

**Title:** Optimized alternative housing and management strategies enhance sow well-being  
NPB #08-128 revised

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### Industry Summary

These data provide scientific support that the type of individual stall a sows is housed in for the 1<sup>st</sup> 30 days prior to being moved to group pen or throughout gestation can impact sow immune status, behavior, body weight gain and loss, and litter traits. Sows housed in standard gestation stalls had a different immune status than did sows housed in turn-around stalls—for the most part—sows housed in standard stalls had a more stimulated innate and adaptive immune status (or more balanced immune response) than did sows housed in turn-around stalls. In fact, sows that were housed in a standard stall prior to being housed in a pen had a more stimulated immune status at d 90 of gestation than did sows that were previously housed in a turn-around stall. Sow body weight gain throughout gestation was greatest among sows that were housed in pens regardless of the previous stall environment. However, sows housed in stalls throughout gestation loss less body weight at the end of lactation than did sows housed in group-pens—with those sows being housed in a standard stall and then moving to group pen losing the most body weight at end of lactation. Despite those sows being housed in pens from d 30 till d 110 of gestation gaining the most body weight, sows housed in standard stalls throughout gestation loss the least amount of weight and had better litter performance traits. Based on all measures of well-being these data support that the best housing environment or management strategy may be housing sows in standard gestation stalls throughout gestation or in turn-around stalls for 30-days and then moving them to pens for the remainder of gestation. The worse housing environments or management strategies based on measures of well-being are housing sows in turn-around stalls throughout gestation or housing sows in standard stall and then moving to pen.

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## **Keywords:**

Behavior, Gestation, Immune, Pen, Stall, Sow, Turn-around stall, Well-being

## **Scientific abstract**

New housing systems or management strategies are being implemented without scientific support that confirms these alternatives systems improve sow well-being. The objectives of this study were to evaluate the effects of housing sows in either an individual standard (**STS**) or turn-around (**TAS**) stall throughout gestation (d 6 till 110), or housing sows in either STS or TAS till d 30 of gestation, and then housing 10 sows in a pen for the remainder of gestation on sow well-being. Forty sows across 5 blocks (n = 200 sows) were allocated to 1 of 4 treatments: STS (**S:S**) or TAS (**T:T**) for entire gestation or STS till d 30, then group-pen (**S:GP**), or TAS till d 30, then group-pen (**T:GP**). Group-size was held constant and floor space allowance in each pen was 2.3 m<sup>2</sup>/sow. On d 30 and 90 of gestation sow immune and endocrine traits (n = 162 sows) were measured. On multiple days throughout gestation sow behavior (n = 150 sows) was registered during time periods 0800-0900 h, 1200-1300 h, and 1600-1700 h (n = 150 sows). Sow BW was measured on d 30, 90, 110, and end of lactation. Litter performance was collected at farrowing and weaning. Data were analyzed using Proc MIXED with repeated measures (SAS). There was a stall type × day of gestation interaction for sow behavior and immune status ( $P < 0.05$ ); on d 30 plasma cortisol was greater and NK cytotoxicity was less for sows housed in TAS compared with those in STS. Standing and ONF behaviors were greater ( $P < 0.05$ ) for sows housed in TAS on both d 6 and 30. Sows housed in TAS performed more ( $P < 0.05$ ) standing and eating behavior than did sows housed in STS. Stall type and time of day affected immune and behavior traits ( $P < 0.05$ ) with NK cytotoxicity and lymphocyte proliferation being greater ( $P < 0.05$ ) for sows housed in STS prior to pen placement (S:GP) compared with sows in T:GP on d 90. Sows from TAS and housed in group pens (T:GP) performed more ( $P < 0.001$ ) bouts of aggression especially during time period 1 (0800-0900 h; feeding). Regardless of day of gestation, sows housed in S:GP had greater total WBC count ( $P < 0.05$ ), neutrophil phagocytosis ( $P < 0.05$ ), and NK cytotoxicity ( $P < 0.10$ ) than sows in T:GP while sows housed in T:GP had greater neutrophil chemotaxis ( $P < 0.05$ ). Sow body weight gain was not affected by previous stall environment but sows in pen gained more ( $P < 0.001$ ) body weight than did sows in stalls and sows in S:GP losing the most body weight at end of lactation ( $P < 0.09$ ). Sows housed in S:S had better litter performance than did sows housed in T:T or S:GP ( $P < 0.05$ ). These data support that stall environment prior to housing in pen and throughout gestation can impact sow well-being based on multiple measures of well-being.

## **Introduction:**

There is mounting concern among pork producers and consumers regarding the impact of current housing systems on the welfare of the gestating sow. In 2013, only group housing of pregnant sows from 4-wk after service to 1-wk prior to farrowing will be allowed in the European Union (EU) (directive 2001/88/CE).

The minimal space allowance will be 2.25 m<sup>2</sup>/sow and for groups of ≤ 6 sows this space must be increased by 10%. Despite these new EU requirements, the appropriate floor space for small groups of sows housed in pens and floor-fed or the appropriate housing environment prior to moving into group pens has not been adequately assessed or scientifically defined based on multiple measures of sow well-being.

It is incumbent upon those of us in research and outreach to assist producers in adopting new technologies and management schemes that help maintain their position and grow their competitive advantage in the global marketplace, while maintaining consumer trust through improving sow well-being. First and foremost, scientists must understand the impact that various housing systems have on the physiological and psychological (behavioral) aspects of the sow. Moreover; scientists must understand the underlying consequences of implementing alternative housing systems and management strategies without scientifically sound information. These are crucial unknowns that must be investigated so that we do not unwittingly compromise sow well-being.

To date, most scientific reviews of dry-sow keeping systems indicate that the welfare of the sow is equivalent in stalls and group-pens based on behavior, productivity, and well-being (reviewed by McGlone et al., 2004; Rhodes et al., 2005; Curtis et al., 2009). Management techniques utilizing group-pens and individual housing systems must be assessed using a multi-disciplinary approach to determine if combination of both systems can potentially improve sow well-being (Gonyou 1994; Trevisi and Bertoni, 2010). Therefore, the objective of this study was to evaluate the impact of housing sows in two different types of individual stalls (standard or turn-around) from d 6 to 30 of gestation and then housing sows in pen for the remainder of gestation on sow well-being.

### **Objectives:**

To identify alternative individual environment(s) that impact sow performance and well-being by determining the effect(s) of housing sows in either stall type for part of or entire gestational period in conjunction with group-pen housing system.

### **Project Objectives:**

Experiment 1: to evaluate the impact that housing sows in either standard gestation stall or turn-around stall throughout gestation has on sow well-being.

Experiment 2: to evaluate the impact that the individual housing system a sow is housed in for 30 d and then moved to group-pen has on sow well-being.

### **Materials and Methods**

Crossbred primi- and multi-parous sows were used in this study. All sows were artificially inseminated within 24 h after estrus onset and again 24 h later. Pregnancy was diagnosed at d 25 post-breeding using an Aloka 500V ultrasound machine (Aloka Inc, Tokyo, Japan) for trans-abdominal examinations, with a 3.5 MHz

convex linear-array transducer. All newly bred sows (or gilts) were moved to their assigned stall type at d 6 of gestation based on BW and parity. Sows were housed in well insulated, mechanically ventilated rooms. The ambient temperature was set at 21° C. Lighting was set at 10:14 h, light:dark cycle with lights on at 0700 h and lights off at 1700 h.

In a 2 x 2 factorial design, forty sows per block (n = 5 blocks; n = 200 total sows) were allotted to stall type: standard (**STS**) or turn-around (**TAS**) stall for 30 d post-breeding and then a housing environment of a stall or group-pen for the remainder of the gestational period. On d 6 post-breeding, sows were assigned based on body weight and parity to STS (Control) or TAS (Treatment) till d 30 of gestation. Then on d 30, 20 of the 40 sows remained in an individual stall (STS or TAS) while the other 20 sows (10 per stall type) were moved to a pen with a floor space of 2.3 m<sup>2</sup> per sow, resulting in 4 treatment groups: **S:S**, **T:T**, **S:GP**, or **T:GP**. The outside dimension of both stalls was 2.13 m x 0.69 m, but the TAS provided an additional 1.73 m of width in the rear of the stall.

All sows were floor-fed, however, sows housed in group-pens were fed as a group on the solid portion of the floor between 0800 and 0900 h by the same team of qualified persons to ensure consistency of feed dispersion. All sows had free access to water. Each stall was equipped with an individual waterer while in the group pens there was one waterer centrally located with 2 nipples. Based on previous results, all sows were fed a modified gestation diet which was based on corn, soybean meal, wheat middlings (15%), and soybean hulls (30%). This diet contained 13.2% CP and provided 2,885 kcal ME/kg. The ADF and NDF were 16.6 and 28.3 %, respectively. All nutrients were formulated to meet or exceed current requirements (NRC, 1998). During d 6-90 of gestation all sows were fed 6,700 kcal ME/d and then 10,720 kcal ME/d for remainder of gestation, with levels of energy corresponding to 2.3 and 3.7 kg/d, respectively.

#### *Plasma and Immune Assays*

Physiological measures were assessed for sows in the blocks 1 through 4 (n = 162 sows) on d 34 and 90 of gestation. Blood samples (~10 mL) were obtained via vena-puncture using Vacutainers with either heparin or EDTA. Total white blood cell counts (WBC) were made electronically using a Coulter Z1 particle counter. Whole blood smears were made, fixed in methanol, stained with Hema-3® staining system and viewed under a light microscope to determine leukocyte differential counts. Using a validated commercial radioimmunoassay (Coat-A-Count®) plasma cortisol concentration was measured following manufactured protocol with minor modifications (Sutherland et al., 2005). Intra- and inter-assay CV were 4.5 % and 7.62 %, respectively.

For functional immune assays, whole blood was diluted with RPMI layered over Histopaque® -1077, (density = 1.077 g/mL) and -1119 (density = 1.119 g/mL) and centrifuged at 700g 30 min at 25°C. Lymphocytes were removed from 1077 layer and neutrophils from 1119 layers. Isolated cells were washed twice and resuspended in RPMI. Cell concentrations were adjusted with RPMI based on the specific immune assays' respective requirements.

Neutrophil chemotaxis was measured using an assay previously described by Salak et al. (1993). Neutrophils were used at a concentration of  $3 \times 10^6$  cells/mL to evaluate the ability of cells to migrate toward assay medium (control; random migration) or recombinant human complement-5a ( $10^{-7}$  M; Sigma Aldrich), and recombinant human IL-8 (100  $\mu$ g/mL) (chemotaxis-directed migration). Neutrophil phagocytosis was measured using a flow cytometry-based assay as previously described by Jolie et al. (1997) with minor modifications as described by Niekamp et al. (2006). Fluorescent beads were pre-incubated 30 min with nonheat-inactivated porcine serum before adding beads to the samples at a 10:1 (beads-to-neutrophils) ratio and then cells and beads were incubated together for 45 min. The percentage of engulfment of beads by cells was evaluated using a flow cytometer.

Mitogen-induced lymphocyte proliferation assay was performed using a CellTiter 96® nonradioactive cell proliferation assay following the manufacturer's protocol with minor modification as previously described by Sutherland et al. (2005). Briefly, lymphocytes at a concentration of  $5 \times 10^6$  cells/mL were added in triplicate to a sterile 96-well flat-bottom plate. Concanavalin A (**CONA**) and lipopolysaccharide (**LPS**) were used as mitogens (0, 0.2, 2.0 and 20  $\mu$ g/mL) to stimulate T and B cells, respectively. Plates were incubated 68 h at 37°C in a 5% CO<sub>2</sub> humidified incubator and then Promega Dye was added to each well, and the plates were incubated for an additional 4 h. Promega Stop solution was added and the plates were incubated overnight at 37°C, and then read using a microplate reader (BIO-TEK Instruments) at wavelength 550 nm with reference wavelength 690 nm. Results are expressed as a proliferation index (**PI**):  $\text{Optical density}_{(550/690 \text{ nm})} \text{ stimulated cells} \div \text{Optical density}_{(550/690 \text{ nm})} \text{ non-stimulated cells}$

Natural killer (NK) cell cytotoxicity was measured using a commercially available nonradioactive cytotoxicity detection kit as described previously by Sutherland et al. (2005). Briefly, lymphocytes were adjusted to  $1 \times 10^7$  cells/mL and K-562 cells were adjusted to a constant 10,000 cells per well. Samples were run in triplicate at effector (lymphocytes) to target-cell (K-562) ratios of 12.5:1, 25:1, 50:1, and 100:1, respectively. Plates were read using a microplate reader at wavelength 490 nm and reference wavelength 690 nm. Percent cytotoxicity was calculated as described by Lumpkin and McGlone (1992) and an assay was considered valid if maximum release divided by spontaneous release was  $\leq 20\%$ .

### ***Behavioral Measures***

Live remote behavioral observations (n = 150 sows) were registered over 5 blocks using Geovision GV-1240 (Geovision, Inc., Irvine, CA) video capture combo card and Web-Cam (remote capability with POS Live View via IE Browser with Geovision Remote Monitoring Software; Geovision, Inc., Irvine, CA). Behavior was observed and registered for 3-h (time periods: 0800-0900 h; 1200-1300 h; 1600-1700 h) on d 6 (individual stalls only), 30, 45, 65, 90, and 110 of gestation. Total of 90-h of behavioral observations were made and registered on various gestation days across blocks of sows. Using a web-cam live behavioral observations were made by viewing 5 sows in each of the individual stalls and 10 sows in each group-pen. Using continuous-sampling techniques eating, laying, standing, sitting and oral-nasal-facial (**ONF**) behaviors were registered and

analyzed. For sows housed in group-pens aggressive encounters and drinking behavior were also registered. Duration and percentage of time sows spent engaged in each behavior was analyzed.

### ***Statistical Analysis***

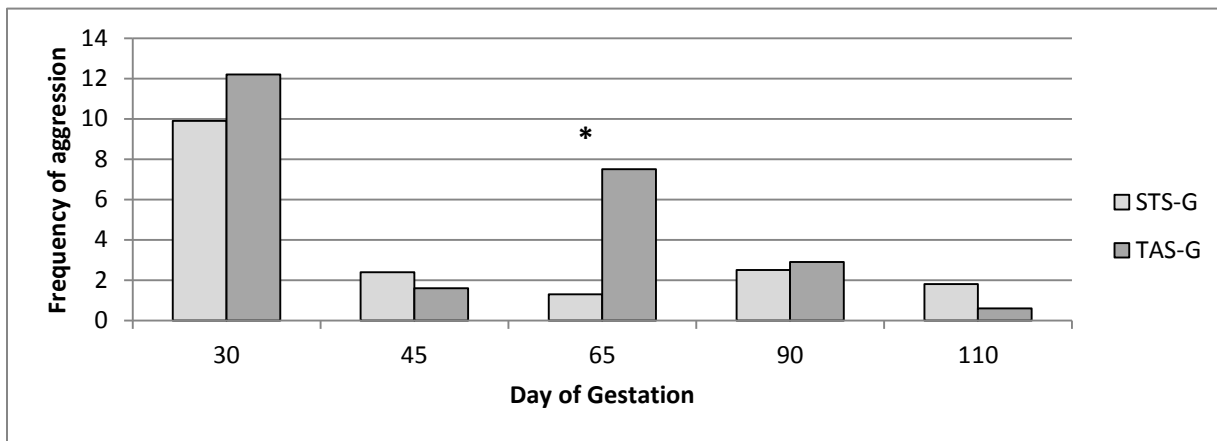
Statistical analyses were performed using SAS (SAS Inst. Inc., Cary, NC). All traits were tested for departures from a normal distribution. Natural logarithmic transformation was applied to all traits deviating from a normal distribution to facilitate the interpretation of results. A linear mixed effects model was used to analyze the physiological measurements. The model included the fixed effect factors of stall type TRT (2 levels: STS or TAS), stall type prior to group pen TRT (2 levels: STS-GP or TAS-GP), parity (4 levels: 1 to  $\geq 4$ ), day of measurement, and all interactions among fixed effects, as well as, the covariate of the corresponding blood measurement at the start of the trial for stall type prior to group-pen. A random effect of group (5 levels: sow groups 1 through 5) was included in the model to account for potential environmental and management differences across groups. The measurements corresponding to TRT were from a single sow and thus, the experimental unit was sow. Behavior model also included hour of measurement in the behavioral model. Estimates were obtained using the PROC MIXED of SAS. Significance was set at ( $P \leq 0.05$ ), and trends were discussed at ( $P \leq 0.10$ ).

## **RESULTS**

**Interactions:** There was a stall type  $\times$  day of gestation interaction for both immune status and behavior of dry sows ( $P < 0.05$ ). On d30 of gestation, sows housed in STS had greater ( $P < 0.05$ ) eosinophils and NK cytotoxicity than did those sows housed in TAS, whereas, sows in TAS had greater ( $P < 0.05$ ) plasma cortisol. On d30 of gestation, both percentage and duration of laying behavior was greater ( $P < 0.01$ ) for sows housed in STS, whereas, standing and ONF behaviors were greater ( $P < 0.05$ ) for sows housed in TAS. Sows housed in TAS spent more time standing during time period 1 (0800-0900 h) than did sows housed in STS ( $P < 0.05$ ). There was a stall type  $\times$  parity interaction for sow BW gain from d 6 to d 30 of gestation among gilts, with those gilts housed in STS gaining more ( $P = 0.04$ ; [23.3, STS vs. 14.6, TAS]) weight, while parity 5 and 6 sows gained least ( $P = 0.05$ ; [5.7, STS vs. 16.0, TAS]) body weight when housed in STS. Conversely, parity 5 and 6 sows housed in STS gained more BW from d 30 to 90 ( $P < 0.02$ ; [60.1, STS vs. 39.0 TAS]) and d 90 to 110 ( $P = 0.03$ ; [125, STS vs. 102, TAS]) compared with those sows housed in TAS.

Among sows housed in group-pens after d30 of gestation, there was a stall type  $\times$  day of gestation interaction for immune status and behavior. On d 90 of gestation, both NK cytotoxicity and CONA-induced lymphocyte proliferation were greater ( $P < 0.05$ ) for sows housed in S:GP compared with sows in T:GP. On d 65 sows housed in T:GP performed more aggressive behavior than did those sows housed in S:GP ( $P < 0.05$ ; **Figure 1**). Moreover, there was a stall type  $\times$  time period interaction for sow aggression ( $P < 0.001$ ); during time period 1 (0800-0900; feeding) sows kept in T:GP had more aggressive interactions than did sows housed in S:GP at d 65 of gestation.

**Figure 1. Effect of stall type prior to group-pen placement and day of gestation on sow aggression**



**Main effects of housing treatment:** There were main effects of stall type on sow physiology and behavior. Sows kept in TAS had greater ( $P = 0.08$ ) LPS-induced lymphocyte proliferation index and neutrophil chemotaxis (LPS:  $1.6 \pm 1.0$  index;  $62 \pm 5.9$  no/4 fields) than did sows housed in STS (LPS:  $1.12 \pm 1.0$  index;  $45 \pm 6.7$  no/4 fields). All other immune or endocrine traits were similar among sows kept in either stall type throughout gestation ( $P > 0.10$ ). Sows housed in TAS spent more time standing, eating, and performing ONF behaviors ( $P < 0.05$ ) than did sows in STS (**Table 1**). Among group-penned sows, type of stall that they were kept in prior to pen environment had an effect on immune status ( $P < 0.05$ ; **Table 2**). Sows in S:GP had greater ( $P < 0.05$ ) total WBC count than did sows in T:GP. Neutrophil phagocytosis was greater for sows in S:GP whereas neutrophil chemotaxis was greater for sows housed in T:GP ( $P < 0.05$ ; **Table 2**).

**Table 1. Effects of stall type on sow behavior (least squares means  $\pm$  SE)**

Behavior	Stall Type		P-value
	STS	TAS	
<b>Lay</b>			
Duration, min/bout	$23.5 \pm 1.0$	$23.3 \pm 1.0$	0.86
Percentage, %	$52.2 \pm 1.6$	$50.5 \pm 1.5$	0.44
<b>Sit</b>			
Duration, min/bout	$1.02 \pm 0.2$	$1.19 \pm 0.2$	0.56
Percentage, %	$3.1 \pm 0.7$	$3.3 \pm 0.6$	0.88
<b>Stand</b>			
Duration, min/bout	$20.9 \pm 0.9^b$	$24.7 \pm 0.9^a$	0.003
Percentage, %	$42.4 \pm 1.5^d$	$46.0 \pm 1.5^c$	0.09
<b>Eat (0800-0900h only)</b>			
Duration, min/bout	$27.0 \pm 0.8^b$	$30.7 \pm 0.8^a$	<0.001
Percentage, %	$46.0 \pm 1.2^b$	$51.2 \pm 1.3^a$	0.004
<b>ONF</b>			
Duration, min/bout	$11.4 \pm 0.8$	$12.4 \pm 0.7$	0.38
Percentage, %	$28.4 \pm 1.5^d$	$32.0 \pm 1.4^c$	0.08

<sup>a,b</sup> Within a row, means without a common superscript letter differ ( $P \leq 0.05$ ) or <sup>cd</sup>( $P < 0.10$ ).

NK cytotoxicity tended to be greater ( $P = 0.07$ ) for sows housed in S:GP than for sows in T:GP. All other physiological measures (**Table 2**) and behavior (**Table 3**) were similar among sows kept in different stall types prior to moving to group-pen ( $P > 0.10$ ). However, during time period 1 (feeding time) sows housed in T:GP were more aggressive compared with sows in S:GP (**Figure 2**) throughout gestation.

**Table 2. Main effects of stall type prior to group-pen on endocrine and immune status of gestating sows (least squares means  $\pm$  SE)**

Immune trait	S:GP	T:GP	P-value
Total WBC, $10^7/\text{mL}$	$2.29 \pm 0.07^a$	$2.09 \pm 0.07^b$	0.044
Neutrophils, $10^7/\text{mL}$	$5.67 \pm 0.35$	$5.40 \pm 0.33$	0.571
Lymphocyte, $10^7/\text{mL}$	$2.94 \pm 0.24$	$2.90 \pm 0.23$	0.886
Neutrophils, %	$37.7 \pm 1.3$	$36.3 \pm 1.3$	0.464
Lymphocytes, %	$53.9 \pm 1.4$	$54.9 \pm 1.3$	0.587
Monocytes, %	$4.67 \pm 0.5$	$5.57 \pm 0.5$	0.997
Eosinophils, %	$3.69 \pm 0.3$	$3.47 \pm 0.3$	0.600
Neutrophil-to-lymphocyte ratio	$0.75 \pm 0.07$	$0.78 \pm 0.06$	0.799
Phagocytosis, %	$55.1 \pm 1.3^a$	$51.5 \pm 1.2^b$	0.047
LPS-induced proliferation 02	$1.13 \pm 0.12$	$1.34 \pm 0.10$	0.171
ConA-induced proliferation 02	$1.28 \pm 0.12$	$1.07 \pm 0.10$	0.177
NK cytotoxicity, % 50:1	$63.4 \pm 8.9^c$	$44.3 \pm 5.1^d$	0.069
Chemotaxis, IL8	$37.3 \pm 6.3^b$	$59.5 \pm 6.9^a$	0.021
Chemotaxis, C5a	$44.2 \pm 6.6^b$	$68.6 \pm 7.3^a$	0.015
Plasma cortisol, ng/mL	$35.7 \pm 2.0$	$38.3 \pm 1.9$	0.348

<sup>a,b</sup> Within a row, means without a common superscript letter differ ( $P < 0.05$ ).

<sup>c,d</sup> Within a row, means without a common superscript letter differ ( $P < 0.10$ ).

**Table 3. Main effects of stall type prior to group-pen placement on behavior of gestating sows (least squares means  $\pm$  SE)**

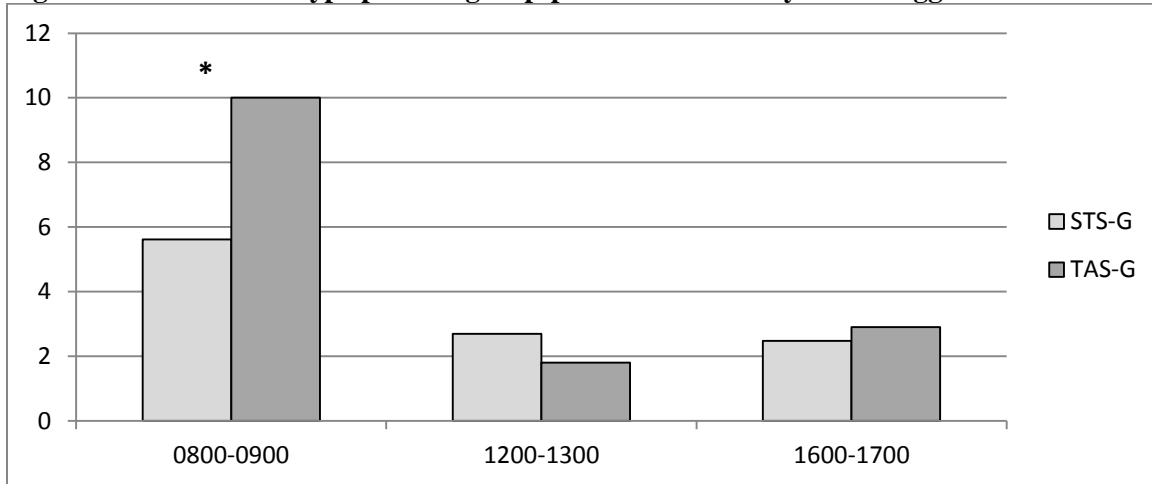
Behavior	S:GP	T:GP	P-value
<b>Lay</b>			
Duration, min/bout	$17.2 \pm 1.8$	$17.6 \pm 1.8$	0.867
Percentage, %	$43.7 \pm 3.6$	$41.1 \pm 3.5$	0.615
<b>Sit</b>			
Duration, min/bout	$2.9 \pm 0.6$	$1.9 \pm 0.6$	0.242
Percentage, %	$19.0 \pm 3.2$	$19.4 \pm 3.2$	0.933
<b>Stand</b>			
Duration, min/bout	$15.6 \pm 1.5$	$13.2 \pm 1.5$	0.272
Percentage, %	$39.1 \pm 3.3$	$36.0 \pm 3.2$	0.509
<b>Eat<sup>1</sup></b>			
Duration, min/bout	$9.0 \pm 2.3$	$9.5 \pm 2.4$	0.902
Percentage, %	$24.5 \pm 7.2$	$26.9 \pm 7.6$	0.821
<b>Drink</b>			
Duration, min/bout	$0.7 \pm 0.1$	$0.51 \pm 0.1$	0.185
Percentage, %	$8.2 \pm 1.2$	$6.0 \pm 1.1$	0.159
<b>ONF</b>			
Duration, min/bout	$9.5 \pm 1.2$	$9.1 \pm 1.2$	0.813
Percentage, %	$32.8 \pm 3.1$	$31.4 \pm 3.1$	0.744

<sup>a,b</sup> Within a row, means without a common superscript letter differ ( $P \leq 0.05$ ).

<sup>c,d</sup> Within a row, means without a common superscript letter differ ( $P < 0.10$ ).

<sup>1</sup> eat behavior only registered during time period 1 (0800-0900).

**Figure 2. Effect of stall type prior to group-pen and time of day on sow aggression**



\*denotes that treatments differ ( $P < 0.01$ ) on during specific time period.

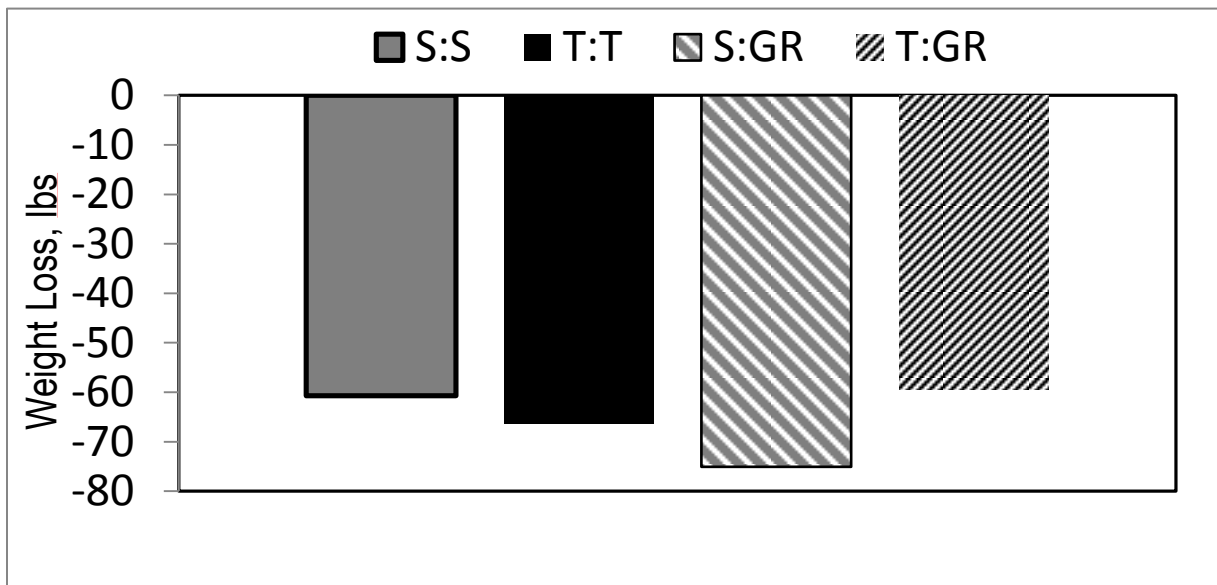
Sow BW gain (**Table 4**) and loss (**Table 4, Figure 3**) were affected by gestation treatment but not by stall type prior to group-placement. Sows housed in either S:S or T:T gained less ( $P < 0.0001$ ) BW than did sows housed in S:GP or T:GP from d 30 to 90, d 30 to 110 and the entire gestational period (d 6 to 110).

**Table 4. Effects of gestation environment on sow body weight gain and loss.**

Measure	Gestation environment				P-value		
	S:S	T:T	S:GP	T:GP	TRT	PAR	TRT* PAR
Gain, d6 to 30	14.0±2.2	8.8±2.3	8.7±2.3	13.9±2.5	0.17	0.005	0.21
Gain, d30 to 90	41.9±3.2 <sup>e</sup>	39.5±3.3 <sup>e</sup>	67.2±3.4 <sup>d</sup>	63.1±3.6 <sup>d</sup>	<0.0001	0.51	<0.0001
Gain, d30 to 110	98.7±3.9 <sup>e</sup>	97.2±4.0 <sup>e</sup>	122.4±4.0 <sup>d</sup>	121.7±4 <sup>d</sup>	<0.0001	0.07	<0.0001
Gain, d6 to 110	112.7±4.3 <sup>e</sup>	105.9±4.5 <sup>e</sup>	131.1±4.5 <sup>d</sup>	135.6±4.8 <sup>d</sup>	<0.0001	0.82	<0.0001
Loss, d131 to 110	-59.6±4.7 <sup>b</sup>	-63.5±5.1 <sup>b</sup>	-76.7±5.5 <sup>a</sup>	61.1±5.5 <sup>b</sup>	0.09	0.52	0.034

Sow body weight gain from d 29 to d 110 of gestation was greatest among sows moved to group pens at d 30 of gestation, regardless of stall environment ( $P < 0.0001$ ). Sow body weight gain from d 6 of gestation to d 110 of gestation was greatest for sows in T:GP compared to those sows in T:T or S:S ( $P < 0.0001$ ). Sow body weight loss during lactation was least ( $P = 0.032$ ) among sows kept in S:S compared to those that were moved from STS to pen (S:GP; **Figure 3**). Among sows housed in pens, those that were kept in STS prior to pen (S:GP) loss more ( $P = 0.025$ ) weight than did those in TAS prior to pen (T:GP).

**Figure 3. Effects of gestation environment on body weight loss (d131-110)**



There were no significant main effects of stall type on litter traits for sows that were housed in either a STS or TAS from d 6 to 30 of gestation (**Table 5**). However sows housed in TAS tended to have more stillborn piglets ( $P = 0.09$ ) and less mummified piglets ( $P = 0.08$ ) than did sows housed in STS (**Table 5**). Sows housed in STS also tended to wean piglets with greater ( $P = 0.09$ ) weight than did sows housed in TAS (**Table 5**).

**Table 5. Effects of stall type prior to placement in group-pen on litter traits**

Litter Trait	Stall Type (d6-30)		P-value
	STS	TAS	TRT
Total birth weight	35.4 ± 0.9	35.1 ± 1.0	0.82
Live birth weight	33.6 ± 0.9	34.2 ± 0.9	0.61
Total no. born	11.7 ± 0.3	11.6 ± 0.3	0.95
No. born alive	10.8 ± 0.3	11.1 ± 0.3	0.41
No. stillborn	0.80 ± 0.08	1.2 ± 0.09	0.09
No. mummy	0.42 ± 0.1	0.11 ± 0.1	0.08
No. weaned	8.6 ± 0.2	8.5 ± 0.5	0.77
Wean weight	124 ± 3.5	116 ± 3.5	0.09
Adj. wean weight	122 ± 3.7	120 ± 4	0.88

There were several main treatment effects, parity and treatment x parity interactions for litter traits (**Table 6**). Live birth weight was greater ( $P = 0.06$ ) for piglets from sows that were housed in T:GP compared with sows housed in either T:T or S:GP, whereas piglets from sows housed in S:S was similar to all groups. Sows housed in S:S gave birth to more ( $P = 0.013$ ) total number piglets than did sows housed in T:T or S:GP (**Table 6**). These sows (S:S) and sows housed in T:GP had greater ( $P < 0.001$ ) number of piglets born alive

than did those sows housed in either T:T or S:GP (**Table 6**). Sows housed in either S:S or T:T weaned greater number of piglets ( $P = 0.02$ ) and had less ( $P < 0.01$ ) stillborn piglets than did sows housed in S:GP or T:GP. Sows housed in T:GP had more stillborn piglets.

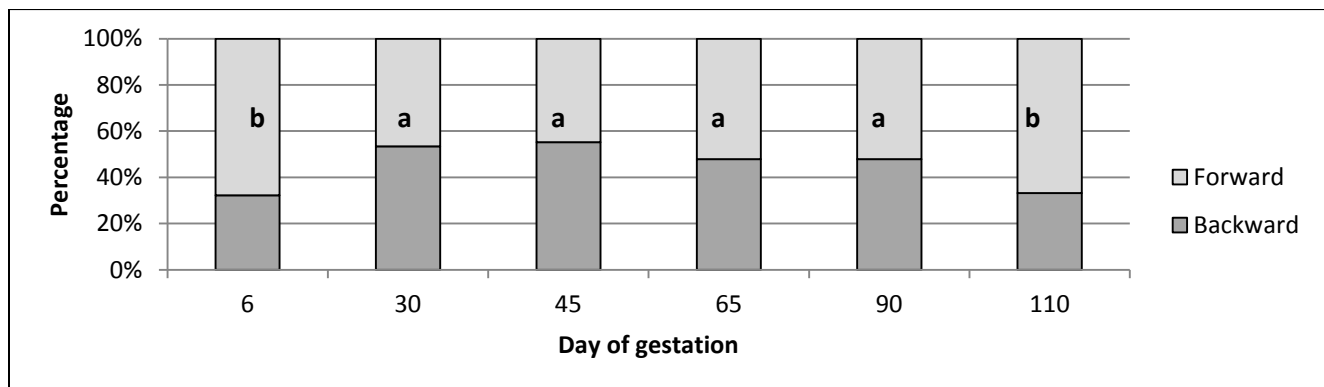
**Table 6. Effects of environment on litter traits for gestating sows**

Litter Trait	Gestation environment				P-value		
	S:S	T:T	S:GP	T:GP	TRT	PAR	TRT* PAR
Total birth wt.	36.6 ± 1.3	35.6 ± 1.4	34.2 ± 1.4	34.7 ± 1.4	0.26	0.66	0.017
Live birth wt.	34.9 ± 1.2 <sup>ab</sup>	32.7 ± 1.3 <sup>b</sup>	32.2 ± 1.3 <sup>b</sup>	36.0 ± 1.3 <sup>a</sup>	0.06	0.29	0.37
Total no. born	12.6 ± 0.4 <sup>a</sup>	11.2 ± 0.5 <sup>b</sup>	10.4 ± 0.5 <sup>b</sup>	11.8 ± 0.5 <sup>ab</sup>	0.013	0.17	0.04
No. born alive	11.5 ± 0.4 <sup>a</sup>	10.1 ± 0.5 <sup>b</sup>	9.6 ± 0.4 <sup>b</sup>	12.1 ± 0.5 <sup>a</sup>	0.0003	0.54	0.012
No. stillborn	0.54 ± 0.2 <sup>c</sup>	0.93 ± 0.3 <sup>c</sup>	1.3 ± 0.3 <sup>b</sup>	2.0 ± 0.3 <sup>a</sup>	0.002	0.004	0.09
No. mummy	0.53 ± 0.2	0.12 ± 0.2	0.35 ± 0.2	0.10 ± 0.2	0.33	0.22	0.60
No. wean	8.9 ± 0.3 <sup>a</sup>	8.8 ± 0.3 <sup>a</sup>	7.8 ± 0.3 <sup>b</sup>	8.0 ± 0.3 <sup>b</sup>	0.02	0.02	0.003
Adj. wean wt.	122 ± 3.7	120 ± 4.0	123 ± 3.9	119 ± 4.2	0.88	0.99	0.99

<sup>a-c</sup>Means within row without common superscript differ at ( $P \leq 0.05$ ). S:S = STS before and STS after; T:T = TAS before and TAS after; S:GP = STS before and group-pen after; T:GP = TAS before and group-pen after.

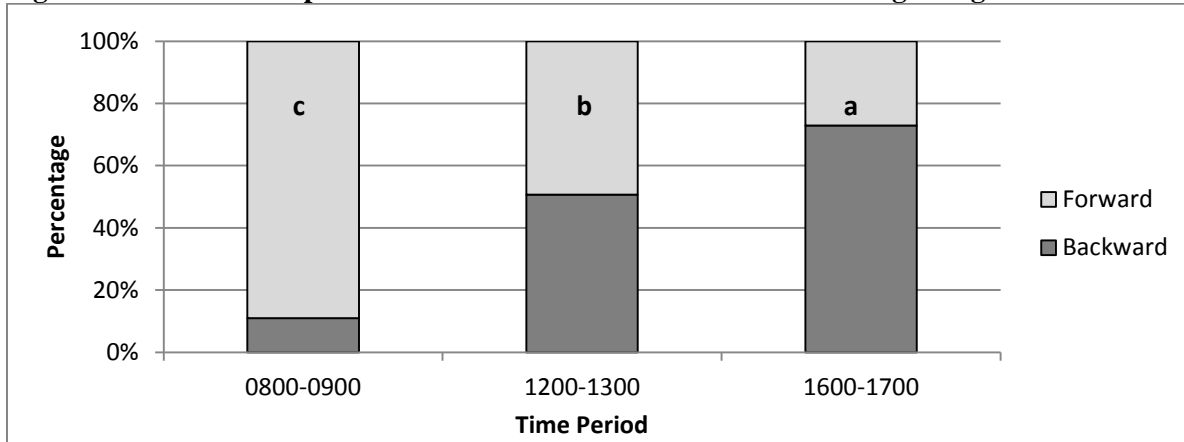
**Other factors that affected physiological and behavior traits:** Sow head direction in TAS was influenced by day of gestation and time of day; sow kept head in front of stall a greater ( $P < 0.001$ ) percentage of time on d 6 and 110 compared with all other days (**Figure 4**). During time period 1 (0800-0900 h; feeding time) and 2 (1200-1300 h) sows spent majority of the time with head forward but also spent greater percentage of time during time period 2 (1200-1300 h) than during time period 3 (1600-1700 h) ( $P < 0.001$ ; **Figure 5**) with head forward.

**Figure 4. Effect of day of gestation on direction of sow's head in TAS throughout gestation**



<sup>a-d</sup> across days of gestation, means without a common superscript letter differ ( $P < 0.001$ ).

**Figure 5. Effect of time period on direction of sow's head in TAS throughout gestation**



<sup>a-c</sup> across time periods, means without a common superscript letter differ ( $P < 0.001$ ).

Sows had more neutrophils and less lymphocytes resulting in a greater N:L ratio on d 90 compared with d 30 of gestation ( $P < 0.05$ ; **Table 7**). Also, sows had greater neutrophil chemotaxis and phagocytosis, but less NK cytotoxicity on d 90 compared with d 30 ( $P < 0.05$ ; **Table 7**).

**Table 7. Day of gestation affects endocrine and immune status of dry sows**

Immune trait	Day of Gestation		P-value
	30	90	
Total WBC, $10^7/\text{mL}$	$2.20 \pm 0.06$	$2.13 \pm 0.06$	0.399
Neutrophils, $10^7/\text{mL}$	$5.88 \pm 0.26$	$5.39 \pm 0.25$	0.179
Lymphocyte, $10^7/\text{mL}$	$3.30 \pm 0.12^a$	$2.55 \pm 0.12^b$	<0.001
Neutrophils, %	$35.0 \pm 1.3^b$	$39.9 \pm 1.4^a$	0.011
Lymphocytes, %	$54.4 \pm 1.3^a$	$51.7 \pm 1.3^b$	0.013
Monocytes, %	$5.21 \pm 0.4$	$4.41 \pm 0.4$	0.195
Eosinophils, %	$3.67 \pm 0.3$	$3.69 \pm 0.3$	0.943
Neutrophil-to-lymphocyte ratio	$0.68 \pm 0.07^b$	$0.91 \pm 0.07^a$	0.018
Phagocytosis, %	$51.4 \pm 1.4^b$	$58.6 \pm 1.4^a$	<0.001
LPS-induced proliferation 02	$1.15 \pm 0.18$	$1.53 \pm 0.19$	0.146
ConA-induced proliferation 02	$1.49 \pm 0.23$	$1.13 \pm 0.24$	0.269
NK cytotoxicity, % 50:1	$58.7 \pm 5.3^a$	$38.9 \pm 4.9^b$	0.007
Chemotaxis, IL-8	$54.2 \pm 21.0$	$54.5 \pm 15.1$	0.991
Chemotaxis, C5a	$44.7 \pm 8.1^d$	$62.2 \pm 6.1^c$	0.081
Plasma cortisol, ng/mL	$40.6 \pm 2.2$	$40.9 \pm 2.2$	0.927

<sup>a,b</sup> Within a row, means without a common superscript letter differ ( $P \leq 0.05$ ).

<sup>c,d</sup> Within a row, means without a common superscript letter differ ( $P < 0.10$ ).

As day of gestation increased, percentage of time spent and duration of laying and sitting behaviors increased while standing behavior decreased ( $P < 0.001$ ; **Table 8**). Duration and percentage of time sows spent performing ONF behaviors decreased as day of gestation increased ( $P < 0.001$ ; **Table 8**).

**Table 8. Day of gestation effects duration and percentage of postural, maintenance, and ONF behaviors of dry sows**

Behavior	Day of Gestation						P-value
	6	30	45	65	90	110	
<b>Lay</b>							
Duration, min/bout	12.2 ± 2.2 <sup>c</sup>	22.2 ± 1.5 <sup>b</sup>	21.2 ± 1.8 <sup>b</sup>	26.9 ± 1.8 <sup>a</sup>	27.2 ± 1.5 <sup>a</sup>	30.5 ± 1.7 <sup>a</sup>	<0.001
Percentage, %	26.5 ± 3.4 <sup>d</sup>	47.2 ± 2.2 <sup>c</sup>	50.9 ± 2.7 <sup>c</sup>	59.1 ± 2.7 <sup>b</sup>	56.7 ± 2.3 <sup>b,c</sup>	67.5 ± 2.6 <sup>a</sup>	<0.001
<b>Sit</b>							
Duration, min/bout	0.2 ± 0.5 <sup>c</sup>	1.2 ± 0.3 <sup>ab</sup>	2.1 ± 0.4 <sup>a</sup>	1.4 ± 0.4 <sup>ab</sup>	0.7 ± 0.3 <sup>b,c</sup>	1.0 ± 0.4 <sup>b</sup>	0.022
Percentage, %	1.6 ± 1.4	3.9 ± 0.9	4.6 ± 1.1	3.4 ± 1.1	1.9 ± 1.0	3.8 ± 1.1	0.383
<b>Stand</b>							
Duration, min/bout	35.6 ± 2.0 <sup>a</sup>	26.6 ± 1.3 <sup>a</sup>	23.4 ± 1.6 <sup>a</sup>	18.1 ± 1.6 <sup>b</sup>	19.0 ± 1.4 <sup>b</sup>	14.1 ± 1.5 <sup>c</sup>	<0.001
Percentage, %	70.6 ± 3.2 <sup>a</sup>	48.9 ± 2.1 <sup>b</sup>	43.6 ± 2.6 <sup>b</sup>	36.6 ± 2.6 <sup>c</sup>	35.8 ± 2.3 <sup>c</sup>	29.7 ± 2.5 <sup>c</sup>	<0.001
<b>Eat</b>							
Duration, min/bout	NA	33.5 ± 1.0 <sup>a</sup>	29.8 ± 1.4 <sup>b</sup>	25.8 ± 1.2 <sup>c</sup>	26.7 ± 1.1 <sup>b,c</sup>	28.3 ± 1.2 <sup>b,c</sup>	<0.001
Percentage, %	NA	55.9 ± 1.7 <sup>a</sup>	51.5 ± 2.4 <sup>ab</sup>	43.9 ± 2.1 <sup>b</sup>	45.9 ± 1.8 <sup>b</sup>	45.9 ± 2.0 <sup>b</sup>	<0.001
<b>ONF</b>							
Duration, min/bout	22.3 ± 1.6 <sup>a</sup>	13.3 ± 1.1 <sup>b</sup>	12.3 ± 1.3 <sup>b</sup>	11.7 ± 1.3 <sup>b</sup>	6.9 ± 1.2 <sup>c</sup>	5.0 ± 1.3 <sup>c</sup>	<0.001
Percentage, %	54.4 ± 3.1 <sup>a</sup>	31.1 ± 2.1 <sup>b</sup>	30.2 ± 2.5 <sup>b</sup>	27.5 ± 2.5 <sup>b,c</sup>	22.4 ± 2.2 <sup>c</sup>	15.4 ± 2.4 <sup>d</sup>	<0.001

<sup>a-c</sup>Within a row, means without a common superscript letter differ ( $P \leq 0.05$ ).

## Discussion

These data imply that the type of stall a pregnant sow is housed in for either the **(a)** the first 30 days of gestation or **(b)** entire gestational period can impact her immune status, behavior, and litter performance but may have minimal impact on body weight gain or litter performance traits—hence housing environment and previous experience can impact sow well-being either in short- or long-term.

For the most part, sows housed in a standard gestation stall for the first 30 days prior to moving to a group pen had a more stimulated immune status and were less active behaviorally than were sows housed in a turn-around stall. Those sows housed in standard stall had more stimulated NK cytotoxicity and T-cell mediated responses and lower plasma cortisol compared with sows housed in turn-around stall potentially implying that sows housed in a standard stall may have a more balanced immune profile indicating that these sows may be less stressed by their environment or less likely to evoke an immunological response to cope with their environment. However, these immune effects were still prevalent at d 90 of gestation among group-kept sows thus indicating that the type of stall a sows is housed in prior to moving to a group pen can impact her immune status.

These data also imply that the type of stall a sow is housed in affects laying, standing and ONF behaviors as well as the amount of aggressive interactions displayed in a pen environment. Overall, sows housed in a turn-around stall spent more time standing and more time performing ONF behaviors while sows in a standard stall spent more time lying throughout gestation. However, the type of stall sow was housed in prior to moving to a pen only impacted aggressive encounters. It is apparent that one physical attribute of a stall—swinging gate—may affect sows well-being throughout gestation, as well as, prior to placement into a group-pen. This swinging gate component allows for an array of various behaviors to be performed, potentially influencing sow perception of the quality of the dynamic space available and sow motivation to utilize the swinging gate for purposes other than “the need to turn-around”. This simple physical component within a turnaround stall however, seemed to reduce sow well-being when kept in the turn-around stall throughout gestation, if behavior and physiology are considered indicators of welfare. Another possibility for these differences in activity level (stand and ONF) may be simply due to increase in amount of space for sow to investigate. Pigs use their snout as a means to investigate the environment; allowing sows to turn-around increases the number of manipulable components (swinging gate and chain) of the environment to become more accessible. This desire to investigate seems to wane as day of gestation increases—hence turning around may not be a true need of a gestating sow but this change in behavior has lasting effects on sow well-being.

Also, sows housed in turn-around stall prior to being housed in group-pen engaged in more aggressive encounters especially around feeding time than do sows that were previously housed in a standard gestation stall. This increase in aggression (especially at d 65 of gestation and at feeding time) amongst sows in turn-around stalls may have developed through a negative behavior shown in early in gestation—using the gate as a “means for controlling their conspecific while in turn-around stall”—previous experience and environment have been known to influence an animal’s ability to cope with stress and therefore the ability to perform aggression in turn-around stalls during early gestation could be compromising the ability to cope with the aggressive behavior and therefore suppressing the immune system and may lead to the negative consequences found on litter traits assessed within.

For the most part, sow body weight is not affected by the type of gestation stall a sow is housed in for the first 30 days except for among 1<sup>st</sup>-parity sows (gilts), they gained more body weight from d 6 to 30 of gestation when housed in a standard gestation stall than when they were housed in a turn-around stall. Although, stall type did not affect body weight gain, housing environment (stall vs. pen) did affect body weight gain and loss. Sows housed in pens from d 30 till 110 of gestation gained more body weight than did sows that were housed in stalls for the entire gestational period. This increase in body weight gain among sows housed in pens has been consistent when compared to sows housed in stalls, however, this increase in body weight gain does not necessarily equate to improved sow well-being based on other measures of well-being. Sows housed in pens loss more body weight at the end of lactation than did sows housed in standard gestation stall throughout gestation. Despite more weight gain among sows housed in group pens, litter traits were not improved among sows housed in group-pens especially when housed previously in a standard gestation stall or turn-around stall throughout gestation. In fact, sows kept in standard stall throughout gestation had better litter performance than did sows housed in turn-around stall throughout gestation or standard stall and group pen throughout gestation. For the most part, sows kept in standard stalls outperformed sows in all housing environments except for those sows that were housed in turn-around for 30 days and then moved to group-pen.

Multiple behavioral and physiological characteristics were influenced by the stall type sows were kept in prior to placement into a group-pen, indicating that previous experience of housing systems does influence future behaviors and other measures of well-being. Also, housing sows in turn-around stalls for the entire gestational period is not recommended based on measures of well-being. Overall, sows kept in standard gestation stall has similar or better well-being than sows kept in turn-around stalls or moved to group-pens.