambs, these behaviours can be influenced by the physical and nutritional characteristics of the feed

(Araújo Camilo et al., 2012; Simeonov et al., 2015), housing (Filho et al., 2014), diet choice (Filho et al., 2016), birth weight (Yildirim et al., 2013) and social interactions (Leme et al 2013).

Understanding how lamb feeding behaviour develops at an early age is important for promoting solid feed intake before weaning to reduce any potential problems during or after weaning. Changes in feeding behaviour occur in response to different diets, whether changes in pasture, forages or concentrates. Managing neonates during critical transitions of early life (weaning from the dam, milk weaning and environmental changes) can impact the development of feeding behaviour, particularly associated with solid feed (Khan et al. 2016). It is important to provide lambs with a diet that maximises energy and nutrient intake, while promoting rumination activity. There is a big research gap in the area of artificially reared lambs, we can use this limited information, as well as dairy calf literature to indicate how artificially reared dairy lambs feeding behaviour may develop.

The pre-ruminant period is critical as the learning and development of feeding behaviour evolves for neonatal ruminants. Arnold and Maller (1977) reported that early exposure to different foraging environments had effects on their preferences towards a certain feed when exposed to it early (before six months of age) compared to being fed it later in life. Early access to solid feed may help with the familiarity towards it once the young are weaned (Rosenberger et al. 2017). Foraging skills are developed and influenced by the type of feed offered. Flores et al. (1989) reported that lambs when offered either shrubs or grasses develop different prehension skills. When fed a differing diet (e.g., grasses over shrubs), the motor skills were 'jerky' compared to lambs that had previous experience of the feed. The development of preferences towards certain foods can occur in ruminants, and is associated with the positive ingestive feedback, while feed components such as toxins can provide negative feedback on intake (Provenza and Balph, 1987). A lamb's ability to develop diet selection can be stimulated by social interactions. Burritt and Provenza, (1991) were able to create a negative feedback towards a shrub for lambs given lithium chloride after consumption of the shrub. This resulted in fewer bites from day one to two and so forth, but when placed in a group of lambs that had no previous experience, they were observed to graze the shrub. As well as illustrating how preferences can be developed, this demonstrated that social facilitation can influence lamb's preferences and foraging habits (Scott et al. 1995).

Feeding behaviour of ruminants follows a diurnal pattern (Dulphy et al. 1980), and is characterised by several periods of grazing throughout the day, with the two longest periods occurring during dawn and before sun down (Dulphy et al. 1980; Simeonov et al. 2015). The rest of the feeding periods throughout the day are separated with bouts of rumination, resting and grooming (Dulphy et al. 1980; Broom and Fraser, 2007). Orr et al. (1997) reported differences in diurnal grazing patterns for sheep grazing either white clover or ryegrass during four periods of the day (7:30 am, 11:30 am, 15:30 pm and 19:30 pm) showing how the nutritional composition of feed can influence the feeding behaviours of sheep. Parsons et al. (1994) reported that sheep prefer clover in the morning, but this slowly changes towards ingesting more grass as the day goes on. Dulphy et al. (1980) reported that sheep spent 4-12 hours grazing a day, while dairy cows grazed 6-11 hours per day. The amount of grazing time depends on feed quality and availability (Rutter et al. 2002).

Following periods of grazing, ruminants will spend short bouts of time ruminating; previously consumed feed will be regurgitated, masticated, lubricated, reduced to smaller pieces for a greater surface area for fermentation by the microbial colony of the rumen Reid et al. 1981).

Grazing behaviour is allelomimetic; if others are performing the behaviour (grazing), this will influence others to performance of the same behaviour. Thus, if available, the lamb/calf will use its mother or pen mates as a model, to mimic the solid feeding behaviour (Phillips and Youssef, 2003). A young ruminant will begin mimicking its mother by mouthing and biting at pasture and, as it ages, will begin to ingest and consume larger quantities of pasture. De Paula Vieira et al. (2010) showed how paired-housed calves ingested solid feed earlier than did calves that were individually reared during the pre-weaning (milk feeding) period. Among lambs, individually reared lambs were reported to have a greater opportunity to feed adequately, but spent less time feeding, ruminating and chewing then those group housed (Filho et al. 2014). Penning et al. (1993) reported that differences in stocking rates from one sheep up to 15 in a group resulted in a greater time spent grazing compared to sheep within a group of lower stocking densities. Leme et al. (2013) reported that smaller group sizes (two lambs per pen) had a greater time spent feeding than larger group sizes (10 lambs per pen). Having adequate space allowance provides room for important activities (rumination and lying) which may improve the welfare of the lambs (Sevi et al. 2009).

While lambs have been observed to consume small quantities of solid feed during the first weeks of life, it is an insufficient quantity to provide energy to replace MR (Forbes, 1986). Peterson et al. (2006) observed that compensatory grazing behaviour occurred in triplets which would spend more time grazing than did twin-born lambs. This difference in grazing time is due to the non-linear association between milk production of ewes and their number of offspring. In contrast, Jochims et al. (2014), reported no significant difference between twin and single lambs-at-foot in time spent grazing (491 *vs.* 477 minutes per day, respectively). Grazing becomes more pronounced as lambs continue to age and weaning occurs. Joyce and Rattray (1970) noted that young lambs can utilise pastures at six weeks of age, but can suffer low liveweight gains when milk is removed. After removing milk, lambs increase their time spent grazing. Joyce and Rattray (1970) observed little to no difference in the initiation of solid feed intake (grazing of pasture) when lambs were raised with their dam, or when they were artificially reared with high or low milk intakes. Early weaning practices of lambs reared artificially have been successful when they are weaned onto good-quality pasture (Jagusch et al. 1970). Thus, pasture availability, physical and nutritional composition are important factors when it comes to feeding behaviour and performance of sheep, including lambs reared artificially. Pasture intake is correlated with sward height (cm), pasture mass (kg DM/ha), pre-and post-grazing masses (kg DM/ha) and pasture allowance (kg DM/head/day) (Cosgrove and Edwards, 2007).

Bite mass increases with sward height (Penning et al. 1994), and similarly, grazing time was negatively correlated with sward heights (Penning 1991) but results in a greater intake per minute and greater daily intake. Kenney and Black (1984) reported that caged sheep had preferences towards feeds that could be eaten faster than others. Black and Kenney (1984), reported how sward characteristics affects the grazing behaviour and intake of sheep, with higher sward heights and density pasture providing a greater time spent grazing, with a greater height of the sward resulting in greater grams per dry mater intake per minute of grazing and a greater intake per prehension bite (mg DM).

Arnold (1960) demonstrated how high stocking rates (24 *vs.* 12 sheep) resulted in greater grazing time, reduced rumination time and a negative liveweight change. Ruckebusch and Beuno (1978) observed the grazing time of cattle under restricted field sizes whereby smaller field allowances were associated with lower grazing time and more grazing occurring during the night. Different pasture species also affect the feeding behaviour of sheep (Penning et al. 1991). Sheep grazing white clover rather than perineal ryegrass have been observed to have greater intake rates, have greater bite mass, while having reduced grazing and rumination time (Table 1).

Table 1 The effects of herbage species white clover *vs.* ryegrass on grazing and rumination behaviour of lactating ewes with twin lambs (Penning et al. 1991).

	Clover	Ryegrass
Time spent grazing (minutes per day)	355	476
Time spent ruminating (minutes per day)	112	261
Number of grazing bouts per day	8.8	7.4
Number of ruminating bouts per day	6.2	10
Mean length of grazing bouts	38	68
Mean length of rumination bouts	16	26

Diet preferences

Sheep display preferences towards different feeds, but may be limited in consuming that feed due to environmental factors leading to a 'selection' of differing pastures or forages rather than a 'preference' (Rutter, 2010). Penning et al. (1995) reported that sheep have a preference towards white clover over ryegrasses, but select a mixed diet when given the opportunity. Similarly, sheep select different sward components, and have preferences towards leafy green pasture occurs over stems, dead and brown leafy material (Cosgrove and Edwards, 2007). Sheep actively consume a higher quality diet than that on offer by selecting greener and leafier patches that are higher in metabolisable energy than the dead material or stems. Thus, ruminants must spend energy deciding which feeding area they want to graze, and such selection is dependent on the type of pasture (Baumont et al. 2000). Penning et al. (1995) reported that sheep have preferences towards white clover over grasses, but when given an option of monocultures or both, they would select around 70% clover and 30% ryegrass (Rutter, 2010). The selection of a mixed diet may be a mechanism whereby ruminants are balancing the carbon (C) and nitrogen (N). Clover is higher in N than ryegrass and requires further energy to excrete the excess N (Rutter, 2010), leading to a diet selection involving multi-cultures rather than a monoculture. Simonov et al. (2015) reported the effects of feeding lambs with roughage and concentrate or just concentrate. Lambs without roughage compared to lambs with roughage consumed 10% more concentrate and had a shorter time spent eating (113.8 *vs.* 208.6 minutes spent feeding), and had fewer meals (28.7 *vs.*41.7) and rumination bouts (10.2 *vs.* 16.7). The lack of roughage lead to an increased intake of dry matter and a shorter rumination time due to the faster intake and digestion of the feed.

Rumen capacity and gut fill

The rumen capacity directly regulates the intake of ruminants due to the stretch- and mechano-receptors present in the stomach wall (Reid et al. 1977). Feed that is high in indigestible content takes longer to digest and can cause the rumen to fill (Baumont et al. 2000). This is known as 'gut fill' and reduces the intake of ruminants. Feeds affect intake through a model explained by Baumont et al. (2000), in which the nutritive value of a feed, the fill effect and sensory properties (taste, smell, touch; Arnold, 1966) effect the ability of a ruminant to ingest the feed. The physical and chemical signals regulate the motivation to continue eating, changing the intake duration (feeding time), size of meals, number of meals, and rumination activity. Feeds with low digestibility and high fibre (such as Lucerne hay), result in longer rumination time as the rumen becomes easily filled, while concentrate diets are more readily digestible, leading to lambs spending less time feeding and ruminating (Baumont et al. 1990).

Pasture *vs.* concentrates

Within pastoral systems in New Zealand, concentrates or grains help supplement animals when deficits in pasture cover, energy or crude protein occur (Kenyon and Webby, 2007). The provision of concentrate for lambs has been used in several large-scale sheep dairy farms to maximise early growth and to promote rumen development before weaning, allowing for early weaning (Jensen et al. 2017). Concentrates have been shown to reduce the time spent ruminating (Dulphy et al. 1980), compared to lambs fed forages such as grasses. Dairy calves weaned onto pasture with access to concentrates had less grazing and rumination time is less with greater quantity of concentrates (Vendramini et al. 2006). De Araújo Camilo et al. (2012) observed a change in feeding behaviour of Morada Nova lambs when metabolisable energy was increased in the diets. There was a reduced eating time and rumination time (hour per day) decreasing linearly as energy levels increased in the diet and as dry matter, organic matter, crude protein increased. Phillips, (2004) reported that dairy calves fed cut-and-carried pasture spent less time consuming concentrate when reared as groups and increased their rumination time compared to calves reared singularly. Calves having previous experience to grass inside spent more time grazing once outside when housed. Different ratios of forage to concentrate have been shown to affect the feeding behaviour of young ruminants (Khan et al. 2016), but little research has been done regarding this with lambs reared artificially.

Behaviour observations can be used for the evaluation of lamb performance (e.g., liveweight gains). Cardoso et al. (2017), found a positive correlation between time spent consuming feed and the time spent ruminating, and final body weight. In addition, there is greater variation in body weight per day for feedlot lambs on a concentrate diet without roughage. Similarly, in grazing heifers, Hasegawa and Hidari (2001) reported that reduced time spent grazing and ruminating was associated with lower average daily gains compared to heifers that were observed grazing and ruminating for longer.

Rumination

The breakdown of plant material is the main process of ruminant digestion which facilitates nutrient intake (Reid et al. 1977). Rumination is the regurgitation, re-mastication and the re-swallowing of slightly chewed and fermented plant matter which has come from the rumen and was previously ingested (Murphy et al. 1983; Hart, 1985; Gregorini et al. 2013). The rumen motility, facilitates the passage of digesta from the stomach further down the digestive tract (Dulphy et al. 1980; Bae et al. 1979). Unlike grazing, the dominant time for rumination occurs after midnight (Das et al. 1999), with shorter bouts of rumination occurring during the day time (Dulphy et al. 1980). Once feed is ingested, it is mixed and churned in the reticulo-rumen where microorganisms begin breaking down the feed into smaller particles around <1 mm diameter (Reid et al. 1977). Feed intake is influenced by rumen motility and small feed particles leaving the rumen stimulating further intake. The microbial colony within the stomach is vital in digesting in reducing particle size (Welch , 1982). Impairing rumination can result in lower intake (Welch, 1982), and may have welfare implications with respect to behavioural expression (Gregorini et al. 2013). The dry matter (DM) content within the rumen-reticulum changes following the ingestion of a meal as feed flows into the intestines. Large feed particles (>4 mm) are broken down after a meal, with the majority leaving the rumen at 1 mm in size around 19 hours after the initial meal occurred (Reid et al. 1979). The chewing that occurs during rumination is deliberate and is inversely related to the digestibility of the diet. Following the ingestion of feed, it takes around 20-24 hours for 95% of the feed to be completely ruminated (Reid et al. 1979). A difference in rumination time is observed when the diet is pelleted *vs.* grass. Waghorn and Reid (1983) reported that sheep spent a total of 40-50% their day feeding and ruminating when offered grasses or chaff compared to when sheep were fed a pelleted diet reducing the feeding and ruminating time to 25% of the day.

Play behaviour and social interactions of lambs

Play is a multifaceted behaviour that is observed in young neonatal animals (Jensen et al. 1998; Hass and Jenni, 1993). Play behaviour develops from an early age in ruminants and continues to develop with peaks of play behaviour occurring around 3-4 weeks of age, after which a slow decline to minimal events are observed at older ages. Low activity of play is still observed in lambs over the age of 12 weeks (Fagen, 1981; Hass and Jenni, 1993; Chapagain et al. 2014), but has also been observed in older ewes and rams, although it can be associated with sexual behaviour (Lynch et al. 1992).

The description of "play" for this literature review is adapted from the early definitions of Fagen (1981), play was defined as a category of behaviour given to certain locomotor, manipulative, and social behaviour characteristics of young lambs in relation to certain conditions and environments (Fagen, 1981). These behaviours may be continuous, a one off, done in groups or by a singular lamb, with slight variation occurring between each lamb. Play behaviour, like many other behaviours (e.g., Consumption of food or grooming) is believed to be associated with a state of happiness when the animal is in a positive affective state (Boissy et al. 2007).

There are several types of play behaviour that lambs express (Table 2). Lambs can interact with themselves (gambols, frolicking, digging, kicking) or with other lambs (gambols, mounting, head-butting). Lambs can be strongly attracted to other lambs (Geist, 1971), which may help in promoting play behaviour, particularly lambs that are reared artificially without a mother.

There is a sex difference in the expression of play, with males being more playful than females. Sachs and Harris (1978) observed a higher proportion of male lambs exhibiting mounting and head-butting behaviours while females were observed to gambol more than males. Similarly, Hass and Jenni (1993) observed male lambs expressing more playful bouts, which were more commonly mounts.

Table 2 A list and description of different play behaviours commonly expressed by lambs for observing and recording purposes. Adapted from Sachs and Harris (1978).

Play behaviour	Description of play behaviour
Gambols (frolicking/jumping)	Fast-paced jumping motions with the head and body of the lamb may twist in different directions during/before or after the jumping motion occurs. This can happen repeatedly or singularly with one to several lambs exhibiting the behaviour at once.
Running	The fast-paced movement of a single or multiple lamb(s) around the paddock or pen, can occur for several minutes with backwards and forwards motion.
Jumping	Either two or four legs lifting off the ground.
Mounting	More common in males (Sachs and Harris, 1978) mounting is when a lamb will jump up on the posterior area of another lamb and playfully mount. The mounted lamb will not usually stand still but move to remove the mounted lamb.
Head-butts	A lamb getting into a postured position putting its head down and paws at the ground before charging at another lamb and head butts the other, or when a lamb simply butts heads with another lamb without charging. Both can be reciprocal when both foreheads collide.
Digging/kicking	A lamb will stand still and kick or dig at the ground with one of the front legs, commonly occurs prior to the lamb lying down.

This may be due to the expression of play behaviours commonly associated with adult sexual behaviours during courtship, mating selection, interspecific competition, and arousal between males and females (Orgeur and Signoret, 1984; Lynch et al. 1992; Hass and Jenni, 1993). The development of these adult behaviours through play may help young lambs successfully develop into adulthood (Hass and Jenni, 1993).

Jensen et al. (1998) found that social interaction and space allowance affects play behaviour. Young calves that were group reared, in large pens (3.0 m by 5.4 m for four calves) exhibited a higher level of locomotor play compared to those in smaller pens (1.8 m by 3.0 m for four calves) and single-reared calves in pens (0.9 m by 1.5 m). Play behaviour is reduced after weaning, and is also influenced by the diet offered. Krachun et al. (2010) observed calves with high- and low-energy diets before and after weaning and reported that calves to be more active and playful prior to weaning in both diets, with calves fed smaller quantities of milk replacer (6 litres *vs.* 12 litres) less playful after weaning.

There has been little research into play behaviour of artificially reared lambs, while artificially reared calves have had extensive research. Play behaviour is an important factor for lambs reared artificially as it promotes social facilitation and greater social interactions than lambs that are reared by themselves, as well as reducing stress associated with the removal from the dam. It has been suggested that play behaviour may be an indicator of good welfare (Broekman, 2014). Zito et al. (1977) evaluated how different rearing environments can influence the development of social behaviour of lambs using lambs reared in a flock (F), lambs individually-reared with their dam (ID) and lambs artificially-reared in groups (GR) or individually (IR). Group-reared lambs were observed to be more playful and had a lower number of events of aggression towards unfamiliar lambs during an eight-week period. However, IR, F and ID lambs were apprehensive towards other lambs and didn’t begin playing with the newly introduced lamb until a couple of weeks after the expression of aggressive behaviours towards the outsider lamb (Zito et al. 1977).

The separation of lambs from the dams can be stressful for both the dam and lamb(s) as the mother-young bond is broken (Dwyer et al. 2003). Lambs that are reared in groups showed less distress than did lambs that were individually reared. A bond is created between the rearer (farm handler) and the lamb, a contrasting bond to that of the ewe and lamb (Rault et al. 2011). Thus, the distress of the lamb when removed from the mother can be reduced when a human positively interacts with the lamb, or when the lambs are grouped together (three or more).

Feeding behaviour can be affected by play behaviour. Simeonov et al. (2015) reported a negative correlation between standing and playing with time devoted to eating when lambs were fed meal with or without roughage before weaning. Time spent lying down was associated with increased time spent ruminating. The lambs time spent lying may have been associated with satiety.

Conclusion

As the sheep dairy industry grows in New Zealand, a greater number of farms will employ artificial-rearing systems for their lambs. The above discussion of literature highlights three main topics of this thesis around the artificial rearing of dairy lambs: 1) The importance of monitoring lamb health during the indoor period of artificial rearing operations and its relationship with welfare, 2) It reviews the changes from a liquid diet on to a pasture-only diet and how nutritional and environmental weaning transitions, as well as the nutritional and physical composition of feeds, can lead to differing developments in feeding behaviour and associated behaviours of lamb,. 3) the gap in the research around artificial rearing of dairy lambs in New Zealand.

In some of the current rearing systems, lambs are offered MR *ad libitum* and early access to a grain-based meal. This supports early weaning methods by accelerating rumen growth and development. There is the potential to replace early access to meal with early access to good-quality pasture to help reduce the high costs associated with artificial-rearing systems for dairy lambs. This created the leading objective of this study, which was to determine whether artificially reared dairy lambs in New Zealand could be weaned early on to good-quality pasture without previously being offered access to a grain-based meal. This lead to the development of two dietary treatment groups of lambs to evaluate the difference between lambs with (M lambs) or without early access to meal (NM), with both groups having access to MR and once outside, pasture.

Thus, this chapter has provided a basis for developing supplementary objectives around the leading objective of this study to focus on; 1) The development of feeding behaviour between lambs offered early access to meal *vs.* lambs without early access to meal as they transition from an indoor rearing system onto pasture and weaning onto solely pasture. 2) To monitor the milk intake behaviour of groups with or without meal access. 3) Report the health status and illness of young dairy lambs while they are reared intensively indoors for three weeks before being moved outdoors. The next chapters will focus on the study undertaken to evaluate these objectives.

Chapter Three: The behaviour of artificially reared dairy lambs with or without early access to meal

Introduction

The New Zealand sheep dairy industry is growing, currently, there are three large-scale operations and multiple small to medium-sized farms (Peterson and Prichard 2015). These large commercial sheep dairy farms remove lambs from their dams within the first four days of life and employ artificial-rearing methods. It is common to artificially rear lambs in Europe and America (McKusick et al. 2001; Bimczok et al. 2005; David et al. 2014), while, in New Zealand large scale artificial rearing methods are uncommon. Removing lambs early after birth is utilised to maximise milk production as 25% of total milk production that occurs within the first month of lactation (McKusick, et al. 2001). In some systems, lambs have access to milk replacer (MR) *ad libitum* and a grain-based solid feed (Bimczok et al. 2005). Compared to young ruminants fed a milk-only diet, early access to solid feed stimulates rumen development (Baldwin et al. 2004) and earlier onset of rumination (Khan et al. 2016) to allow early weaning off MR (Bimczok et al. 2005). Earlier rumen development through access to meal may also encourage earlier grazing of pasture and greater rumination, thereby supporting early weaning. The potential to replace meal with early pasture access as the sole solid feed source to support early weaning has not been evaluated.

Understanding how behaviours (e.g., rumination, grazing, and play) develop under different rearing systems is important to improve performance and welfare of lambs reared artificially. Behavioural observations can be a tool for diet evaluation and animal health monitoring of ruminant feeding management. In young lambs, feeding behaviour can be influenced by feed availability and nutritional characteristics (De Araújo Camilo et al. 2012; Simeonov et al. 2015), physical environment and housing (Filho et al. 2014), birth weight (Yildirim et al. 2013) and social interactions (Leme et al. 2013; Simeonov et al. 2015). The development of lamb feeding behaviour, especially in artificial-rearing systems, has received little attention compared to the feeding behaviour of dairy calves (Khan et al. 2015).

The aim of this study was to compare the behaviours (rumination, consumption of meal, consumption of wood shavings, grazing pasture, standing, lying, playing, suckling of milk, other oral behaviours, drinking water and aggressive behaviour) of lambs reared indoors over the first three weeks of life with or without meal, their transitions from indoors to outdoors onto pasture, and at weaning off MR and meal. Firstly, we hypothesised that while inside, lambs with early access to meal would initiate rumination earlier and, once outside, would spend more time grazing than lambs without access to meal. Secondly, lambs with access to meal would play less compared to lambs without access to meal, with both groups of lambs expressing little aggressive behaviour both inside and outside. Thirdly, lambs without access to meal would spend a greater time standing and consuming wood shavings while inside compared to lambs with meal access. Lastly, time spent grazing would gradually increase once moved onto pasture for both treatments as would rumination behaviour.

Methods and materials

All the procedures involving the lambs in this study including welfare, husbandry and experimental design were approved by the Animal Ethics Committee of AgResearch Grasslands, Palmerston North, New Zealand (AE #13945) under the New Zealand Animal Welfare Act, 1999.

Animals, experimental design and feed management

Sixty female East Friesian-cross ewe lambs were sourced from a commercial farm and removed from their dams at 2-3 days of age to help ensure adequate colostrum intake, and transported to the Ulyatt Reid Large Animal Facility at AgResearch Grasslands (Palmerston North, New Zealand). When lambs were collected at the farm they were separated into singles/twins (n=30) and triplets/quadruples (n=30). Due to farm management practices, it was not possible to distinguish birth ranks between singles and twins or between triplets and quadruples. On arrival, lambs were weighed and randomly allocated to one of two treatment groups; MR *ad libitum* without access to meal (no meal; NM; treatment group) or MR *ad libitum* and unrestricted access to meal from week 1 to week 9 (meal; M; control group). Lambs were identified using ear tags and spray paint with their allocated number. Both groups were balanced for initial live weight (M: 4.3±0.15 kg: NM 4.4±0.15 kg) and birth rank.

Lambs were numbered 1-60; M lambs were numbered 1-30 and spray painted red while NM lambs were numbered 31-60 and spray painted green. All lambs were provided with an adjustable microchipped collar (with their allocated number) while reared inside, which allowed individual access to the automatic milk feeders and recording of milk intake per feed and the time of each feed. Lambs were weighed once a week at the same time of day for the period of the study and are presented elsewhere (See, Jensen et al. 2017).

The study ran for 12 weeks, from 20th of August to 11th of November 2016 and was divided into four main periods based on feeding and management conditions, with behavioural observations recorded during each transition. The periods and transitions are outlined in table 5, illustrating the changes in diets and management conditions (transitions) during the trial.

In period 1, the lambs were housed indoors in groups (n=30/treatment) for three weeks with a pen size of 4.4 m by 7.2 m allowing sufficient room for each lamb to perform natural behaviours without being hindered. Un-treated kiln-dried pine wood shavings were used as bedding material (Figure 3), providing a clean, dry and absorbent material for urine and faeces. An extra layer of wood shavings was spread on top at the end of week two.

Figure 3 Pens containing lambs with access to meal (M, n=30) and lambs without access to meal (NM) with their collars for milk feeder identification, spray-painted sides for visual identification.

Milk replacer (mixed at 230 g/L; AnLamb, RD1 Ltd., New Zealand) was offered warm (37 °C) *ad libitum* via automatic feeders (CalfMOM ALMA Urban Feeder, PPP Industries, Tuakau, New Zealand) with one teat per pen with a head space of 12.5 cm per lamb.

The automatic feeder entrance to access the teat was designed to stop other lambs from pushing in and/or bumping the suckling lamb off, thus reducing potential competition for the teat. The automatic feeder was activated by each lamb's collar (CalfMOM ALMA Urban Feeder, PPP Industries, Tuakau, New Zealand) allowing for milk intake, time (hourly) and duration to be recorded for each individual lamb (Figure 4).

Figure 4 The automatic feeders with two entrances. Each entrance had one artificial teat and was for one of the two treatment groups; lambs with meal access (M, n=30) and lambs without meal access (NM).

In period 2, the lambs were randomly allocated to three cohorts per treatment group (n=10/cohort) and moved into paddocks at the beginning of week 4, with unrestricted access to good-quality pasture. The pasture was a mixture of white clover (*Trifolium repens*) and perennial ryegrass (*Lolium perenne*) with an allowance between <1700 kg DM/ha and 5000 kg DM/ha (Jensen et al. 2017). Pasture samples were taken during each period. The nutritional composition of the pasture changed over periods two to four and can be found in Table 3.

Milk replacer was provided fresh at room temperature twice daily (8 am and 4 pm) in each paddock *via* a cafeteria milk feeder with four teats (Figure 5). Meal was offered *ad libitum* to M lambs in troughs inside and outside. The meal consisted of soy, canola meal, maize, barley, molasses, vegetable oil, and lamb additive mineral mix (details not available in addition to chemical composition for publishing; TLC lamb meal, Gavin's Grain Ltd, Hamilton, New Zealand), and recorded daily by refusals. The composition of meal and pasture were evaluated using near-infrared spectroscopy (RJ Hill Labs, Hamilton, New Zealand).

Table 3 Composition of pasture grazed by lambs with meal access (M, n=30) and without meal access (NM, n=30) during the periods 2 (week 4-5) of milk, meal and pasture access (M lambs) or milk feeding and pasture access (NM lambs), period 3 (week 6-10) of meal and pasture access (M lambs) and pasture access (NM lambs), and period 4 (10-12) of pasture feed for both groups.

Nutritive component	Treatment group	Period 2	Period 2	Period 4
Dry matter (%)	M	17.1	16.7	16.9
	NM	17.1	16.4	15.1
ME (MJ/kg DM)	M	11.9	11.0	11.2
	NM	11.9	11.1	11.3
Crude protein (%)	M	22.7	21.5	15.5
	NM	25.2	21.6	20.6
Ash (%)	M	10.7	9.7	8.6
	NM	10.9	9.8	10.0
NDF (%)	M	41	41.1	43.2
	NM	38.8	43.5	37.9
ADF (%)	M	18.4	19.8	22.8
	NM	18.0	20.5	19.1

ME=Metabolisable energy; NDF=Neutral detergent fibre; ADF=Acid detergent fibre. *=as a percentage of DM. Composition was determined by NIR analysis (Nutrition Laboratory, Massey University, Palmerston North, New Zealand).

Figure 5 Lambs without access to meal (M, n=30) huddling around the milk feeder buckets with 4 artificial teats after fresh milk replacer was supplied at 8 am during the study.

While being reared inside, headspace per M lambs at the meal feeding trough was 26 cm (Figure 6) and outside 20 cm (Figure 7) allowing for adequate access for all lambs to consume meal at the same time. All lambs were abruptly weaned off MR at the beginning of week 6, to mirror commercial practice on the farm the animals were sourced from. Thereafter, all lambs had unrestricted access to pasture and M lambs had access to meal *ad libitum* until the beginning of week 9. In period 3, M lambs were gradually weaned over nine days by decreasing the quantity provided by 10% per day until completely weaned by the middle of week 10. In period 4 (week 10 to 12), all lambs had unrestricted access to pasture until the end of the trial. Lambs were rotated between paddocks, when pasture was observed to be <1700 kg/DM/ha. Water was provided *ad libitum* throughout the trial.

Figure 6 Plastic troughs filled with a grain-based meal for lambs with access to meal (M, n=30) while reared inside during the first 3 weeks of the study.

Figure 7 A shelter containing buckets filled with a grain-based meal for lambs with access to meal (M, n=30) during the outside part of the study.

Behavioural observations

All individual lamb behaviour measures were undertaken during the three transition phases; (1) indoor housing to outdoor and onto pasture transition between period 1 and 2 with observations during week 2, 3 and 5; (2) MR weaning transition between period 2 and 3 with observations during week 5 and 7; and (3) meal weaning transition (M lambs) to a pasture-only diet between period 3 and 4 with observations during week 7, 10 and 12. Each observation week was chosen to coincide with the occurrence of one of the listed transitions (Table 5). The behaviour-recording sheets had lamb identification (1-60) with a column for each behaviour. Two types of recording sheets were created; the first one was created while lambs were still inside. The second recording sheet was an updated version for when lambs were moved outside and allowed for recordings on a single piece of paper.

The behaviours recorded are listed and explained in Table 4. Several of the behaviours were only observed during one period (i.e. consumption of wood shavings, play, and aggressive behaviours) due to changes in environments (indoors to outdoors). Similarly, several behaviours (play, aggression and other oral behaviours) were not recorded as they occurred between each 10-minute interval. All behaviours selected were based on previous behaviour research in both lambs/sheep (David et al. 2014; Filho et al. 2014; 2016; Zito et al. 1977) and calves (Back et al. 2016; Overvest et al. 2016).

All behaviours were recorded by one observer (trained by M. A. Khan and S. McCoard), in consecutive 10-minute intervals for 2-4 hours per day over 2-3 consecutive days. Data were collated to give a total of nine hours of data (8 am to 5 pm) during each observation week (Table 5).

Each behaviour was recorded based on visual observation of either the presence or absence of a particular behavioural trait. Five-minute intervals for behavioural observations were originally planned but it wasn't possible for the observer to record the behaviours for each individual lamb.

During the test run of behaviour recordings, it was unachievable to record all sixty lambs individual behaviours, resulting in a change to 10-minute intervals. The behaviours being expressed changed regularly, resulting in many behaviours being expressed not being captured due to it falling between each 10-minute observation interval. This was common for behaviours such as consumption of wood shavings and drinking milk.

Table 4 Type, description and recording period of behaviours observed during the study. For lambs with access to meal (M, n=30) and without access to meal (NM, n=30). During period 1 (week 0-3) lambs were reared inside with milk and meal for M lambs and milk for NM lambs, periods 2 (week 4-5) of milk, meal and pasture access (M lambs) or milk feeding and pasture access (NM lambs), period 3 (week 6-10) of meal and pasture access (M lambs) and pasture access (NM lambs), and period 4 (10-12) of pasture feed for both groups.

Behaviour	Description	Recording period
Grazing pasture	Heads down, actively biting, chewing and ingesting pasture.	2 to 4
Rumination	The bottom jaw expressing a circular rigorous motion and regurgitation, either standing or lying down.	1 to 4
Suckling milk	Actively suckling on the artificial teats of either the automatic milk machine (inside) or the artificial teats on the cafeteria system (outside).	1 to 2
Consumption of meal	Head down in the meal trough, actively observed chewing and ingesting the meal.	1 to 3
Drinking water	Head down in the water trough, consuming water.	1 to 4
Consumption of wood shavings	Head down, actively chewing at the ground and ingesting wood shavings.	1
Standing	Lambs that are observed standing on all four feet.	1 to 4
Lying down/sitting	Belly firm on the ground, and or bum firm on the ground with front two legs standing.	1 to 4
Play behaviour	Lambs that are jumping around (frolicking) with themselves or other lambs. Digging at the ground (exploring). Running around by themselves or with other lambs. Scratching their head against fence posts. Rolling around.	1
Aggressive behaviour	Lambs actively charging at other individuals and head butting or kicking another lamb.	1
Other oral behaviours / exploratory behaviour	Suckling or chewing of the surrounding environment (fences, wires, plastic, troughs) or other lambs (navels, ears, noses, tails, hooves, wool).	1

Table 5 The periods and transition phases during the study for lambs with meal (M, n=30) and without meal access (NM, n=30). All lambs were allowed unrestricted access to all feeds during the study.

Periods and transition phases	Meal lambs (M) (n=30)	No-Meal lambs (NM) (n=30)
1 (week 0-3) Inside	Milk replacer and meal	Milk replacer
Transition 1 (Beginning of week 4)	*Moving from indoors to outside on pasture*	
2 (week 4-5) Outside	Milk replacer, meal and pasture	Milk replacer and pasture
Transition 2 (beginning of week 6)	*Abrupt weaning off milk replacer*	
3 (6-10) Outside	Meal and pasture	Pasture
Transition 3 (week 9-10)	*Gradual weaning off meal*	-
4 (week 10-12) outside	Pasture	Pasture

During the recording of behaviours inside, 15 minutes was allocated for the lambs to adapt to the observer's presence before the observations were recorded. Rotating around the outside of the pens without disturbing the lambs, their individual behaviours were recorded. Lambs were identified and behaviour expressed were marked down on a recording sheet with a '1'. Every consecutive 10-minute interval, all lambs were recorded to be either standing or lying, as well as their other behaviours (i.e., standing and playing).

Statistics

A repeated-measures ANOVA was used with a linear mixed effects model consisting of diet (NM *vs.* M) and observation week as fixed effects, lamb as random effect, and behavioural traits (listed above) as the response variables. Rumination, consumption of wood shavings and meal required a logarithmic transformation to allow satisfactory ANOVA assumptions, the rest of the behaviours (Figure 8) were not log transformed. The behaviours; drinking of water and aggressive behaviour were not analysed due to a lack of observations over the weeks of recording. All analyses were carried out using the R software (R Core Team, 2016).

Data are presented as the percentage (%) of time (out of the total 9 hours) the lambs in each group demonstrated the observed behaviour in each observation week.

Results

Rumination was observed in three and nine M lambs during weeks two and three, respectively, while rumination in NM lambs was first observed in week three (3 lambs). All lambs expressed play behaviour with a time-by-diet interaction (P<0.001), whereby from week two to three, M lambs decreased play events (190 *vs.* 127) and decreased the time spent playing (Table 6), while NM lambs increased play events (101 *vs.* 223) and increased the time spent playing (Table 6). Only 11 events of aggressive behaviour were observed during weeks two and three involving 10 lambs across both treatment groups. The number of events in which lambs were observed expressing other oral behaviours decreased from week two (43 *vs.* 59) to week 3 (19 *vs.* 36) in M and NM lambs, respectively. The time lambs observed were to express other oral behaviours was low in both groups (<3%) but decreased from week 2 to week 3 in both groups and was greater in NM compared to M lambs in both week 2 and 3 (Table 6) Play, aggressive and other oral behaviours were not observed once lambs were moved outside.

Table 6 Percentage (%) of time lambs were observed expressing other oral behaviours (suckling or chewing objects other than the automatic-feeder teat), consuming wood shavings, and playing for lambs with meal access (M, n=30) and without meal access (NM, n=30), during weeks 2 and 3, and the significance of differences.

	Percentage (%) of total time observed						
	Week 2		Week 3		p values		
Behaviour	M	NM	M	NM	Diet	Week	Diet x Week
Other oral behaviours	2	3	1	2	0.014	0.001	0.685
Consuming wood shavings	2	3	1	5	<0.001	0.306	0.001
Play	12	7	6	12	0.165	0.746	<0.001

There was a time-by-diet interaction for observations of consumption of wood shavings (P<0.001), whereby during week three NM lambs spent more time consuming wood shavings than M lambs (Table 6). For M lambs, the time spent consuming meal increased with advancing age (P<0.001) and time spent consuming meal increased from week two to three. From week three to five, there was a decrease in time spent consuming meal, followed by an increase during week seven (Table 7).

Table 7 The effect of time (week) on the average percentage (%) of time spent consuming meal for lambs with meal access (M, n=30) during weeks 2, 3, 5, and 7 of the study.

Percentage (%) of total time observed					p value
	Week 2	Week 3	Week 5	Week 7	Week
M	9	14	6	14	<0.001

There was little evidence of a time-by-diet interaction for time spent consuming milk (P>0.05) during weeks two, three and five (Table 8). Similarly, there was no difference between M and NM lambs (P>0.05). However, there was an interaction between weeks (P<0.001), whereby lambs had little change between week two to three (1.70 % *vs.* 1.00 %), with a large increase in time spent consuming milk during week five (6.82%).

Table 8 Percentage (%) of time lambs in each treatment (n=30/group) were observed consuming milk during the nine-hour observation period (8 am to 5 pm) during week 2, 3 and 5 and the p values. The two treatment groups were; lambs with meal access (M) and without meal access(NM).

Percentage (%) of total time observed				p values
	Week 2	Week 3	Week 5	Diet x week
M	1.76	1.03	7.15	>0.05
NM	1.64	0.97	6.48	

There was a time-by-diet interaction for rumination (P<0.001), whereby during week five, NM lambs spent less time ruminating than M lambs (5% *vs.* 8%), but by week twelve, NM lambs spent more time ruminating than M lambs (26% *vs.* 17%), (Figure 8). There was no difference in rumination between groups at weeks seven and ten.

There was a time-by-diet interaction for grazing pasture (P<0.001) whereby NM lambs spent more time grazing than M lambs, during weeks five (36% *vs.* 32%), seven (72% *vs.* 39%) and twelve (68% *vs.* 60%) (Figure 9). The grazing time for NM lambs increased from week five to seven and remained constant to week twelve. In contrast, there was only a small increase in grazing time of M lambs from week five to seven (32% to 39%) which was associated with increased meal intake (130 g/day to 610 g/day), and an increase in time spent consuming meal (8% to 15%), with a later increase in grazing from weeks seven to ten (39% to 73%). In both NM and M lambs, grazing decreased from week ten to twelve (73% to 68%, and 73% to 60% respectively).

There was a time-by-diet interaction for standing behaviour (P<0.001). While lambs were inside, NM lambs increased their time spent lying from week two to three while M lambs increased standing time (Figure 10). Once outside NM lambs spent more time during week seven standing compared to M lambs (72% *vs.* 57%), while during week five, ten and twelve, there was no difference in time spent standing. The inverse of standing was time spent lying whereby a time-by-diet interaction occurred (P<0.001) (Figure 11).

Figure 8 Percentage (%) of time lambs in each treatment (n=30/group) were observed to ruminate during the nine-hour observation period (8 am to 5 pm) during weeks 3, 5, 7, 10 and 12, respectively. The two treatments groups were; lambs without meal access (NM) ●— and lambs with meal access (M) ▲---. Transition 1 (T1); moving from inside to outside, transition 2 (T2), abrupt weaning off MR, transition 3 (T3), gradual weaning off meal (M lambs only). Significance; P<0.001 = **.

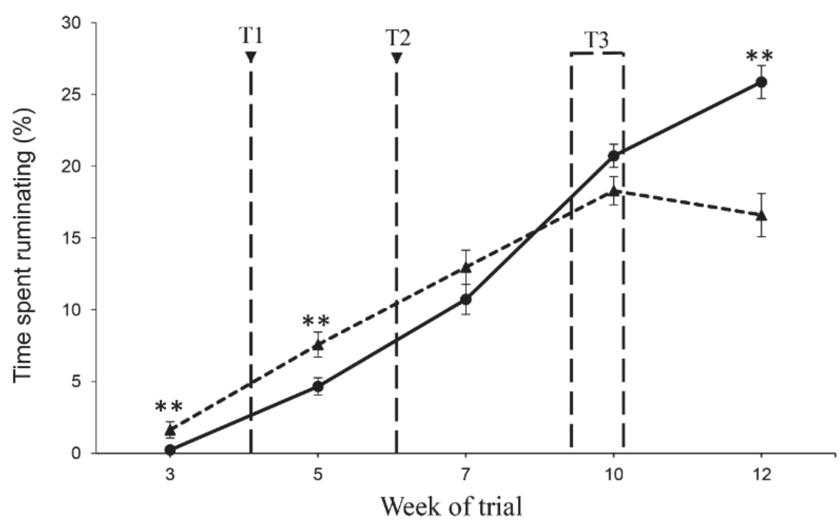


Figure 9 Percentage (%) of time lambs in each treatment group (n=30/group) were observed to graze pasture during the nine-hour observation period (8 am to 5 pm) during weeks 5, 7, 10 and 12, respectively. The two treatments groups were; lambs without meal access (NM) ●— and lambs with meal access (M) ▲---. Transition 2 (T2), abrupt weaning off MR, transition 3 (T3), gradual weaning off meal (M lambs only). Significance; P<0.001 = **, P<0.05 = *.

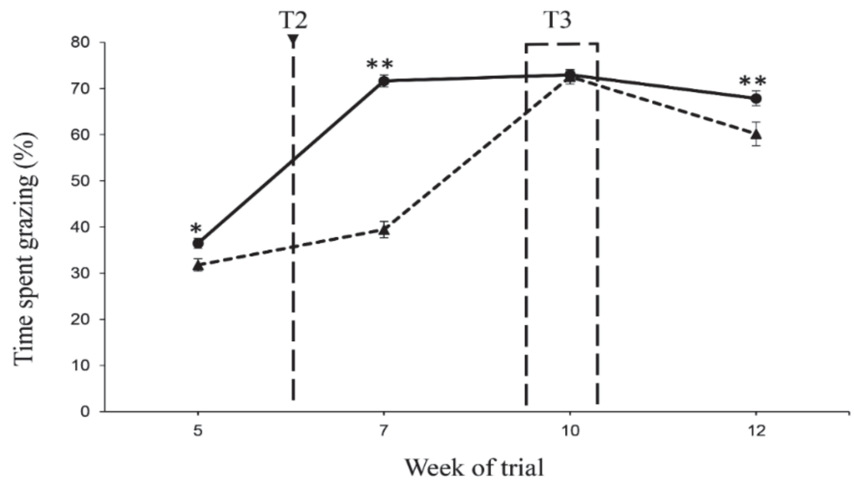


Figure 10 Percentage (%) of time lambs in each treatment group (n=30/group) were observed to stand during the nine-hour observation period (8 am to 5 pm) during weeks 2, 3 ,5 ,7 ,10 and 12, respectively. The two treatments groups were; lambs without meal access (NM) ●— and lambs with meal access (M) ▲---. Significance; P<0.001 = **, P<0.05 = *.

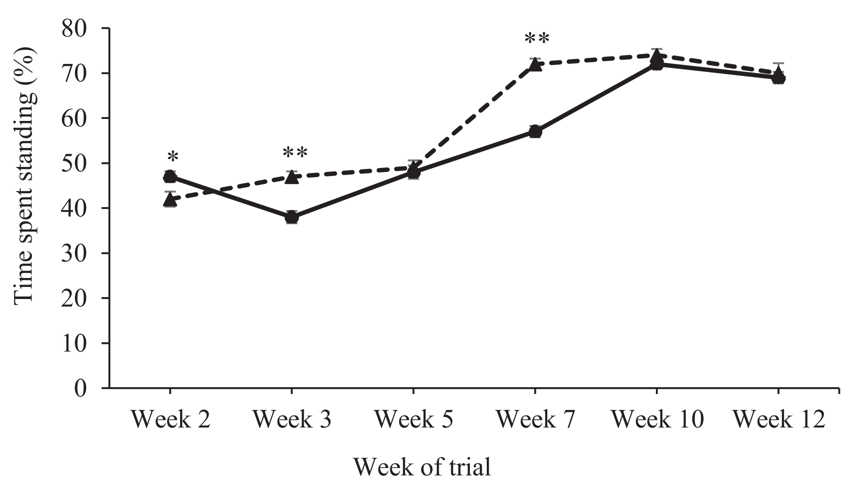
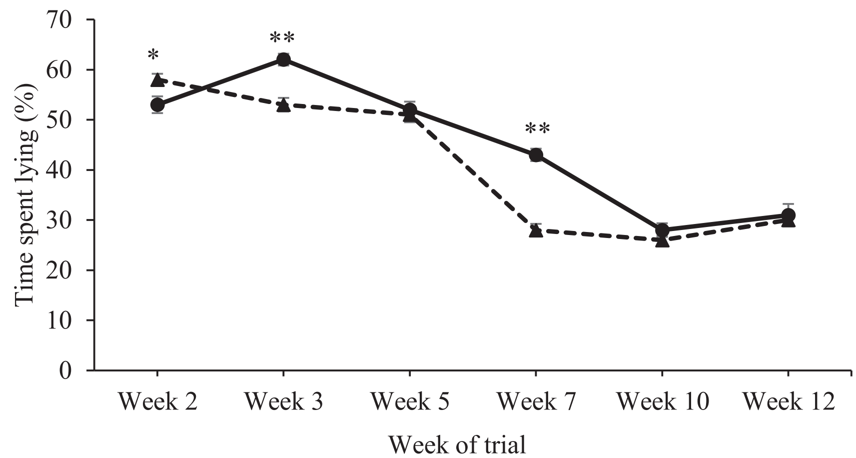


Figure 11 Percentage (%) of time lambs in each treatment group (n=30/group) were observed to lie during the nine-hour observation period (8 am to 5 pm) during weeks 2, 3 ,5 ,7 ,10 and 12, respectively. The two treatments groups were; lambs without meal access (NM) ●—and lambs with meal access (M) ▲---. Significance; P<0.001 = **, P<0.05 = *.



Discussion and conclusions

The objective of this study was to the compare the development of behaviours associated with dietary (introduction to pasture and weaning off MR and meal) and environmental (movement from indoors to outdoor) transitions of lambs reared artificially with or without early access to meal. The key findings were, lambs provided with early access to meal initiated rumination earlier while lambs not offered meal once given access to pasture spent more time grazing and had more consistent grazing behaviour up to 12 weeks of age.

Initiation of solid-feed intake triggers rumination (Baldwin et al. 2004), which occurs around ten days of age. By two to three weeks of age lambs can be observed ruminating (Stephens and Baldwin 1971; Kilgour and Dalton, 1983). The drive to ingest solid feed increases with age, even with access to large quantities of milk (Khan et al. 2011). In this study, early consumption of meal enabled M lambs to begin ruminating by two weeks of age. Rumination behaviour was observed by three weeks in NM lambs receiving no solid feed. This likely resulted from the consumption of wood shavings, which in the absence of solid feed, would help stimulate rumination (Khan et al. 2011). Both groups were observed to actively consume wood shavings. This finding is consistent with the notion that young ruminants actively seek out a fibre source (Khan et al. 2016), suggesting that the absence of a dietary fibre source triggered ingestion of wood shavings in the current study. Previous literature in dairy calves found that wood shavings stimulated rumination and a small amount of rumen development, but was not substantial for adequate rumen development (Smith, 1960). Smith (1960) noted that calves fed exclusively on milk were observed to have a ‘considerable appetite’ towards wood shavings, which was similar to lambs during this study.

Simeonov et al. (2015) found lambs deprived of roughage spent more time standing and playing compared to lambs with roughage in their diet. Similar observations were evident in this study, as lambs without access to meal spent less time lying but more time consuming wood shavings and playing during week three. These behaviours were consistent with the notion that young ruminants start looking for solid feed and, if not available, they crave for it (Forbes, 2007). Margerison et al. (2003) reported that calves that begin consuming concentrate or hay and ruminating by the three weeks of age, had reduced non-nutritive oral behaviours. A similar result was seen in the current study as both M and NM lambs spent less time performing other oral behaviours.

The shorter duration spent lying by NM lambs could have led to more engaging activities such as social interaction and play. Once outside, both groups were not observed to express other oral behaviours. This may have been potentially due to the new environment (pasture) being more natural than the indoor environment (Phillips, 2004). Play behaviour of lamb’s peaks at around 3-4 weeks of age, and slowly declines soon after (Hass and Jenni, 1993). Less time was spent on play by lambs in both outdoors groups compared to indoor. This may be due to changes in the environment, diurnal play patterns (outside the observation period) and or an age effect. Aggressive behaviours have regularly been classified as a type of play behaviour (Fagan, 1981; Chapagain et al. 2014) and is less common in female than male lambs (Sachs and Harris, 1978), which may explain the low observations of aggression between lambs due to all lambs in the study being female.

Diet selection and feeding behaviour of ruminants is influenced by both the nutritional and physical characteristics of the diet (Miller-Cushon and DeVries, 2015). Grazing time in both groups was initially low indicating a preference towards MR and/or an adaptation to a new environment and diet source. The time spent consuming milk was higher when lambs were moved outside, which may have been due to the change in feeding dispenser which allowed four lambs to suckle at a time and a greater intake of MR as lambs aged. The increase in time spent grazing by NM compared to M lambs was consistent with pasture being the only source of solid feed available. The preference for meal consumption by M lambs was highlighted by the small increase in time spent grazing pasture and an increase in time spent consuming meal in this group following MR weaning. This transition was associated with increased meal intake, compared to the dramatic increase in grazing time in NM lambs from weeks 5 to 7. A preference by M lambs toward meal compared to pasture could be ascribed to a higher energy density of the meal compared to pasture (De Araújo Camilo et al. 2012) and lamb's previous experience eating meal (Miller-Cushon and DeVries, 2011). The results of this study are consistent with observations in calves (Vendramini et al. 2006) in which both grazing and rumination time were negatively correlated with greater concentrate allowance. While there is the potential to overestimate or underestimate some social behaviours when animals are in groups and the data recording interval is 10-minutes, every attempt to standardise the groups (age, weight, sex) were attempted to minimise the impact.

This study indicates that M lambs' ability to transition to pasture was hampered by their preference for meal. When meal was removed, their time spent grazing decreased with a concomitant decrease in time spent ruminating compared to NM lambs, which in turn, exhibited a sharp increase in the time spent grazing. These results indicated that a smoother transition onto pasture. These differences may be due to the inability of M lambs to ingest and utilise pasture to fulfil their nutrient requirements (Brandano et al. 2004). In addition, it may reflect a stress response to the change in diet, or a diurnal change in grazing behaviour not captured in the nine-hour observation period employed in this study. Although meal inclusion was associated with early rumination, the transition off meal was related with lower grazing. The impact of the treatment regimens on intake and growth performance is detailed by Jensen et al. (2017). Furthermore, early unrestricted access to good-quality pasture did not adversely affect the establishment of rumination in lambs provided access to MR *ad libitum*. This may provide an alternative feeding management system for lamb-rearing operations.

Chapter four: Milk-feeding behaviour and health of dairy lambs reared indoors for the first three weeks of life

Introduction

The expansion of the sheep dairy industry in New Zealand has been driven by overseas markets and the demand for alternative healthier food options (Peterson and Prichard, 2016; C. Pritchard, personal communication, 2017). Continued growth will likely result in a greater number of large scale operations which will employ artificial lamb-rearing methods. Unlike conventional sheep farms, dairy sheep lambs are removed from their dam at 2-4 days of age allowing sufficient time for adequate colostrum intake, and are then moved into large sheds where they are reared in pens of 10 to 25 lambs (depending on pen size). Generally lambs are then offered milk replacer (MR) and a starter meal *ad libitum* for the first three weeks of life before being moved onto pasture and weaned off both MR and meal.

Neonatal lambs are vulnerable to starvation and hypothermia (Stafford, 2013) and when removed from the dam, they must be reared at a high standard to ensure their welfare is not compromised (Sevi et al. 2009). It has been reported that artificially reared lambs can have lower immune function (Napolitano et al. 1995; Napolitano et al. 2003), express abnormal suckling behaviour (inter-suckling) (Wood et al. 1967; Stephen and Baldwin, 1971; Kilgour and Dalton, 1984; Houpt, 1987; Napolitano et al. 2008), consume bedding material (Karaagac et al. 2004) and can have a high incidence of health problems, such as scours, bloat and respiratory infections (Bull and Binnie, 2006; Gonzalez et al. 2016; Dwyer et al. 2015). Health problems can lead to morbidity and mortality reducing the performance and profit of the farming system (Emsen et al. 2004) and thus have negative effects on their welfare (Stafford, 2013). The survival of lambs is crucial for profitability, supply of future replacement ewes and sires to the dairy flock and for the sale of surplus lambs for meat production.

Recent methods of artificially rearing systems for lambs have used automatic milk dispensing machines (David et al. 2014; Bimczok et al. 2005) that can be modified to offer different levels of MR (restricted *vs. ad libitum*) and are comparable to the methods of rearing dairy calves (Hepola, 2003; Roth et al. 2009; Rosenberger et al. 2017). Lambs must be trained to suck from the artificial teats with their survival dependent on transitioning correctly (Sevi et al. 1996). The time taken to teach each lamb to suck the artitficial teats differs and can be influenced by the type of teat used (Fraser, 1987). Using automatic milk dispensers allows large groups of lambs to be reared together with greater MR intake (Bimczok et al. 2005; David et al. 2014). It enables the milk feeding behaviour to be captured (without visual observation) and utilised for understanding the development of milk feeding behaviour (David et al. 2014), lamb performance (Bimczok et al. 2005) and can help with improved management and feeding regimens. Further, understanding the milk feeding behaviour of lambs during the early weeks of their life on automatic feeding machines can be utilised to determine future management decisions and may help to improve lamb performance and welfare in New Zealand sheep dairy farms. It has been suggested that the use of milk feeding behaviour may have the potential to be used to understand the relationship between behaviour and the number of days with illness (Weary, et al. 2009; Johnston et al. 2016; Rosenberger, 2017; Knauer et al. 2017) allowing for improved and faster methods of detection.

The aim of this study was to monitor the milk-feeding behaviour and health of artificially reared dairy lambs with or without early access to meal while being reared indoors over the first three weeks (23 days) of the study described in chapter three. Firstly, we hypothesised that both groups of lambs would have similar milk-feeding behaviour (number of rewarded meals, intake per meal and intake per day), as solid feed is only consumed in small quantities during the first two to three weeks of life. There was the opportunity to capture the qualitative data on the health of the lambs of each group to explore the potential difference in response to dietary regimes. We hypothesised that there would be no difference in health issues between either lambs with or without meal access.

Methods and materials

Milk feeding behaviour

The experimental design has been previously described in the methods of chapter three. In short sixty lambs were allocated to either one of two diets; early access to meal (M) or no early access to meal (NM). All lambs were recorded indoors for the first 23 days of the study. The milk-feeding behaviour of lambs was recorded hourly via the automatic milk dispensing machine, 24/7 from day 0 to day 23 (CalfMOM ALMA Urban Feeder, PPP Industries, Tuakau, New Zealand). The behaviours recorded by the automatic milk dispenser are listed in Table 9.

Manipulating milk machine data

The milk-feeding data recorded from the CalfMOM had to be manipulated and transformed before statistical analysis was possible. Firstly, the 552 individual hourly output sheets of milk feeding behaviour were imported into Microsoft Excel (2016). The data titles were converted from German into English. Each hour the cumulative milk intake was recorded. The hourly output sheet within Excel consisted of each individual lamb's milk feeding behaviour repeating 60 times continuously. This was reduced and only the first line of data for each individual lamb was used for analysis. There were several extra columns of data (e.g., maximum and minimum quantity of MR allocated) which were unimportant for data analysis, therefore deleted. Following the clean-up of the data, all 552 excel sheets of milk feeding behaviour data were cut and pasted into a single excel spreadsheet using Excel Macro programming. With all the data within one Excel spreadsheet, consumptions per hour were calculated (total consumption X hour – previous hour X; Example [1276 ml – 1132 ml = 144 ml intake for hour X]). Total unrewarded meals per day were calculated for each individual lamb daily by adding up all the unrewarded meals per hour for each day. With the total intakes per hour, unrewarded meals, using R software, the average MR per meal (hour), total MR intake per hour, daily rewarded meals and unrewarded meals could be calculated and used for statistical analysis. Unfortunately, the automatic milk dispensing machine was configured to record meals below 100 ml as unrewarded and not 0 ml, therefore, an accurate number of unrewarded meals was unable to be calculated.

Problems can arise using automatic milk feeders, they are costly and need to be cleaned regularly to reduce spread of illnesses and are prone to malfunction, as was the case in this study on two separate days. There were two peaks and troughs in the milk-feeding behaviour (total milk intake per day, average intake per meal, average number of rewarded and unrewarded meals) during days three and seven, which has been attributed to the automatic milk dispenser turning off during the night unexpectedly, resulting in lambs unable to consume the MR they would have and skewing the data on those days. Another peak on day fourteen was not associated with the machines turning off or any other known cause.

Health

For the first 23 days of the study, all lambs had their health monitored twice daily (8 am and 4 pm). Health score sheets were created and computed at each monitoring period by a trained person.

Table 9 Milk-feeding behaviours recorded hourly from an automatic milk feeder.

Milk-feeding behaviour	Observations
MR intake per suckling bout (meal)	The average intake per suckling bout was recorded hourly.
Total MR intake per day	Total milk intake per day per lamb.
Rewarded suckling bout (meal) frequency	Total number of suckling bouts that occurred daily that were 1 ml or above in consumption.

Table 10 Potential health complications and clinical signs for lambs reared artificially inside for 23 days.

Potential health complications	Clinical signs
Lameness	Walking is impaired, lamb(s) are observed walking unnaturally, or not walking at all. Mitigating pressure from one or more limbs.
Eye infection (Pink eye)	Gunky and/or crustiness (white to green consistency) around the eyes/eyelids. Eyes not open properly and/or not open at all. Red eye.
Inverted eyelids	Inside of the eyelids are rolled in towards the eye(s).
Navel injuries	Signs of inflammation/swelling around the navel region. Signs of discharge (blood and/or pus).
Scours/diarrhoea	Faeces runny/watery consistency, light / yellow/ brown to dark brown/black in colour. Hunched back (poor posture). Blood in the faeces.
Bloat (Abomasal)	Lamb belly (abdominal area) looks larger than normal, awkward posture when standing, and lying on their side. Respiratory distress, mouth breathing.
Respiratory problems (Pneumonia)	Lambs coughing, sneezing and having difficulty breathing properly. The nose is checked for any abnormal serous or fluid discharge. Low rectal temperature. Potential cases were handled by veterinary services that checked for abnormal 'popping' or 'crackling' sounds from within the lungs, then diagnosed and treated.

Health checks consisted of inspecting each individual lamb by picking it up and visually examining their eyes, mouth, navel, rectum and feet, for any potential health issues (Table 10). Each potential health issue was individually recorded on the visual observation of either presence or absence. Data are presented as the number of lambs observed with recorded health issues over the 23-day period and the number of lambs observed with health problems per week (1, 2 and 3). If any serious health issues were observed, veterinary services were called to assist. Lambs with eye infections were treated with Orbenin eye ointment (Pfizer, New Zealand) and lambs with pneumonia were treated with Metacam and Bivatop (Boehringer Ingelheim, New Zealand).

Statistics

A repeated measure ANOVA was used with a linear mixed effects model consisting of diet (NM *vs.* M) and observation day as fixed effects, lamb as random effect and response variables; rewarded and unrewarded suckling bout frequency, intake per suckling bout and total milk intake per day. All analysis was carried out using the R software (R Core Team 2016). The milk-feeding data from day one to day twenty-two was used in the analysis, as on day twenty-three the lambs were moved outside skewing the data.

Results

Milk-feeding behaviour

The six most common times of day that lambs consumed milk were at 12 am, 7 am, 9 am, 5 pm, 7 pm and 8 pm. In total, there were 11649 rewarded meals, 6186 rewarded meals for M lambs and 5464 rewarded meals for NM lambs. There was a diet effect whereby the milk feeding behaviour traits (average number of rewarded meals and the average intake of MR per rewarded meal) were greater for M lambs than NM lambs. On average M lambs had 9.2rewarded meals and consumed 228.8 ml per rewarded meal compared to NM lambs of 8.2 rewarded meals and 205.4 ml per rewarded meal. There was no diet effect between M and NM lambs for the average total MR intake per day (Table 11).

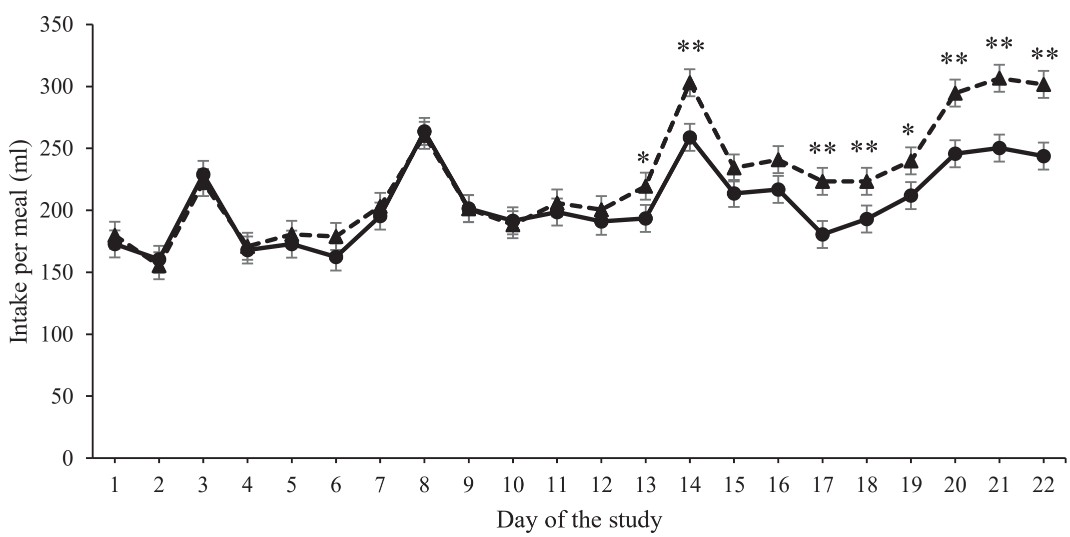
There was a diet-by-day interaction for the average intake of MR per rewarded meal ($P<0.001$), whereby both M and NM lambs consumed similar quantities per meal in the first 12 days, after a divergence in intake from day 13 onwards between groups occurred such that M lambs consumed more per meal than NM lambs with days 14 and 15 being non-significant (Figure 12).

Table 11 The analysis of diet effect and diet-by-day interaction for the milk feeding behaviour traits; average number of rewarded meals, average MR intake per meal and average total MR intake per day, standard errors and significance for lambs with meal access (M, n=30) and lambs without meal access (NM, n=30).

		Average number of rewarded meals	Average MR intake per meal	Average total MR intake per day
Diet	M	9.2 ± 0.30	228.8 ± 6.08	2133.2 ± 63.21
	NM	8.2 ± 0.30	205.4 ± 6.08	1973.2 ± 63.21
P values	Diet	0.0175	0.0118	0.0786
	Diet * Day	<0.001	<0.001	<0.001

A diet-by-day interaction was observed for the average total consumption of MR per day (P<0.001), whereby M lambs had a greater total intake of MR on days 13, 14, and 16 to 22, while each other day there was no significant difference between diets. A gradual increase in consumption of MR was observed over time (Figure 13).

Figure 12 The diet-by-day interaction for the average milk replacer intake per meal each day for lambs with access to meal (M; ▲- - -, n=30) and without early access to meal (NM; ●—, =30) over 22 days of the study when lambs were being reared inside. Significance; P<0.001 = **, P<0.05 = *.



There was a diet-by-day interaction for the average number of rewarded meals (P<0.001), with a minimum of one meal a day, and a maximum of nineteen. During day one, M lambs on average had seven meals while NM lambs had 5.9 meals. By day 22 there was little difference between M and NM lambs (8.1 meals *vs.* 7.5 meals, respectively). Overall there was a greater number of meals consumed by M lambs compared to NM lambs during days 1, 2, 4, 5, 7, 9, 10, 13, 15 and 16 (Figure 14).

Figure 13 The diet-by-day interaction for the average total consumption of milk replacer each day for lambs with access to meal (M; ▲---, n=30) and without early access to meal (NM; ●—, n=30) over 22 days of the study when lambs were being reared inside. Significance; P<0.001 = **, P<0.05 = *.

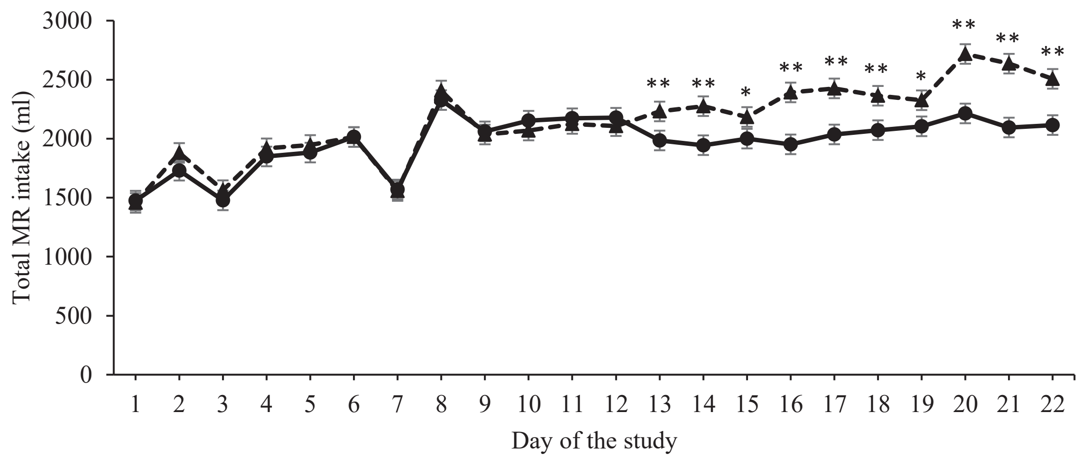
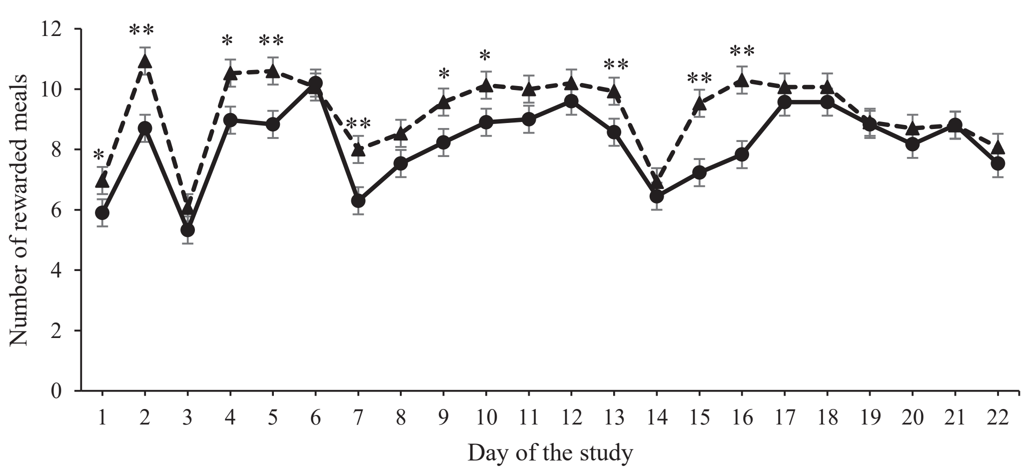


Figure 14 The diet-by-day interaction for the average number of rewarded meals per day for lambs with access to meal (M; ▲---, n=30) and without early access to meal (NM; ●—, n=30) over 22 days of the study when lambs were being reared inside. Significance; P<0.001 = **, P<0.05 = *.

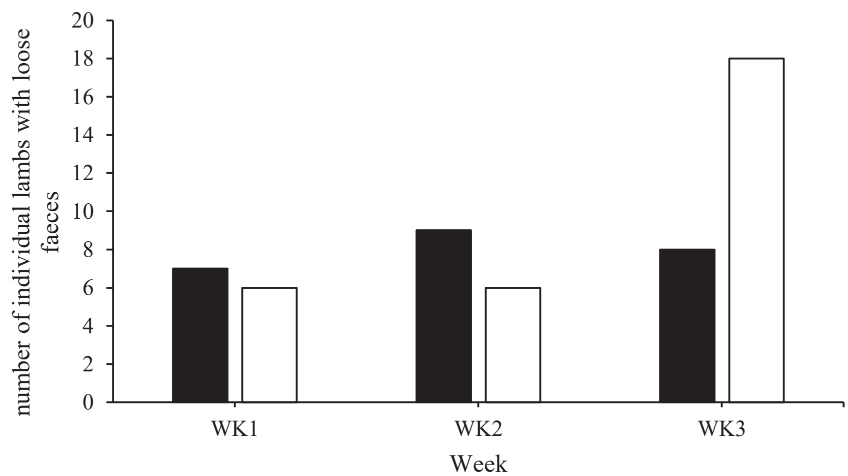


Health

No mortalities occurred during the study for either M or NM lambs. No lambs were observed with scours but there were some loose faeces which were not considered severe enough for treatment as lambs showed no signs of depression of appetite or dehydration, fever or blood in their faeces. All lambs were monitored closely to ensure they maintained a good level of health. Lambs were also observed to have pink eye, navel infections and pneumonia, while lameness and bloat were not observed. One lamb was diagnosed with pneumonia during the second week of the study and recovered after treatments.

The number of M lambs with loose faeces remained constant from week to week, with 7, 9 and 8 individual lambs during week one, two, and three, respectively. The number of NM lambs with loose faeces, respectively (Figure 15). During week 3, NM lambs had the highest number of lambs with loose faeces, while for M lambs it was week 2 (Figure 15).

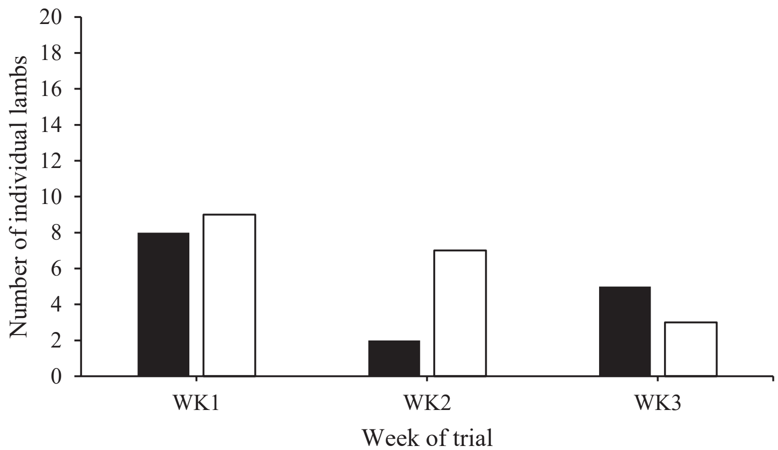
Figure 15 The number of lambs offered meal (M; ■, n=30) or no meal (NM; □, n=30) that had loose faeces during week one, two and three of the study when lambs were being reared inside.



Both M and NM lambs were observed to have pink eye during the study period. The number of lambs with pink eye diminished from week one to three (Figure 16). Week one had the highest number of lambs with pink eye for both M and NM lambs (Figure 16). Week three had the lowest total number of lambs with pink eye.

A small number of lambs were observed to have navel illness with signs of inflammation and blood. During week 1, two M lambs and one NM lamb were treated for navel injuries, and during week 2, two M lambs and two NM lambs were treated with no observations of navel injuries during week three. Each lamb identified with navel injuries was only treated once, with no reoccurring symptoms.

Figure 16 The number of lambs offered meal (M; ■, n=30) or no meal (NM; □, n=30) that had pink eye during week one, two and three of the study when lambs were being reared inside.



Discussion

The objective of this study was to compare the milk feeding behaviour and health of artificially reared lambs raised indoors with or without early access to a grain-based meal during the first three weeks of life. There were no mortalities in either treatment group. Loose faeces and pink eye were the most commonly observed illness for both diets. There was a diet-by-time interaction for all milk feeding behaviour traits. Lambs with access to meal consumed on average more MR per meal and per day than lambs without meal during the third week. Lambs with meal had a greater number of rewarded meals than NM lambs throughout week one and two, with little difference during week three.

Milk feeding behaviour

The provision of MR *ad libitum* to neonatal ruminants leads to increased MR intakes, growth and changes in feeding behaviour compared to neonatal ruminants that are fed restricted quantities of MR (Appleby et al. 2001; Jasper and Weary, 2002; Borderas et al. 2009a; Bach et al. 2013). As lambs age, MR intake increases, MR intake per suckling meal increases, and there is a decline the number of rewarded meals (Teke and Akdag, 2011; David et al. 2014). In the present study, although there was an increase in the total MR consumption per day and average intake per meal, there was no reduction in the number of meals. The mean meal sizes of the lambs in this study were higher than those reported by David et al. (2014). In their study David et al. (2014) reported that lambs fed *ad libitum* MR had similar number of meals per day (9.5 ± 3 meals/day).

It is likely that due to the milk-feeding systems being identical for both diets, and lambs being balanced in each diet for birth rank and live weight, that there would not be much variation and difference in the milk-feeding behaviour during the study and between diets. Overvest, et al. (2016) reported no difference in milk intake when calves were offered the same amount (*ad libitum*) and provided different solid feeds (concentrate and different forage). In the present study there was no difference in MR intake until the last week of the study. This may be due to M lambs consuming more MR compared to NM lambs and/or because there were several NM lambs with loose faeces decreasing appetite. This may be associated with their early access to meal and a greater intake of MR during the indoor rearing period leading to a greater average daily gain (reported elsewhere; Jensen et al. 2017; M lambs 414.96 ± 7.53 g/day *vs.* NM lambs 377.90 ± 7.53 g/day).

Mortality and health

The lack of mortality in this study, while being the ideal outcome, contrasts with prior studies which have reported varying rates of mortality. Bimczok et al. (2005), rearing 205 German Grey heath lambs had a mortality rate of 3.9%, whilst David et al. (2014) reared 94 Romane lambs and had a mortality rate of 12% and Emsen et al. (2004) reported a 15% mortality rate for 20 Awassi lambs. In New Zealand, a study reported mortality rate of 31% from 217 lambs from two South Island farms that were artificially rearing orphaned lambs (Schouten, 2004). Variations occur among farm practices and management can lead to different mortality rates. It may be that lambs in this study were cared for intensively and treated as soon as illness was observed leading to no deaths. Safeguarding health and minimising potential health issues is crucial to lamb survival, performance, and contributes to good animal welfare practices.

Health problems frequently arise in neonatal ruminants being artificially reared, particularly due to young animals being sensitive to infections and pathogens (Meganck et al. 2015). The most common health problems are scours (diarrhoea), respiratory infections (e.g., pneumonia) and navel infections (Hepola, 2003; Gökçe and Erdoğan, 2009; Crawford, 2013; González et al. 2016), which is of concern to the lambs' welfare and profitability (Emsen et al. 2003; Roth et al. 2009).

Diarrhoea or scours develops due to lamb susceptibility, environmental and nutritional factors, and management practices (Navarre et al.2012). Scours can be either infectious (e.g., E. *coli*, *Salmonella*, *Cryptosporidium*) or nutritional (Kohoe, 2014; Cho and Yoon, 2014). Scours effects the performance and growth by reducing MR intake, water intake (Borderas et al. 2009; Knauer et al. 2017) and death if left untreated. Nutritional scours can lead to infectious scours due to lambs becoming more susceptible when weak (Large, 1965). The lack of scours in the study may be attributed to the cleanliness of the environment and close monitoring of the lambs for any signs of illness.

In this study, lambs without access to meal had a greater number of days with loose faeces/mild scours and a greater number of individual lambs affected during week three compared to lambs with access to meal. Access to meal was associated with lambs spending less time consuming wood shavings (Nieper et al. 2017, Chapter 3). Greater consumption of wood shavings may have led to an increase in exposure to pathogens causing loose faeces, although that was not confirmed by veterinary services. Nutritional scours may have risen due to the MR being the only feed source while indoors for NM lambs. The observations of lambs with loose faeces were the only signs of any potential scours but were not severe enough to require treatment as there were no signs of depression of appetite and or dehydration.

The bedding was topped up with more wood shavings once during the three-week study and may have been infected with pathogens from faeces or urine. It is important to clean the bedding material that lambs are raised on. Less-routinely changed bedding material can have more pathogenic agents leading to a greater contact with pathogens and the potential for infection (Binns et al. 2002; Dwyer et al. 2015).

Pink eye is a contagious infection (commonly *Mycoplasma* or *Chlamydophila* species) and results in crusty, watery and shut eyes that can cause poor vison and high percentage of morbidity of lambs on farms (Beleke et al. 1992). It is also possible that the ink eye cases may bahve been due to dust particles from the bedding material. It was first noticed before the study began as the lambs first arrived, and persisted throughout the study. The decrease in the number of lambs with pink eye from week one to three may be due to lambs being treated morning and afternoon when health checks were undertaken. The origin of outbreak was mostly from the commercial farm from which the lambs were sourced. Reoccurring outbreaks of pink eye can happen, with some lambs being more susceptible than others

(Boileau and Gilmour, 2012). This may be the reason why several lambs were consistently treated each week.

Pneumonia is a common respiratory problem for neonatal lambs and has been highlighted as a severe problem leading to mortality when rearing lambs artificially (Crawford, 2013), on feedlots (Gonzalez et al. 2016), and in more conventional pastoral systems (Motha et al. 2003; Goodwin-Ray and Heuer, 2008). Pneumonia results from the interaction of pathogens, the environment and immune function leading to coughing/wheezing, lethargic lambs, and if untreated it can hinder performance and lead to death (Oruc, 2006; Plummer et al. 2012). There was only one lamb diagnosed with pneumonia which was treated during this study. It is likely that pneumonia is more problematic in large-scale artificial-rearing operations where hygiene and good ventilation may be hard to maintain (Gökçe and Erdoğan, 2008; Binns et al. 2002).

Navel infections (umbilical infections) can occur in young lambs after birth (Navarre et al. 2012). In the present study only seven lambs were observed to have navel infections, which occurred in the first week and were treated when first observed. While abomasal bloat has been highlighted as a potential problem in artificially reared lambs in early literature (Glimp, 1972) and more recently (Bull and Binnie, 2006), it was not observed during this study.

Conclusion

It is not surprising that there was a significant interaction between diet and day for the milk-feeding behaviour due to changes in lamb development over time, for example increases in MR intake per day (David et al. 2014). Lambs with meal access had more rewarded meals, consumed a greater quantity of MR per meal and per day from day 13 onwards over lambs without meal access. We speculate that lambs with meal access spent more time consuming meal as they aged and were potentially thirstier due to the dryness of the grain-based meal leading to a greater intake of MR and number of meals.

Lamb health is an important welfare consideration, particularly since neonatal lambs are susceptible to many infections and diseases (Stafford, 2013). Previously, scours (nutritional and infectious) and respiratory problems have been highlighted as having significant impacts on lamb mortality and morbidity. During this study, scours and pink eye were the main health problems encountered with pneumonia and navel infections being less prevalent. It is important to have steps for minimising and treating minimizing the spread of diseases/illnesses such as pneumonia, scours and pink eye as they can reduce farm profitability due to poor animal performance, morbidity and mortalities. While there were few differences in lamb morbidity and mortality between diets, large-scale studies are required to understand health problems for artificially reared lambs in New Zealand. Such studies may potentially highlight key areas of rearing methods and management where improvements could be made to minimise health issues.

Chapter five: General discussion

Introduction

Sheep dairy is a growing industry in New Zealand where several large-scale farms employ artificial-rearing methods to maximise milk production. In some systems, lambs are offered access to milk replacer (MR) and a grain-based meal *ad libitum,* to accelerate rumen growth and development to support early weaning systems. Large-scale artificial-rearing systems for lambs are expensive. A potential approach to minimise these expenses that was explored in this study by removing meal from the diet of the lambs and replacing it with early access to good-quality pasture. This created the leading objective of this study, which was to determine whether artificially reared dairy lambs in New Zealand could be weaned early on to good-quality pasture without previously being offered access to a grain-based meal (see chapter three). To evaluate the leading objective, two treatment groups of dairy lambs with different diets were used; lambs with meal access (M) and lambs without meal access (NM), both having access to MR *ad libitum* and pasture once moved outside. This led to supplementary objectives 1) To observe the changes and development in feeding behaviour as lambs go through environmental and nutritional transitions during the first 12 weeks of life (chapter three); 2) To monitor and observe the milk-feeding behaviour while reared inside for the first three weeks of life using data collected by the automatic milk dispensers; 3) Lastly, to monitor and report the health of dairy lambs while reared inside for the first three weeks of life.

Key findings

Behaviour

The key finding of the behaviour study were that some lambs that had early access to meal initiated rumination earlier than lambs without early access to meal. Early intake of solid feed by neonates triggers rumination and rumen development (Baldwin et al. 2004). As lambs age, the drive to consume solid feed increases, even when offered large quantities of MR (Khan et al. 2011). While inside, NM lambs were observed to spend more time consuming wood shavings and playing as they aged, while M lambs decreased time spent consuming wood shavings and playing, instead they increased their time spent consuming meal. Once the lambs were moved outside, other oral behaviours (suckling of objects other than the feeder teats), play and aggressive behaviour were not observed. Time spent grazing was greater for NM lambs during week 5, 10 and 12 and rumination was greater for NM lambs by the end of the trial during week 12. Once moved outside at the beginning of week 4, the lambs were able to begin grazing as they were abruptly weaned off MR. Lambs quickly distributed their time to consuming pasture. In contrast, when M lambs were weaned off MR they spent more time-consuming meal, with little change in time spent grazing. When weaned off meal they exhibited a similar increase in grazing time as did NM lambs when weaned off MR. During the last week of the study, after meal weaning for M lambs, they exhibited a decline in time spent grazing and ruminating. Previous experience with meal (Miller-Cushon and DeVries, 2015) and differences in rumen microorganisms (Khan et al. 2016) may have effected the M lamb's ability to transition onto pasture leading to the decline in behaviours of M lambs. In both diet groups behavioural needs to consume solid feed and ruminate were met. Overall, withholding meal from the lambs' diets enabled them to transition onto pasture without impairing other behaviours (e.g., rumination) at an earlier age than lambs with meal. Lambs with meal had less time spent grazing after meal-weaning.

Milk-feeding behaviour

The key milk-feeding behaviour findings were that each trait had a diet-by-time (day) interaction, whereby daily changes in milk-feeding behaviour were observed throughout each week due to age. Lambs with meal access had a greater number of rewarded meals, greater MR intake per meal, and a greater intake of total MR daily. Overall, these results indicate that lambs with meal access had a greater intake of MR, by having a greater number of meals of greater size due to early access to meal. Although, on average small quantities of meal were being consumed, and individual intakes of meal were unable to be calculated.

Health

The key findings from the health monitoring were that there were no mortalities for either diet during the study. Loose faeces was the most commonly observed health issue, although it had no other observable health issues associated with the loose faeces (e.g., dehydration, poor appetite) with no treatment interventions required. While loose faeces was observed more for NM lambs compared to M lambs, it may have been associated with the increased time spent consuming the bedding material or possibly the lack of fibre/solid feed provided, as noted earlier. Pink eye (although not confirmed) was likely due to prior exposure at the commercial farm from which the lambs were sourced. Overall, these results indicate that lamb health was not negatively impacted by the lack of solid feed when reared indoors for the first three weeks of life. This is most likely due to lambs beginning to consume greater quantities of solid feed around four weeks of age when they were moved onto pasture. It likely that due to our facility being very clean and hygienic that may have led to the low incidence of health issues compared to other studies.

Limitations

There were several areas of the study that could be improved if the opportunity materialised. Firstly, the total recording days for each recording week of lamb behaviour could have occurred on one day in order to reduce the potential for day-today variation. The variation in weather conditions from day-to-day may have impacted on the feeding behaviour of the lambs (Kilgour and Dalton, 1980). To improve the accuracy of the study, the total observation time should be increased from 9 hours per observation week to either 12 hours or 24 hours. It is known that most of the time spent ruminating occurs during night time and ruminants follow a circadian rhythm (Dulphy et al. 1980).

While there is the potential to overestimate or underestimate some social behaviours when animals are in groups and the data recording interval were 10-minutes, every attempt to standardise the groups (age, weight, sex) were attempted to minimise the impact. It is acknowledged that 10-minute intervals do not work well for some behaviours (e.g., play, drinking water) that were observed.

Instead of visually observing the behaviour and writing down individual behaviours every 10-minutes, it was originally attempted to use high-quality video-recording cameras. This would have enabled the behaviour to be reported as "X minutes spent expressing X behaviour". Before the trial was started, a trial using cameras was tested, but due to the number of cameras needed and the large quantity of data collected, it was out of the scope of the study to successfully review the long duration footage that would have been generated over the 12-week study.

A greater number of milk-feeding behaviour traits recorded by the automatic milk feeder machine (e.g., milk suckling speed) would have improved the analysis of behaviour changes between diets. Similarly, correlation analysis could be done between health scores and changes in milk-feeding speed. Milk feeding speed has been found by others to increase when calves are ill and offered high milk allowances (Borderas et al. 2009b). Due to the lack of health issues, correlations between health scores and milk-feeding behaviour were not completed. If there were a greater number of lambs ill, it may have provided insight into how lambs milk-feeding behaviour can be influenced by illness as highlighted in recent calf literature (Knauer et al. 2017).

The data gathered from the automatic milk feeders was useful for observing the differences in feeding behaviour traits between M and NM lambs. The data could be improved by having the automatic feeder configured to record each individual meal rather than hourly data, as the number of meals observed is most likely higher than what was reported, as well as being able to report the accurate number of unrewarded meals.

Implications and future research

These results suggest that lambs offered MR *ad libitum* with unrestricted access to good quality pasture were able to successfully be weaned without any detrimental effects on the development of behaviour. These lambs eventually spent more time grazing and ruminating than lambs which were provided with early-access to meal. Lambs with meal access when weaned off meal spent less time grazing, ruminating and had a greater loss of live weight (Jensen, et al. 2017). While a greater quantity of MR was consumed per meal and per day for lambs with meal access over lambs without, these differences were not substantial. There were no adverse effects on health by not providing meal when lambs were inside, besides a slightly greater number of lambs with loose faeces, before being moved on to pasture. These results may help the industry by providing information on alternative feed-management systems where meal is partially or completely removed from the early diet of dairy lambs, reducing the input costs and helping with the improvement of artificially reared lamb welfare and performance. Both artificial rearing methods may benefit the New Zealand sheep dairy industry depending on the farm operation. Replacement ewe lambs may benefit from being reared straight onto pasture as the NM lambs were. While, ram lambs may benefit from being fed a grain-based meal early on to reach an acceptable weight to be sold off farm or taken to the works. It should not be neglected, that all lambs being reared indoors off pasture should have access to a solid feed with nutritional value to mitigate the ingestion of wood shavings as this may be a risk to their health.

Future research of artificially reared lambs should focus on evaluating this study on a larger scale to determine whether the results are consistent. Using milk feeding behaviour traits to see if a correlation is observed in relation with lamb illness, would provide validation for using changes in milk-feeding behaviour for early detection of illnesses and reducing potential morbidity and mortality of lambs on sheep dairy farms.

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