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Improving young pig welfare on-farm: The Five Domains Model

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Lay Summary: Considering welfare through the "*neonatal and nursery pig perspective*" is an exciting approach. Overlaying this with the Five Domains Model, as we suggest in this review, points to practical on-farm improvements that provide each pig the opportunity to experience positive mental states. The first four domains consider physical and functional states; with Domains 1 through 4 being Nutrition, Physical Environment, Health and Behavioral Interaction respectively. All interweave with Domain 5: Mental state. A plethora of examples are discussed; Domain 1 critiques optimal colostrum intake, and milk and feed quality that result in feelings of fullness and contentment. Domain 2 considers space complexity, key resource access, and thermal and physical amenities with these efforts resulting in feelings of comfort and agency. Domain 3 discusses congenital and hereditary health, environmental pathogen load, colostrum quality and quantity effects on the microbiome and how these improve pig vitality and feelings of good health and fitness. Domain 4 discusses opportunities for the pig to express its behavioral repertoire, particularly positive social interactions, play, and exploration with feelings of control and agency. Improvements will result in pigs feeling calm, safe, comfortable, enjoying companionship, engaged, interested and leading a rewarding life.

Teaser Text: Considering welfare through the "*neonatal and nursery pig perspective*" is an exciting approach, and one that resonates with consumers. Overlaying this with the Five Domains Model highlights on-farm opportunities that provides pigs with positive mental states.

ABSTRACT: Considering welfare through the "*neonatal and nursery pig perspective*" is an exciting approach, and one that resonates with consumers. Overlaying this with the Five Domains Model, as we suggest in this review, points to practical on-farm improvements that provide each pig the opportunity to experience positive mental states. The Five Domains Model is broken into physical and functional states, that includes Domain 1 Nutrition, Domain 2 Physical Environment, Domain 3 Health and, Domain 4 Behavioral Interaction, and Domain 5 Mental State. The Five Domains Model can build on the breadth and depth of swine welfare science to highlight opportunities to improve welfare on-farm. In Domain 1 management of increasingly large litters is considered, with examples of sow vs. artificial rearing, colostrum quality and quantity, and creep feed management strategies. Efforts can result in positive mental states such as feeling full and content and the ability to experience pleasure of drinking and food tastes/smells. Domain 2 considers space complexity and access to key resources, along with thermal and physical amenities, to promote feelings of physical comfort. Domain 3 considers pig health in three broad, yet inter-linking categories, (a) congenital and hereditary health, (b) environmental pathogen load and, (c) colostrum quality and quantity, and its effect on the microbiome. Improvements can result in a pig that displays vitality and feels healthy. Domain 4 provides the pig opportunities to express its rich behavioral repertoire, specifically positive social interactions, play, and exploration. These efforts can result in pigs feeling calm, safe, comfortable, having companionship, engaged, interested and rewarded. In conclusion, using the Five Domains Model can highlight numerous opportunities to improve current and future housing and management through the "*neonatal and nursery pig perspective*" with a focus on inducing positive mental states that can result in improved quality of life and welfare state.

Key words: Affective, Farm, Health, Mental, Piglet, Weaner

INTRODUCTION

Pigs have been - and will continue to be - used as an animal protein source to supplement the human diet. When utilizing animals for food, fiber and research there comes ethical considerations. To address these, governments, international organizations, non-governmental organizations and producers have developed farm animal welfare standards (Croney and Millman, 2007; OIE, 2022). Many of these efforts have been based around the Five Freedoms (Webster, 2016), but Mellor (2016a) noted two key disadvantages with using these *"...(1) first, although originally intended to mean "as free as possible from" each of the experiences or states included in the Freedoms, it has often been apparent [to the author], during extensive interactions, that some animal-based scientists not directly involved in animal welfare and some lay animal protectionists have come to regard the Freedoms, implicitly or explicitly, as "completely achievable" and even as "rights*" *and, (2) they have sought to focus on negative states."* Mellor (2016b) reported the benefits of addressing animal welfare as "*a life worth living*" and argued that it was not possible to consider this concept when the predominate focus was centered on survival-critical measures and negative based affective experiences. He considered how the Five Domains Model might be a more robust framework for assessing animal welfare state. The Five Domains Model has evolved since 1994 (see Mellor, 2016a, b; 2017, 2019; Mellor and Reid, 1994; Mellor et al., 2020) and has been gaining traction with livestock industries (Cargill, 2022; Fairlife, 2022; Tyson, 2021). Historically, animal welfare state assessment has been based on physiological functioning, production performance and economics. Yet, consumers tend to be more concerned about how an individual animal is coping and feeling (Alonso et al., 2020). Kells (2021) considered the Five Domains Model and how it could be applied to the pig industry by identifying risk factors that could negatively or positively affect pig welfare. Considering welfare through the "*perspective of the neonatal and nursery pig*" is an exciting approach, and one that resonates with consumers. Overlaying this approach with the Five Domains Model, this review discusses practical on-farm improvements that provide each pig the opportunity to experience positive mental states that can result in improved quality of life and welfare state.

FIVE DOMAINS MODEL APPLICATION TO ANIMAL WELFARE STATUS

The Five Domains Model is based on two premises. The first is that welfare is a state within the animal that is influenced by how the individual experiences its own world and its own life. Second, the model considers the animal's mental state (Domain 5) as a key driver that shapes animal welfare. Both negative and positive mental states have some meaning to the individual animal that drives its experiences and responses. The Five Domains Model is broken into physical and functional states, that includes Domain 1: Nutrition, Domain 2: Physical Environment, Domain 3: Health and, Domain 4: Behavioral Interaction, and Domain 5: Mental State. The model helps us to organize objective and measurable indicators (i.e. animal behavior, physiology, performance, neuroscience, and pathophysiology) from Domains 1 through 4. Next, the model considers how the animal's nervous system interprets these measures and relays it into generating mental experiences. It is important to note that mental experiences for both human and non-human animals are subjective, which means that we cannot measure or observe them directly. However, the Five Domains Model allows us, with caution and evidence, to infer and justify what these individual mental experiences are. In turn, the Five Domains Model provides a framework for humans, and in the future automation, to assess animal welfare state. To correctly use the model, it is important to (1) understand the premises, (2) correctly use the Five Domains, (3) have species expertise to understand the biology, ecology and biological functioning, (4) apply the animals biological attributions into the situational context, (5) balance both positive and negative situations and, (6) identify animal mental state(s) that can be justified by the objective evidence measured (Beausoleil, 2020).

BEHAVIOR AND AGENCY

Before applying the Five Domains Model it is essential to consider where to correctly place behaviors, and what we mean by agency. Although it seems intuitive to place all behaviors into Domain 4 (Behavior), this is not correct. Domain 4 considers behaviors that are associated with situational-related affective states; so, whether the animal can achieve its goal(s), is rewarded through behavioral expression, and consequently experiences contentment and/or pleasure. Conversely, if thwarted from achieving its goal(s), it likely feels unfulfilled, bored or frustrated. In contrast, Domains 1 to 3 consider survival-critical behaviors and affective states. These are states that stimulate behaviors that help the animal to maintain homeostasis (Beausoleil, 2020), such as searching for food to alleviate hunger (Domain 1), seeking shade to keep cool (Domain 2) and withdrawal from a painful stimulus to avoid injury (Domain 3).

Agency can be defined as inner-motivated behavioral engagement with the environment (Špinka, 2019), and the author proposed four tiers of agency (a) passive/reactive (b) action-driven, (c) competence-building and (d) aspirational. Agency is important when considering animal welfare in three ways. First, engagement in action-driven- and competence-building agencies are accompanied by pleasurable emotional experiences that contribute to an immediately positive welfare state. Second, through competence building agency, the ability to cope with upcoming challenges is improved, so this contributes to a future positive welfare state.

Third, agency can enrich animal selfhood/awareness. As an animal enacts action-driven and competence-building agency, the probability of successful actions that generate posititve affective states increases, and awareness gets fuller and more richly structured. In the remainder of this review, we will take the Five Domains Model, and apply some contextual situations to discuss several case studies of where we would advocate inclusion on farm to enhance the positive mental experiences for the neonatal and nursery pig (Table 1).

FIVE DOMAINS MODEL: APPLICATION TO THE YOUNG PIG

Domain 1: Nutrition: The pig's evolutionary strategy is to overproduce offspring, thus investing relatively low levels of maternal investment into each piglet (Edwards, 2002). This is so that in suboptimal conditions, larger, stronger piglets can outcompete their weaker siblings, increasing their likelihood to survive. Piglets are precocious at birth, but are born with low bodily energy reserves, very little adipose tissue, and no brown fat (Herpin et al., 2002). Nevertheless, the weight-specific requirement for energy in pigs is at its highest at birth (Herpin et al., 2005) with an immediate challenge to restore a dramatic drop in temperature during the first hour post-partum (Schmitt and O'Driscoll, 2021). Piglet vitality is considered key in enabling this because it impacts the piglets' ability to find the udder, successfully compete for a teat, and consume colostrum (Edwards, 2002). This provides energy and immunoglobulins to the immunologically naive piglet, and its consumption is considered a primary determinant of piglet survival (Devillers et al., 2011). Although the interaction between hypothermia, starvation, disease, and ultimately crushing (often the outcome from some level of each of the former three; Muns et al., 2016) is complex (Edwards, 2002), what is extremely important is that piglets are rapidly able to access and consume colostrum.

Coping with the postnatal life is increasingly challenging for piglets due to the growth in commercial litter sizes, associated with lower average birth weights (Riddersholm et al., 2021). Low piglet birth weight is associated with lower energy reserves, fewer vitality indicators, and greater surface to volume area, exacerbating heat loss (Muns et al., 2016). Moreover, competition for colostrum increases, as colostrum yield does not increase with increased litter size (Quesnel, 2011). This persists through lactation; the very nature of how piglets nurse from sows, by establishing a teat order that facilitates each piglet quickly latching on to consume milk during an extremely brief let-down period (~ 10 s; Petersen, 2011), means that when there are more piglets than teats, some will miss each milk let-down, particularly the smaller ones (Kobek-Kjeldager et al., 2020).

It is clear that the strategy of increasing sow output through breeding for larger litters has inadvertently caused piglet welfare problems related to Domain 1. Methods to ameliorate associated problems broadly fall into two main strategies; to supply additional nutrition (colostrum, energy boosters, milk and creep feed), or to remove piglets from the sow so that there is a functional teat for each remaining one. Energy boosters are generally administered shortly after birth to promote colostrum consumption, and thus improve survivability. The energy provided is generally from lipids (Mellor and Cockburn, 1986), with the aim of helping piglets find the udder and suckle. However, results from controlled studies are mixed; there is some evidence of reduced mortality, particularly in low birth weight piglets (Declerck et al., 2016; Muns et al., 2017; Moreira et al., 2020), but other studies have shown little or no benefit (Schmitt et al., 2019a; Muns et al., 2015). Reasons include little consistency across studies (e.g. amount of supplement, timing and number of doses) and potentially the booster's composition; the lipid component of colostrum is primarily composed of long-chain fatty acids (Schmitt et al., 2019a), whereas most energy boost products contain medium-chain fatty acids, and even within the medium-chain family there can be significant effects of fatty-acid chain length on utilization (Odle, 1997).

An alternative is to take direct steps to ensure sufficient colostrum is consumed. One option is to dose piglets directly, and indeed this may confer additional welfare benefits to piglets with regard to growth (Moreira et al., 2020; Miguel et al., 2021). A second option is to use split-suckling; this involves temporarily preventing the heaviest piglets, or firstborn piglets from accessing the udder for a short period of time after farrowing, to reduce competition for the lighter / later born piglets. Although this strategy is commonly used commercially however, there has been little research into how to best apply it (e.g. duration separated, which piglets to separate etc.), and results have varied. A recent study attempting to determine the optimal duration found that colostrum intake of smaller piglets was not improved, and it was reduced in heavier piglets, when split suckling was used (Vandaele et al., 2020). Moreover, Arnaud et al. (2022) found that providing post-partum analgesic to the sow (to improve comfort and promote piglet acceptance) actually improved piglet growth, and reduced anti-inflammatory treatment of suckling piglets, more than split suckling did. Thus, further work is needed to refine practices during the first day of life to promote colostrum intake.

Once the window for colostrum consumption has closed (~24-48h post-partum; Le Dividich and Herpin, 2005), further strategies to improve milk consumption can be employed. In general, methods that facilitate the natural behavior of both sows and piglets are those that work best when it comes to both animal welfare and performance. At the other extreme is artificial rearing (AR), which involves complete piglet removal from the sow, and sometimes movement to a specialized rearing enclosure at an age when they are still entirely dependent upon milk as their primary form of nutrition. Milk replacer is often provided via shallow troughs or ‘cups’, with fresh milk dispensed every time a piglet noses a lever in the cup (Schmitt et al., 2019b). This is entirely different to being fed by a sow, whereby approximately once per hour all piglets are called to the udder via nursing grunts, where they feed simultaneously, in synchrony, and milk let down is discrete and quick. This type of rearing system has recently experienced a resurgence in interest, particularly in Europe due to the growth in litter size, and indeed several artificial rearing systems are available commercially. They are labour and space saving relative to nurse sow systems, and are often used to finish rearing litters that are 7-14 days into lactation, rather than newly born piglets. Theoretically AR systems provide piglets with more agency to feed whenever they feel like it, than when they are kept with a sow. However, they are entirely at odds with the type of feeding behavior that piglets naturally perform, and there is no evidence that they improve welfare. Prior to weaning AR piglets often grow more slowly than sow reared (SR) piglets (Schmitt et al., 2019b), and if they do not, any advantage is unsustainable post weaning (Cabrera et al., 2010; van Beirendonck et al., 2015). Importantly, they also perform more belly nosing, an abnormal behavior associated with early weaning (Schmitt et al., 2019b; Rzezniczek et al., 2015), thought to develop from redirected suckling behavior, and reflecting unfulfilled nursing-related behavioral needs (Widowski et al., 2008). Indeed, providing milk through nipples and/or an artificial udder can reduce the negative effects of AR, and results in piglets performing less nosing, chewing and sucking on pen-mates than when fed from a trough. Overall, it is clear that simply providing an *ad libitum* source of milk is not sufficient to maintain good welfare. As well as providing nutrition, the sow provides cues and comfort to piglets that enable them to develop normally. Performance of abnormal behaviors reflects conditions that do not meet the animal’s behavioral needs. Belly nosing in particular is likely associated with feelings not only of physical hunger, but also of mental frustration due to the inability to satisfy the behavioral need to nurse (Domain 5).

A more welfare friendly option is to leave large litters in the farrowing crate with their mother, but with an artificial milk feeding system installed. The idea is to provide an *ad libitum* milk supply to complement the sow. This practice has been shown to increase piglet survival, although later on in lactation, not during the early days of life. Detailed behavior analysis demonstrated that although piglets had a clear preference for suckling the sow over milk replacer (Kobek-Kjeldager et al., 2020), about half of the piglets with low suckling success were able to compensate and sustain growth by drinking milk replacer. As such, when it is not possible to reduce litter size so that each piglet has a teat, provision of supplementary milk could play a role in reducing hunger. Finally, moving piglets to a nurse sow to ensure that all have access to a teat is probably the best strategy to ensure optimal nutrition. This involves weaning piglets off a sow at the normal age, yet keeping the sow in the farrowing rooms for an extended lactation and placing new piglets on her. These can be supernumerary day-old piglets, or an entire litter from another sow earlier in lactation. Using this two-step nurse strategy better aligns to young piglets' nutritional needs rather than keeping back on almost weaned sow, reducing her milk output (Theil, 2015). Nurse sow strategies appear to have fewer welfare problems than artificial milk feeding. Schmitt et al., (2019c) found that although there was a growth check for one week after fostering, there was no difference in weaning weight for fostered piglets relative to piglets that stay with their mother, although in this study the heaviest piglets were cross-fostered which could explain the lack of difference. Piglets moved to a sow who was early in lactation fought less at the udder than those moved to a late lactation sow. Once supernumerary piglets were removed, there were fewer teat changes at nursing, indicating piglet welfare was improved.

Nevertheless, this system is not without some welfare compromises. Kobek-Kjeldager et al. (2020) compared the behavior and performance of the original, and second litters given to a batch of nurse sows and found that the second litters had reduced growth, more teat fighting and more missed milk let-downs, than the original. The authors concluded that the sow's milk supply was insufficient for a new litter of young piglets; thus, matching sow lactation stage to the age of piglets, where possible, appears to be important. Nevertheless, given the challenges that piglets from large litters face, moving to a nurse sow is probably the least bad option when it comes to mitigation strategies.

Other than being born to a large litter, the second largest nutritional challenge for piglets is the transition from being milk fed, to eating solid food. Pigs reared under more natural conditions are able to observe their mother's feeding behavior (Petersen, 1994). Even from the first few days of life, outdoor-reared piglets perform behaviors functionally associated with foraging and eating solid food, such as rooting, biting, chewing, and sniffing at various substrates (Petersen, 1994). These behaviors seem to be innate, as they are performed even by piglets reared in standard farrowing crates (Schmitt et al., 2020). Thus, it is likely that evolution has shaped these behaviors being spontaneously performed as part of the piglets' normal development, as they aid the transition from milk to solid feed. Nevertheless, for highly precocious animals such as piglets, eating random items in their environment could be dangerous, as they could accidentally consume toxic substrates. As such, the ability to learn where and what to feed on from conspecifics or older animals is important. Piglets are capable of learning from their mother how to select food not only by consuming it alongside her, but simply by observing her consuming it (Oostindjer et al., 2011). Thus, given the opportunity, piglets are capable at a very young age (3 wk of age; Oostindjer et al., 2011) of exercising both action-driven, and competence-building agency, in the process by which they learn to consume solid food. Commercial piglets are typically weaned suddenly and at a much younger age (3-4 wk) than they would be in free-ranging conditions (~ 17 wk; Petersen, 1994), and the welfare problems they experience (e.g. weight loss, damaging behaviors, gastro-intestinal problems; Oostindjer et al., 2014) can be exacerbated by the stress of being separated from the mother, and being moved to a new environment with unfamiliar piglets. Simply permitting them to observe and eat together with the mother can stimulate early food intake (Oostindjer et al., 2014), and facilitates the piglet's natural behavior, and learning capabilities. This enables expression of agency when it comes to learning about food, and is likely to result in at least a reduction in negative affect associated with hunger post weaning, if not additionally positive feelings associated with being able to perform highly motivated exploratory behavior, that is likely positively reinforced by the food consumed.

Domain 2: Physical Environment: The quality of the early physical environment for neonatal piglets is critical for their survival, growth and development. Piglets experience welfare challenges when kept in barren housing with little or no access to environmental enrichment or environmental complexity; both of these have positive effects on social and cognitive development (De Jonge et al., 1996; Martin et al., 2015), growth rate (Brown et al., 2015), immune responses (van Dixhoorn et al., 2016; Luo et al., 2017), stress regulation mechanisms (Fox et al., 2006) and weaning adaptation (Oostindjer et al., 2011). Therefore, opportunities for welfare enhancements can come from the choice of farrowing and weaning system and the resources provided within it, particularly environmental enrichment. Indirect opportunities to mitigate welfare challenges that relate specifically to farrowing systems include how the physical environment can stimulate positive maternal behavior and management ease which in-turn influences human-animal interactions (Domain 4). When discussing the negative and positive impacts the physical environment has on the pigs' mental experiences (Domain 5), the terms discomfort and comfort can be used respectively.

The predominant maternity system used globally continues to be the farrowing crate. The crate restricts movements, allowing the sow only enough space to get up and lie down but not to turn around, and therefore reduces crushing mortality by significantly limiting the sow's freedom of movement. Piglet mortality is often reported to be higher in loose farrowing pens compared to farrowing crates (Goumon et al., 2022), but it is not always the case as some studies found similar mortalities (for reviews see Baxter et al., 2012; Goumon et al., 2022), particularly when sows are constrained in crates for the first 3-d post-partum and then released (Singh et al., 2017; Heidinger et al., 2022; Goumon et al., 2022). There is also a growing body of evidence that crating beyond d 3 or 4 post-partum brings little piglet benefit (Heidinger et al., 2022; Goumon et al., 2022), could negatively impact suckling for older piglets (due to difficulties gaining teat access; Pedersen et al., 2011) and is detrimental for the sow. Sow welfare in the farrowing environment is discussed elsewhere (Baxter et al., 2012, 2018) and is not considered in this review unless indirect consequences for piglets are apparent, such as the influence restraint of the sow has on hormone production that regulates maternal behavior (Algers and Uvnas-Moberg, 2007) and the production of colostrum and milk thus negatively affecting piglet welfare (see review by Yun and Valros, 2015).

Having greater control of the farrowing environment by using the crate allows very targeted heating of neonates and easy access by staff for interventions. As stated previously, the neonatal piglet is vulnerable to hypothermia (Herpin et al., 2002). Leanness selection and prolificacy have further increased their vulnerability and providing a suitable thermal environment is critical to ensure survival. However, piglets and sows have very different thermal needs, especially immediately post-partum when their lower critical temperature is approximately 34˚C (Mount, 1967). As heat stress for the sow could be fatal (thermal comfort zone typically -10-20°C; Black et al., 1993), providing microclimates is a necessity. Substrate, flooring and the enclosure influences the effectiveness of this microclimate. A covered, heated creep area inaccessible to the sow provides thermal comfort throughout lactation, but piglets often take an extended time to locate and consistently use this area after birth (Vasdal et al., 2010), prioritising time at the udder for the first 24-48h post-partum. Indeed, additional supplementary heat via lamps around the birth site has been shown to improve piglet survival (Morrison et al., 1983).

Udder proximity brings warmth and develops teat fidelity for better colostrum and milk intake, but also brings greater risk of crushing by the sow (Weary et al., 1996). Piglets of marginal viability may not survive this period if their thermal needs are not met. New technologies with more effective types of radiant heat are likely to aid vulnerable piglets in particular (Pedersen et al., 2016), and provision is easy in a farrowing crate system. However, in a loose farrowing pen the birth site cannot be reliably predicted. Higher light intensity and mat temperature differential to the main environment can attract piglets to the creep areas in farrowing pens (Morello et al., 2019). Creep position is also important; corner creeps adjacent to the udder may be better than front creeps, as piglets must walk through the heated area to access the udder, thus promoting use of this warmed and protected area (Baxter et al., 2015).

Thermal (and physical) comfort can also be achieved by provision of deep substrate, particularly straw due to its insulatory properties (Mount, 1967). Deep bedding slows heat loss, having a thermal resistance 11 times greater than that of concrete slats and 22 times greater than solid, wet concrete flooring (Wathes and Whittemore, 2006). This is, in part, why straw management is such an important factor in outdoor pig production (Baxter et al., 2009; Schild et al., 2020). In studies on organic herds in Denmark, Schild and colleagues recorded farrowing nest temperature in the first week post-partum revealing a considerably higher temperature (average 23.4 °C) in the nest compared to the ambient hut temperature (11.7 °C) and outdoor temperature (3.9 °C; Schild, 2018 cited in Schild et al., 2020). Westin et al. (2014, 2015) found that not only did straw promote nest building behavior in sows, for piglets it reduced the development of skin and hoof abrasions, increased daily weight gain and body weight at weaning.

Substrate provision is challenging in conventional farrowing houses as flooring is typically fully or partially slatted to allow for removal of waste into slurry pits below. Substrate retention is possible using strategic provision. Westin et al. (2013) supplied sows with 15 to 20 kg of chopped straw, given as a one-time event two days prior to expected date of farrowing. The straw drained through the floor so gradually there were no issues with clogged slurry pits. Providing such quantities could be challenging, especially in areas where straw availability is sparse and in climates where heat stress is a significant issue, so lower straw quantities and alternative substrates provision have also been studied. Swan et al. (2018) offered six materials (point-source objects, wood shavings, straw, shredded paper and whole newspaper) either attached to the farrowing crate or in amounts of 1–2 L in front of the sows. There were different benefits for the selected options: the newspaper group performed more nest-building and less bar-biting activities, piglet mortality was lowest overall in the straw group and lower in the straw group than in the wood shavings group during the first three days of lactation. This study demonstrated the piglet benefits of nest-building and it is supported by studies both in crates and loose systems showing that facilitating nest-building can improve suckling success and growth rate in piglets (e.g. crates, Edwards et al., 2019; and loose, Yun et al., 2014; Plush et al. 2019) and even reduce stillbirths (Rosvold and Andersen, 2019; Edwards et al., 2019). Enriching the neonatal environment throughout lactation will also benefit piglets. Studies have shown that providing substrates, point-source objects, opportunities for play and socialisation improves cognitive and social skills (Martin et al., 2015), growth rate (Brown et al., 2015), gut health (Oostindjer et al., 2010) and immunity (van Dixhoorn et al., 2016) and can reduce weaning stress. What and how much to provide to achieve benefits is still difficult to quantify in absolute terms, but it appears environmental diversity will accrue the most benefits to different aspects of piglet welfare. As was the case with nutritional complexity (Domain 1), structural complexity provides benefits including opportunities for choice and therefore greater agency (Domain 5).

As piglets are reliant on their mother for nutrition, maximising sow lactational output should be a priority. Changes to the farrowing environment that improve colostrum quality (Yun et al., 2014) and provide easy udder access (Pedersen et al., 2011) have demonstrated positive effects on suckling success and piglet outcomes (Nowland et al., 2019). The use of AR systems described in Domain 1 also impacts on Domain 2. Thermal comfort (via heat lamps) and *ad libitum* milk are provided (See Domain 1), with solid 'creep' feed available dependent on piglet age. However, as well as the welfare issues associated with artificial milk feeding systems described previously, piglets in these systems display the same signs of distress (i.e. vocalisations, growth impairments, development of abnormal behaviors, reduced play; Rzezniczek et al., 2015; Schmitt et al., 2019b,c,d) as those shown by piglets weaned very early (e.g. 6-d postpartum; Orgeur et al., 2001). The systems used in these studies had low space allowance (typical footprint: 1 vs. 3.6-4.3 m^2 in a conventional farrowing pen; Goumon et al., 2022) and limited access to the milk cups which could have increased aggression prevalence, and thwarted play behavior. Although AR reduces the impacts of weaning, often removing the 'weaning check' on growth rate, Schmitt et al. (2019b,d) suggested that, from a welfare point of view, AR systems create an ambiguous situation where welfare improvements post-weaning are consequences of previous welfare detriments. In their studies the results showed that, compared to SR piglets, AR piglets were in a poorer welfare state pre-weaning (more negative behaviors, lower emotional state as determined by Qualitative Behavioral Assessment, and slower growth rate), and had a better welfare status post-weaning, as suggested by a higher emotional state and a lower emotional reactivity. This surprising change in welfare state was attributed to the fact that weaning represented a relative improvement in the environment of AR piglets (e.g. increased space allowance per piglet) and that separation from the mother had already occurred several weeks before. Some systems are being designed to bypass the weaner facility altogether, with the initial objective to reduce antibiotics and zinc reliance (reducing weaning stress, piglet movement, biosecurity breaches etc.). For example, in loose lactation systems piglets might be kept with their mothers for longer (Van Nieuwamerongen et al., 2017; Turpin et al., 2017) or the sows are removed and the piglets stay in the pens for longer before going straight to a grower facility.

Weaned piglet housing traditionally involves prioritising hygiene, heating and feeding. This can equate to barren environments, similar welfare issues to pre-weaning environment. Environmental enrichment provision could lessen weaning impacts and in-turn reduce the aberrant behavioral occurrence (already described when discussing AR). How to provide enrichment, in what quantities and what types has been the subject of much debate (especially in fully slatted systems; Chou et al., 2019) and how well current practices actually meet animal needs has been reviewed elsewhere (van Weerd and Ison, 2019) and is discussed in Domain 4.

Post-weaning thermal needs are more easily met, but encouraging feed intake is more challenging, as already discussed. In addition to considering feed composition, the method of feed provision is also influenced by pen design. Where possible, pigs synchronise behaviors such as feeding, resting, and interaction with enrichment (Zwicker et al., 2013). Thus, ideally pens should be designed with clearly defined functional areas that are large enough for several pigs to use at once. Misra et al. (2021) investigated the effect of three different stocking densities (small, 12 pigs; medium, 24 pigs and large, 48 pigs) on water consumption. Medium and large pens were created by removing partitions between multiple small pens. In the small pens, feed was dispensed in one corner of the pen, from a single-spaced feeder. However, because the medium and large pens were created simply by removing partitions, in these there were multiple feeder areas, spread around the pen perimeter. Likewise, the enrichment items (a rack of grass, hanging rubber toy and plank of wood) in these pens were distributed at random throughout, rather than in a single area. This resulted in feed intake decreasing as pen size increased, due to significant variation in feeder use. Because the pen resources were disorganized, there were no clearly delineated areas, and pigs in the larger pens tended to create dunging and lying areas around some of the feeders, inhibiting their use. In this case, although pigs were able to use agency to select their dunging and lying areas, the poor pen design meant that they made poor choices. In semi-natural environments, pigs select sites for elimination; feeding and lying are organised so that they do not overlap (Stolba and Wood Gush, 1989). Thus, systems should be designed to facilitate this natural behavior. Promoting high levels of hygiene will help protect piglet' health and interacts with Domain 3.

Domain 3: Health: Piglet viability and vitality is multifactorial, and includes health status in the immediate post-partum period. This can depend on; 1) hereditary or congenital health conditions, or health conditions related to sow health, 2) environmental pathogen load that piglets are born into, and 3) colostrum availability and quality. These will impact not only the piglet's immediate health status, but can also have longer-term impacts. Congenital and hereditary conditions, such as splay leg, cleft palate, atresia ani, congenital tremors, cardiac defects and hernias vary in incidence, and depending on the defect type, may result in immediate euthanasia (e.g. atresia ani) or treatment (e.g. splay leg). Euthanasia, which comprises both a decision-making process and the act itself, can adversely affect caretaker welfare and pigs alike (Rault et al., 2017). Factors identified included caretaker attitudes and attributes (empathy affect, empathy attribution, feeling bad about euthanizing, and negative attitudes to pigs), beliefs about the working environment (perceived time constraints and relying on others), and factors related to decision-making (comfortable with euthanasia, trouble deciding and avoid if possible, confidence, insufficient knowledge, seeking knowledge, and using sources to get advice; Rault et al., 2017). Approved methods within the U.S. include intravenous injection of barbiturates, non-penetrating captive bolt, CO_2 inhalation and manually-applied blunt force trauma (AVMA, 2020). **The** development of other acceptable euthanasia methods and decision-making guidance remains a high priority with the swine industry (Webb, 2018). This priority is important because there is a degree of disconnect between published guidelines, industry practice (Mullins, 2017) and euthanasia decision making. Difficulties deciding when to euthanize relate to stockpersons whom lack experience and feel unconfident and unknowledgeable (Campler et al., 2018). Clearly, by definition, hereditary health issues can only be fully addressed by selective breeding, although some health issues may also be inadvertently selectively bred in when selecting for production traits (Rauw et al., 1998). Other congenital conditions or health conditions related to sow health can potentially be addressed post-partum, or can be prevented in future litters, by remedial action in terms of management, though it may also become clear that some conditions previously thought to be non-hereditary, do actually have a genetic basis, such as splay leg (Schumacher et al., 2021). Another piglet condition that has received increased attention over the last few years is that of intrauterine growth restriction or retardation (IUGR). Since the first publication on the topic in 1991, about 50% of all papers and 67% of all citations have occurred in the last 5 yr. An IUGR can be defined as impaired growth and development of the mammalian embryo/fetus or its organs during pregnancy (Wu et al., 2006). For pigs, there are multiple documented factors that play a role in the occurrence of IUGR, including uterine crowding, placental insufficiency and maternal undernutrition and overnutrition during gestation (Wu et al., 2006). Another factor, which is increasingly a factor with IUGR and other issues reported is litter size. Increasing litter size reduces average birthweight, but increases the variation (Moreira et al., 2020) and, potentially, increases IUGR probability (Wang et al., 2017). Low birthweights, irrespective of IUGR characteristics or not, has consequences for pre-weaning mortality as only 28% of piglets born below 1.1 kg survived to 7 d (Marchant et al., 2000), and low birth weight piglets showed cognitive impairment (Roelofs et al., 2019). Intrauterine growth retardation has not only an immediate impact on health and welfare but there is also evidence that IUGR impacts are long term, with negative impacts on body composition and meat quality, growth performance, organ function and development (Wu et al., 2006). There still may be nutritional methods to reduce IUGR incidence, by targeting sow nutrition at critical periods including oocyte development, implantation and late fetal growth (Wang et al., 2017; Farmer and Edwards, 2021), but it may also be possible to select against IUGR by including within-litter proportion of IUGR piglets as a selection trait (Matheson et al., 2018).

Given a healthy piglet at parturition, there is immediate pathogen exposure within the farrowing environment immediately at birth. The piglet has an immature immune system and has received no maternal immunoglobulins *in utero*, hence this pathogen load will challenge the piglet's health status. The physical nature of the farrowing environment on piglet welfare is covered in Domain 2, many facets of which, such as temperature and creep area design may impact the piglet in terms of mortality, so the focus here will be hygiene. Different farms have different biosecurity protocols, biosecurity meaning measures to prevent pathogens from entering farm premises or a group of animals (external biosecurity) or the spreading of pathogens within farm premises or groups of animals (internal biosecurity; Postma et al., 2016a). Within the indoor farrowing environment, the focus is largely on internal biosecurity. The majority of piglets within countries with intensive pig industries, will be born into individual farrowing systems, often with the sow restrained by a crate, and with part- or fully slatted flooring with little or no bedding substrate. From an internal biosecurity viewpoint, this is advantageous, and farms will often use protocols that include washing and disinfecting the rooms after weaning followed by a period of rest before the next farrowing batch move in. Certainly washing, pressure washing and disinfecting can show a stepwise reduction in bacterial load (Kihlstrom et al., 2000) which will reduce the health challenge for the piglet immediately after parturition. There is plenty of evidence to indicate that biosecurity impacts production performance (Laanen et al., 2013; Cornelison et al., 2018), and use of antimicrobials (Postma et al., 2016b; Raasch et al., 2018). However, not all bacteria are harmful and indeed many have been shown to have beneficial impacts when becoming established in the piglet's gastrointestinal tract, not only in terms of performance (Gaukroger et al., 2020), but also impacting behavior and welfare in the short- and long-term (Parois et al., 2020; 2021). Cleaning the farrowing room with a broad-spectrum disinfectant can impact the piglet's gut and nasal microbiome by affecting colonization, and decreasing diversity out to weaning (Law et al., 2021).

The piglet's immune system is immature at birth (Gaskins, 1998). The sow has an epitheliochorial placenta (Wooding and Burton, 2008) which prevents maternal immunoglobulins from crossing to the piglet, and hence passive immunity is dependent on the transfer of immunoglobulins in the sow's colostrum over a few hours post-partum. As the piglet's own innate and adaptive immune systems take 2-4 wk to develop, sufficient colostrum transfer is imperative for defending against pathogens, but it also is a vital source of energy (Le Dividich and Noblet, 1981) and for stimulating development of the gastrointestinal tract (Xu et al, 2000). The amount of passive immunity acquired will be dependent on the quantity and quality of the colostrum, and its accessibility relative to number of competing littermates and the design of the farrowing environment. A number of approaches have been taken to increase colostrum quality and quantity (see reviews by Quesnel and Farmer, 2019; Farmer and Edwards, 2021). Briefly, approaches to increase colostrum quantity have had mixed results with only few such as increasing level of feeding, increasing fat content and including yeast products showing an increase in yield (Quesnel and Farmer, 2019). There does appear to be a fairly consistent negative effect of induction with prostaglandin F2α in reducing quantity (Devillers et al., 2007). Quality components such as fat, protein and lactose can all be manipulated by feed quantity and ingredients such as conjugated linoleic acid (CLA), yeast derivatives, dietary fiber, arginine and β-hydroxy β-methyl butyrate (Quesnel and Farmer, 2019). However, perhaps the most important qualitative changes are those that induce increases in the immunoglobulins – IgG, IgA and IgM.

Some immunomodulating compounds include CLA, shark liver oil, mannan and fructo oligosaccharides, yeast and yeast derivatives and lactobacillus (Quesnel and Farmer, 2019). Not only will good colostrum intake support piglet health status in the short term, it has been positively associated with weight at weaning and at the start and end of the fattening period, but also negatively associated with mortality during the nursery period (Declerck et al., 2016).

Gastrointestinal (GI) tract integrity and health and its mucosal immune system is of crucial importance for piglet survival. The gut mucosa is designed for nutritional absorption, but is also then at risk of pathogen entry. At birth, the GI tract is postulated to be sterile, but quickly becomes colonized by maternal and environmental bacteria, and this microbial population has an important role in shaping the development of the intestinal immune system in both the short and longer term (Stokes, 2017) and together with this role in protection against pathogens, also has roles in digestion, nutrient utilization, toxin removal and regulation of the endocrine and immune systems (Patil et al., 2020). As noted above, disinfecting the environment aims to reduce bacterial load, but is unable to distinguish between beneficial, commensal bacteria and those that may be pathogenic. It is becoming clear, however, that the microbial colonization of the piglet's gut can be managed to benefit the pig throughout its lifetime, by either nutritionally altering the maternal microbiome (Leblois et al., 2017) or directly dosing the piglet (Parois et al., 2021). There is some evidence to suggest that sow nutrition effects on piglet microbial diversity may occur in utero (Leblois et al., 2017), but this remains controversial, and it is more accepted that colonization begins during and immediately after parturition (see review by Duarte and Kim, 2022). The fecal microbiota of the sow and the contents of the sow's colostrum and milk will shape the microbiome of the piglet (Duarte and Kim, 2022) and both of these can be modified by the sow's diet (Yu et al., 2020). The piglet's microbiome can also be influenced directly by delivery of probiotics (Kiros et al., 2019; Parois et al., 2021). These effects of early programming of piglet microbiota can have long-term effects out into the grow-finish period (Wang et al., 2021).

The microbiome establishment during lactation is crucial for the next major health challenge which comes at weaning. Weaning often presents the simultaneous challenges of removal from the dam, change from milk to solid diet, mixing with unfamiliar penmates, change of housing system and, in North America especially, transport. Many aspects of these challenges are covered in the other sections, but the impact on health can be considerable in terms of mortality and morbidity. Within the U.S., mortality within the nursery phase is reported as 3.6% (see review by Gebhardt et al., 2020) from a variety of causes, the major one being respiratory disease. Given the multiple stressors, antibiotics were included in the feed (and in some countries still), to help piglets overcome health challenges. However, given concerns with increasing antimicrobial resistance, there is pressure to decrease antibiotic use worldwide. As with disinfectant regimes, the use of antibiotics can impact the gut microbiome in a relatively non-selective way and alter relative microbial populations and diversity (Lourenco et al., 2021; Parois et al., 2020). The key for the future will be shaping the pig's microbiome in such a way that allows it to cope with the health challenges that it faces from birth to slaughter, without antimicrobials. This will be achieved by a combination of selective disinfectant of farrowing accommodation, pre-programming the piglet's microbiome by maternal nutrition, and post-natal delivery of essential probiotics. In shaping the pig's microbiome to promote health, it is also possible that via the gut-microbiota-brain axis (GMBA), the pig's ability to cope with stress and its mental state (Domain 5) could be positively affected. There are several rodent studies showing this relationship (Foster et al., 2017) and recent work in pigs may show that lactobacillus can reduce anxiety (Verbeek et al., 2021).

Domain 4: Behavioral Interactions: Piglets progressively develop their behavioral repertoire over the first few weeks of life, first focusing on the dam as their source of food, and gradually exploring their physical and social environment. Therefore, their behavioral development can be strongly affected by their environment and their experiences in early life, with effects on their welfare but also possible long-term consequences. Piglets within a litter fight with each other after birth, primarily around suckling time for the first 4 to 5 d to establish a 'teat order' that is very stable afterwards (Puppe and Tuchscherer, 1999). This hierarchy remains relatively stable as long as the group does not change, but disruptions in group composition during events like weaning and other regrouping events with unfamiliar pigs typically reinitiate agonistic interactions to re-establish this hierarchy within the group (Verdon and Rault, 2017). Hence, it is recommended to keep littermates together or with a few littermates to minimize aggression and stress and their detrimental effects on welfare and productivity (Friend et al., 1983). Cross-fostering, which consists of moving piglets from one sow to another, is a common practice (Baxter et al., 2020). Its exact prevalence nowadays is missing but it was common practice in 98% of a sample of 300 U.S. and Canadian farms in 1994-1995, for 8.6% of their piglets (Straw et al., 1998), and cross-fostering has become more common with larger litter size (Baxter et al., 2013). Cross-fostering is most often done in the first week after farrowing and for sows with large or heterogeneous litters (see Baxter et al., 2013 for different methods of cross-fostering), but it can also be practiced at any time during lactation such as when a sow is sick or dies. Cross-fostered piglets can integrate into a new litter, especially if they are of similar size to the other piglets (Pajžlar and Skok, 2019), but the grunt contact call of cross-fostered piglets remain different from the sow's own piglets (Špinka et al., 2019), suggesting that cross-fostered piglets remain distinguishable. Indeed, foster piglets are isolated from play with 'native' non-foster piglets for the first few weeks of life (Clarkson et al., 2021). The implications of cross-fostering for piglet welfare remain to be uncovered, although recent studies report only minor differences when it is done soon after birth (Calderón-Díaz et al., 2018; Byrd et al., 2022).

Pigs have a social life much broader than just fighting with each other, given that social behavior in the wild has evolved to be more beneficial than detrimental to animals living in groups. In addition to sleeping, and lying down in physical contact (Goumon et al., 2020; Camerlink et al., 2022), pigs also have very frequent active social interactions with each other. Social nosing, consisting of two pigs touching each other's snout or coming in very close contact to the snout of one another, appears to be an important aspect of pig social communication (Camerlink and Turner, 2013). Piglets interact frequently through snout-to-snout contact with each other and the sow (Portele et al., 2019; Singh et al., 2017). In fact, social nosing (nosing nose, head and body) represented 78% of all social piglet interactions (Clouard et al., 2022), although the reported prevalence differs between studies depending on whether snout to snout, snout to head or snout to body are accounted for as social nosing (Portele et al., 2019). The implications of social nosing for pig welfare nevertheless remains to be fully understood.

The housing system during lactation also has an effect on piglet social behavior. Piglets interact more frequently with the sow in farrowing pens than crates (Singh et al., 2017), with piglets making nose contact with the sow about 1 time per min in farrowing pens (Portele et al., 2019). Piglets also play more and manipulate each other less in farrowing pens compared to farrowing crates but they missed more nursing bouts (Singh et al., 2017). In wild boars, the dam typically returns to the original group within one to two weeks after farrowing, and this behavior is still observed for example in free-range pigs when the sow and her piglets reintegrate into the group once the piglets are about two weeks of age. Studies have attempted to replicate this by so-called co-mingling of litter, socialization or group lactation (reviewed by van Nieuwamerongen et al., 2014), which can be done in different ways such as by mixed neighboring litters (D'Eath, 2005), or by keeping sows and their litters in groups (Verdon et al., 2019a,b, 2020). Piglets reared in sow groups and their litters are more active (Verdon et al., 2019a), and although mixing of litters can have temporary costs on the piglets such as fights between litters and resulting skin injuries (Verdon et al., 2020), it can also lead to improved benefits in the long-term, such as reduced aggression at weaning (Wattanakul et al., 1997; Verdon et al., 2016, 2019b). Overall, evidence suggests that socializing piglets early makes them more socially competent (D'Eath, 2005; Camerlink et al., 2018; Salazar et al., 2018). However, cross-suckling is frequent when piglets can access sows other than their dam (Wattanakul et al., 1997), which can represent a challenge to manage sows' body condition.

Increased space allowance *per se* can increase exploratory behavior and locomotion (Bolhuis et al., 2005). In addition to providing more space, the benefits of providing pigs with a more stimulating environment, often referred to as 'environmental enrichment', are currently under intense research. Generally, the provision of enrichment materials (for example: wood shavings, peat, straw, branches) allows to redirect the piglets' explorative and manipulative behavior toward their physical environment (floor bedding, enrichment items provided) and prevents the development of belly nosing and manipulative behavior toward other pigs or tail biting (Bolhuis et al., 2005; Oostindjer et al., 2011; Lahrmann et al., 2018). Environmental enrichment can for example increase the secretion of hormones that stimulate neuronal growth like brain-derived neurotrophic factor (Rault et al., 2018), a hormone linked to stress resilience in other species.

Van de Weerd and Day (2009) examined the research on the provision of environment enrichment and concluded that it should meet four criteria: 1) increase species-specific behavior, 2) maintain or improve health, 3) improve the economics of the production system, and 4) be practical to employ. The same study concluded that straw has the highest potential to fulfil those criteria, but that point-source enrichment like straw- or peat-dispensers, or ropes and rubber hoses could be suitable alternative if designed well, but chains and car tyres were not recommended as the pig's interest in them vanishes over time.

Play is also a salient behavior in young pigs. Play can be recognized as hop, scamper, pivot, toss head, shake object and carry object (Newberry et al., 1988). Play is also often split according to locomotory play and social play (Chaloupková et al., 2007). There is a social play period, as play typically peaks between two and six wk of age (Newberry et al., 1988). Play behavior is greater in piglets housed in complex or enriched environments (Bolhuis et al., 2005; Chaloupková et al., 2007; Oostindjer et al 2011; Martin et al., 2015), when piglets are provided with greater space and enrichment materials. Play fighting is nevertheless a special case, as it may represent a non-injurious form of aggression or to ascertain dominance (Weller et al., 2019; Cordoni et al., 2021), and it is often difficult to discriminate between play fighting and real fighting in piglets.

Interactions with humans can also shape piglets' development and their subsequent response to various management procedures. Brief positive human contacts on the first day of life reduced piglets' struggling during handling procedures like tail docking, and reduced the pigs' fear responses to humans (Muns et al., 2015). Generally, regularly spending time near the pigs, and the use of gentle contacts, a quiet voice and slow movement (Sommavilla et al., 2021) helps to develop a positive relationship between the caretaker and the pigs and reduces their fear of humans (Skuse et al., 2020; Rault et al., 2020). Having regular gentle contacts with weaner pigs can even result in them being in a more positive emotional state (Domain 5; Brajon et al., 2015).

DOMAIN 5 AND CONCLUSION

Domain 5: mental state, is considered as being affected and inherently linked to all other four Domains, and it is also the most closely linked to pig welfare (as discussed in this review). Finally, we would encourage key persons with responsibility to consider the Five Domains Model in future educational, assessment and third-party audit swine programs.

DISCLOSURES

The views and opinions expressed in this review do not necessarily reflect the official policy or position of the authors' respective employer or government. Mention of any trade name, proprietary product or specific equipment does not constitute a guarantee or warranty by USDA-ARS and does not imply its approval to the exclusion of other products that may also be suitable. The USDA-ARS is an equal opportunity and affirmative action employer, and all agency services are available without discrimination (JM). All other co-authors (AJ, EB, KD, J-LR) do not have actual or potential conflicts of interest.

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Table 1. Application of the Five Domains Model and neonatal and nursery pig welfare on-farm. Adapted from Beausoleil, 2020 and Kells, 2021

Physical/functional domains	Affective Domain	
Domain 1: Nutrition	**Domain 5:** Mental State	
Restrictions on:	**Negative experience**:	
Limited sow colostrum production, reduced piglet colostrum intake and quality	Pig is hungry and thirsty	
Inadequate amount and quality of creep feed	Pig is hungry and does not have the ability to experience positive tastes/smells	
Opportunities for:	**Positive experience**:	
Appropriate colostrum amount, intake and quality	Pig feels full and content	
Appropriate amount and quality of creep feed	Ability to experience pleasure of drinking and food tastes/smells	
Adequate amount and quality creep		

feed		
Domain 2: Physical environment		
Restrictions on:	**Negative experience**:	
Inadequate space for movement and access to the sow's udder	Piglet feels stiff	**ANIMAL WELFARE STATUS**
Inadequate feeder and water space, design and location placement	Stiff	
Thermal extremes outside of the pigs thermoneutral preferences	Too hot or too cold	
Uncomfortable flooring	Stiff, feelings of being uncomfortable	
Inadequate pig agency to choose where to lie, play, interact etc.,	Frustration, anger	
Inappropriate environmental variability and predictability	Fear, anxiety	
Opportunities for:	**Positive experience**:	
Easy access to sow udder, feeder	Pig feels full and content	

and water resources pen placement	Ability to experience pleasure of drinking and food tastes/smells		
Pigs are within their thermoneutral zone	Thermal comfort		
Comfortable flooring	Physical comfort		
Pig has agency to decide where to lie, play, interact etc.,	Contentment		
Appropriate environmental variability and predictability	Enjoyment		
Domain 3: Health			
Restrictions on:	**Negative experience**:		
Inability for the pig to develop immunity	Pain, nausea, sickness, weakness, exhaustion		
Increased disease prevalence resulting in increased morbidity and mortality			

Opportunities for: Improved sow microbiome Passive and active immunity improvements for the pig resulting in health and vigor	**Positive experience**: Physical comfort and vitality
Domain 4: Behavioral interaction **Restrictions on**: Invariant/barren environment Limited choices Inappropriate social environment	**Negative experience**: Fear, anxiety, boredom, loneliness, frustration and anger
Opportunities for: Varied and engaging environment Ability to choose Stable and positive social environment	**Positive experience**: Feelings of calm, safety, comfort, companionship, engagement, interest and reward