Title: Effects of floor space during transport and journey time on transport losses and well-being of market-weight pigs - **NPB #:**08-037

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Industry Summary:

Transport losses represent a significant economic cost to the swine industry and are of major concern from an animal welfare perspective. Losses include pigs that die during the journey or are non-ambulatory on arrival at the plant. A significant proportion of non-ambulatory pigs exhibit classic symptoms of an extreme stress response (open-mouth breathing, skin discoloration, and muscle tremors); these are often referred to as "fatigued". Previous research funded by the National Pork Board and carried out at the University of Illinois has shown that low floor space on the trailer during transport can increase transport losses. However, that research was carried out with relatively long journey times of about 3 hours. In addition, there is evidence that pigs transported for relatively short journeys ($\leq$ 1 hour) are more stressed on arrival at the plant compared to those transported on longer journeys. The objective of this study was to determine the impact of floor space on the trailer during transport from the farm to the packing plant for short (< 1 hour) and long (~3 hours) journey times on stress responses and transport losses in market weight pigs.

Two treatments were evaluated, namely transport floor space and transport time. Six transport floor spaces (4.3, 4.5, 4.7, 5.0, 5.3, and 5.6 ft^2/pig) were compared on both short (30 to 40 minutes) and long journeys (~3 hours). The pigs used were from wean-to-finish facilities of the same production system that were located between 20 to 30 miles from the plant. Pairs of consecutively loaded trailers were randomly allotted to transport time treatment with the trailers on the short journey time treatment traveling directly from the farm to the plant and those on the long journey time treatment traveling along a predetermined route for approximately 3 hours prior to arrival at the plant. The study was carried out at four times during the year to ensure that the typical range of weather conditions experienced in the Midwest of the US were encountered during the experiment. Pigs were monitored after unloading at the plant and the frequency of pigs exhibiting indicators of stress (open-mouth breathing, skin discoloration, and/or muscle tremors) and of transport losses (dead, non-ambulatory injured, and non-ambulatory non-injured) were recorded.

Overall, the frequency of transport losses observed in this study was extremely low (0.24% of pigs transported) and was considerably below levels observed in previous studies carried out within the production system used for the study, which have generally been within the range of 1.0 to 1.5% of pigs transported. Neither transport floor space nor journey time had any effect on total transport losses or on the incidence of dead or non-ambulatory injured pigs. The incidence of non-ambulatory non-injured pigs was greater on short than long journeys for two of the lowest three, but not for the other, floor spaces. In addition, the frequency of indicators of stress (open-mouth breathing and skin discoloration) in the pigs after unloading at the plant suggested that they were more stressed at the end of short than long journeys, particularly, at the lower floor spaces. Thus, although this study showed no treatment effects on total transport losses, the results suggest that pigs transported for short journey times at low floor spaces are more stressed after unloading at the plant and, consequently, are likely to be more at risk of becoming fatigued. Encouragingly, the results of this study also clearly demonstrate that it is possible to transport pigs from the farm to the plant with very low losses, certainly relative to what historically has been the case in the US.

Keywords: floor space, journey time, pigs, stress indicators, transport losses

Scientific Abstract:

The effects of floor space on the trailer and journey time during transport from the farm to the packing plant on physical indicators of stress and on the incidence of transport losses at the plant (i.e., dead on arrival, non-ambulatory injured, and non-ambulatory non-injured) were evaluated in a study involving 160 loads of pigs (BW 124.7 ± 4.38 kg) using a split-plot design with a 2 x 6 factorial arrangement of treatments: 1) Journey Time from the farm to the packing plant (main plot) [short (<1 h) vs. long (3 h)] and 2) Floor Space on the trailer during transport (subplot) (0.396 vs. 0.415 vs. 0.437 vs. 0.462 vs. 0.489 vs. 0.520 m^2/pig). The incidence of dead and non-ambulatory pigs and the percentage of pigs in each test compartment exhibiting physical indicators of stress (open-mouth breathing, muscle tremors, and/or skin discoloration) were recorded after unloading at the plant. Of the total of 17,652 pigs transported in test compartments, 0.24% died or became non-ambulatory during transport or during unloading. There was no effect ($P > 0.05$) of journey time or floor space on total transport losses or on the incidence of dead on arrival and non-ambulatory injured pigs. There was an interaction ($P = 0.05$) between journey time and floor space for the incidence of non-ambulatory non-injured pigs. There was no effect ($P > 0.05$) of journey time for the lowest and the three highest floor space treatments; however, for two of the lower floor space treatments (0.415 and 0.437 m^2/pig), the incidence of non-ambulatory non-injured pigs was greater ($P < 0.05$) for the short than the long journeys.

The effect of floor space on the incidence of open-mouth breathing was dependent on journey time (floor space by journey time treatment interaction; $P < 0.01$). On long journeys, there was no effect ($P > 0.05$) of floor space on the incidence of open-mouth breathing. However, on short journeys, pigs transported at the lowest two floor spaces (0.396 and 0.415 m^2/pig) had a higher incidence ($P < 0.05$) of open-mouth breathing than those transported at the highest three floor spaces (0.462, 0.489, and 0.520 m^2/pig). The frequency of skin discoloration was greater for pigs transported on short than on long journeys (2.08 vs. 1.30%; $P < 0.001$) and also for pigs transported at the two lowest floor spaces (0.396 and 0.415 m^2/pig) compared to the highest three floor spaces (0.462, 0.489 and 0.520 m^2/pig), with the other floor space treatment (0.437 m^2/pig) being intermediate. In summary, short journey time increased the frequency of physical indicators of stress during unloading at the plant for pigs transported at low floor spaces and, also, increased the incidence of non-ambulatory non-injured pigs at two of the three lower floor spaces evaluated. However, neither transport floor space nor journey time had any effect on total transport losses.

Introduction:

Losses of market weight pigs during transport from the farm to the packing plant are a major issue for the US swine industry from both an economic and also an animal welfare perspective. Reducing such losses is a high priority for the swine industry. The cost of transport losses to the US industry has been estimated at between $46 and $100 million annually (Ellis et al., 2003; Ritter et al., 2009). More importantly, there is no more exact indicator of extremely poor animal welfare than pigs that die or become severely incapacitated.

Transport losses include pigs that either die (dead on arrival [DOA]) or become non-ambulatory during the journey. Pigs can become non-ambulatory due to an injury (non-ambulatory injured [NAI]) or because of some other problem (non-ambulatory non-injured [NANI]). A significant proportion of NANI pigs exhibit indicators of an extreme stress response (i.e., open-mouth breathing, cyanosis, muscle tremors, characteristic vocalization, elevated body temperature); such animals are commonly referred to as "fatigued".

Pigs experience a significant number of potential stressors during the transportation process from leaving the pen at the farm to arrival in the holding pens at the plant. It is well established that low floor space on the trailer during transport can result in high levels of losses during the journey, however, previous work in this area has been conducted within a relatively narrow range of transport times, typically from two to four hours (Ritter et al., 2006b; Ritter et al., 2007).

The impact of journey time from the farm to the plant on losses during transport of market weight pigs is poorly understood. A number of surveys have suggested that journey time has an impact on transport losses, with some indicating that losses are higher for pigs transported short distances (Rademacher and Davies, 2005) whilst other surveys have indicated the exact opposite (Vecerek et. al., 2006; Fitzgerald et al., 2009). However, no controlled studies have been carried out to establish the effects of journey time on transport losses under conditions typically experienced in the US.

There is evidence that pigs exhibit greater signs of stress after short (< 1 hour) compared to long (≥ 3 hours) journey times (Perez et al., 2002). We have shown that most animals will generally recover from the stress associated with loading after journey times of three to four hours (Ritter et. al., 2006b). However, it is possible that with short journeys (≤ 1 hour) pigs may not have sufficient time to recover from the stress associated with loading and the initial part of the journey before the additional stress of unloading occurs. Ritter et al. (2009) showed that a number of the stressors associated with transportation can be additive in their effects. It is possible that the combination of short journey times and low floor space allowances would result in high stress levels on the pig and that this combination could increase the incidence of stress-related transport losses.

Objectives:

The overall objective of this project was to determine the trailer floor space allowance(s) at which transport losses (dead and non-ambulatory animals) were minimized for the range of transport conditions (weather and transport times) typically experienced in the US by harvest weight pigs during transport from farm to packing plant.

To address this objective, the study presented in this report investigated the individual and combined effects (and interactions, if any) of trailer floor space allowance and journey time on indicators of stress and transport losses under a range of weather conditions typical for the Midwest of the US.

Materials & Methods:

The protocol for this study was approved by the University of Illinois Institutional Animal Care and Use Committee.

Experimental Design and Treatments

Effects of floor space on the trailer during transport and journey time from the farm to the plant on the incidence of indicators of stress and transport losses were evaluated in a study involving 160 trailer loads of pigs in four trials which were carried out at different times of the year. Each trial was carried out as a split-plot design with a 2 x 6 factorial arrangement of the following treatments: 1) Journey Time [short (<1 h) and long

(3 hours)] and 2) Floor Space on the trailer during transport (0.396, 0.415, 0.437, 0.462, 0.489, and 0.520 m^2/pig). Transport floor space treatments were randomly assigned to 1 of 6 similarly sized compartments (the front 3 compartments on both the top and bottom decks) on each trailer load of pigs. The main plot was transport time, the subplot was transport floor space. Replicates consisted of two consecutively loaded trailers of pigs which were randomly allotted to journey time treatment.

Animals, Farms, and Pig Handling

Pigs used in this study were market-weight (mean live weight 124.7 ± 4.38 kg) barrows and gilts that were of a standard commercial genotype. Pigs were raised and managed according to the standard procedures used by the production system (The Maschhoffs).

Three farms within the same production system were used. Loads of pigs from Farm 1 were taken when the barns were emptied between November 19 and December 12, 2008 (Trial 1; number of loads = 40) and between May 15 and June 16, 2009 (Trial 3; number of loads = 40). Loads from Farm 2 were taken when the barns were emptied between February 17 and April 1, 2009 (Trial 2; number of loads = 36). Loads from Farm 3 were taken when the barns were emptied between July 22 and August 18, 2009 (Trial 4; number of loads = 44). Pigs were reared in standard wean-to-finish facilities in mixed-gender groups of approximately 32 or 140 pigs for Farm 1 and groups of approximately 115 pigs for Farms 2 and 3. During the wean-to-finish period, the pigs were managed according to the standard operating procedures for the production system and were fed standard commercial diets. Paylean was included in the final finisher diet fed to all pigs in the period prior to shipping to the plant.

Pigs were loaded at the farm between 0300 and 0800 h by personnel from the University of Illinois and the farm loading crews. At Farm 1, the pigs from smaller groups (~32 pigs) were sorted from the pen at the time of loading and immediately moved to the truck. For the larger groups at Farm 1 (~140 pigs/pen), and at Farms 2 and 3 (~115 pigs/pen) the pigs to be transported were sorted into a holding pen located within each of the larger pens at around 18 hours prior to loading. At the time of loading, they were moved directly from the holding pen to the truck. For the loading process, groups of 4 to 6 pigs were moved from the pen to the trailer using sorting boards and, if necessary, electric goads.

Trailer Design and Floor Space Treatments

The trailers used in the study were owned by the production system and operated by a commercial transport company. Two different designs of straight-deck, aluminum trailers with punched sides (Wilson Livestock Trailers, Sioux City, IA) were used in this study. Both trailer designs had 5 compartments on the top deck and 6 compartments on the bottom deck (Figure 1) and were generally similar with the exception that the dimensions of the compartments (Table 1) and the angle of the internal loading ramp (Trailer Design 1 = 21° and Trailer Design 2 = 24°) differed. Trailer Design 1 was used in Trial 1 (number of loads = 40) and Trailer Design 2 was used for Trials 2, 3, and 4 (n = 120).

The six floor space treatments (0.396, 0.415, 0.437, 0.462, 0.489, and 0.520 m^2/pig) were compared in the front three compartments of the trailer on the top and bottom decks. These floor space treatments were selected based on the result of previous studies (Ritter et al., 2006a, 2006b, 2007) and to represent the range in transport floor spaces observed under commercial conditions in the US. If these floor spaces were used for an entire trailer load of pigs, they would have corresponded to a total of 188, 179, 169, 161, 152, and 144 pigs per load for floor spaces of 0.396, 0.415, 0.437, 0.462, 0.480, and 0.520 m^2/pig, respectively. Differences in floor space were created by varying the number of pigs placed into the six test compartments (Table 1). For each replicate (i.e., the two consecutively loaded trailers allotted to the two journey time treatments), the floor space treatments were the same for each compartment. However, for subsequent replicates, floor space treatments were rotated between compartments such that for every six replicates each of the six floor space treatments had appeared in every compartment on the trailer. For identification at the plant, pigs placed in each test compartment were marked with a livestock-marking crayon with a unique color corresponding to the respective floor space treatment.

In total, this study used 17,652 pigs transported in 954 trailer compartments on 160 trailer loads of pigs. The remaining non-test compartments on the trailer were stocked at a floor space of approximately 0.46 m^2/pig, which was the standard used by this system. Pigs from each test compartment were weighed as a group at the packing plant after unloading.

Journey Time Treatments and Transport Procedures

The short transport distance treatment was chosen to represent the situation in which pigs experienced typical levels of stress during loading but had a relatively short journey time in which to recover. The long transport distance treatment represented typical average journey times from the farm to the plant for pigs in the U S. The trailer loads of pigs that had been allotted to the short journey time treatment were transported directly from the farm to the plant. Approximate distances and journey times from the farm to the plant were 27 km and 30 minutes, respectively, for Farm 1 and 45 km and 40 minutes, respectively, for Farms 2 and 3. The loads of pigs allotted to the long journey time treatment were transported along a predetermined route for a distance of ~240 km and a transport time of ~3 hours. The routes used for the short journey treatment were mainly along country roads whereas those used for the long journey time involved travel on country and interstate roads. The times that the trailers left the farm and arrived at the plant and the odometer readings on the truck at the start and end of the journey were recorded.

Event times (loading, waiting period at the farm before transport, journey, waiting period at the plant before unloading, unloading, and total time from the start of loading at the farm to the end of unloading at the plant) were recorded. Six temperature and relative humidity sensors (HOBO H8 Loggers, Onset Computer Corporation, Bourne, MA) were placed on the gates of the six test compartments on each trailer to log (at 1-min intervals) temperature and relative humidity within the trailer. The temperature and relative humidity inside the trailer was calculated for each event averaged across the 6 locations in the trailer.

Assessment of Physical Indicators of Stress and Classification of Transport Losses

During the unloading of the pigs at the plant, the number of animals in each test compartment exhibiting physical indicators of stress (open-mouth breathing, skin discoloration, and/or muscle tremors) was recorded. Transport losses were recorded at the plant up to the time at which the pigs crossed the weigh scale. Plant employees identified all dead and non-ambulatory pigs. Non-ambulatory pigs were defined as pigs that could not walk or keep up with the rest of the group. University of Illinois personnel classified non-ambulatory pigs as either injured or non-injured. Injured pigs were defined as non-ambulatory pigs exhibiting visible signs of an injury. Non-ambulatory non-injured pigs were those displaying physical signs of stress (open-mouth breathing, skin discoloration, muscle tremors, abnormal vocalization). Total transport losses were defined as the sum of non-ambulatory and dead pigs.

Statistical Analysis

Data for transport losses and physical indicators of stress at unloading were not normally distributed, and did not meet the assumptions of ANOVA and, therefore, were transformed prior to analysis using a χ^2 rank-based transformation using the PROC RANK procedure of SAS (SAS Inst. Inc., Cary, NC).

Transformed data were analyzed using the PROC MIXED procedure of SAS as a split-plot design. The main plot was journey time and the subplot was transport floor space. The experimental units for the journey time and transport floor space treatments were the trailer and the trailer compartment, respectively. The model used included the fixed effects of journey time, transport floor space, trial, and all possible interactions and the random effects of transport day nested within trial, replicate nested within day and trial, and transport day by journey time interaction. Differences between least-squares means were separated using the PDIFF option of SAS.

Results:

Transport Conditions

Descriptive statistics for transport event times and conditions are presented in Table 2. Times for loading, waiting at the farm, the journey, waiting at the plant, and unloading averaged 42.1 ± 10.29, 4.7 ± 3.17, 107.1 ± 74.17, 21.2 ± 17.89, and 24.2 ± 9.71 minutes, respectively. The total time from the start of loading to the end of unloading averaged 199.0 ± 85.92 min with a range of 81 to 363 min. There was substantial load to load variation for event times (Table 2). For example, loading times ranged from 17 to 75 min and time spent waiting at the plant ranged from 3 to 107 min. In general, all event times in this study were within the range typically observed within this production system, taking into account the differences in journey times due to the imposed journey time treatments.

Average temperature and relative humidity on the trailer for all loads over the entire study period was 13.7°C and 59.7%, respectively, ranging from -13.2 to 31.5°C and from 24.1 to 100%, respectively (Table 2). Descriptive statistics for transport event times and conditions for each of the four trials are presented in Appendix Tables 1, 2, 3, and 4. As expected, overall average temperatures on the trailer increased with Trial number and ranged between 4.4° C for Trial 1 to 23.4° C for Trial 4. Similarly, overall average relative humidity levels on the trailer increased with trial number from 50.9% for Trial 1 to 66.1% for Trial 4.

Temperature levels on the trailer were on average lowest during the loading period at the farm and highest during the period of waiting at the plant (Table 2). However, there was considerable variation in the minimum and maximum temperatures within each event which reflects the range in ambient conditions experienced during this study. Relative humidity levels on the trailer were greatest during the time that the trailer was waiting at the farm and lowest during unloading at the plant. However, similar to the temperature levels, there was a large variation in the range of relative humidity levels experienced during the study (Table 2). Part of the objectives of this research was to carry out the study under a range of weather conditions typical of the Midwest of the US and the wide variation between the trials in temperature and humidity levels on the trailer confirms that this was achieved.

The event times and temperature and humidity levels during transport for the short and long transport time treatments are shown in Table 3. Time taken to load pigs and time spent waiting at the farm was similar ($P > 0.05$) for the two journey time treatments. By design, the time taken to travel from the farm to the plant was approximately 2 ½ hours longer for the long compared to the short journey time treatment (Table 3). In addition, the time spent waiting at the plant and for unloading was greater for the long compared to the short journey time treatments which reflects the fact that these loads were delivered to the plant later in the day when there were more loads waiting to be unloaded with a resulting increase in waiting time. The overall time from the beginning of loading at the farm to the end of unloading at the plant was 164 minutes greater for the long compared to the short journeys (Table 3).

Average temperatures on the trailer during the times when the trailer was stationary (i.e., during loading, waiting at the farm, waiting at the plant, and unloading) were similar ($P > 0.05$) for short and long journeys (Table 3). Trailer temperature during the journey was lower ($P < 0.001$) for the long than for the short journeys, however, this difference was small (1°C). Humidity levels on the trailer at the farm (i.e., during loading and waiting) were similar ($P > 0.05$) for short and long journeys (Table 3). However, for the other periods (the journey, waiting at the plant, and unloading) and for the overall period, humidity levels were lower ($P < 0.001$) for the long compared to the short journeys. Nevertheless, the difference between the journey times for trailer humidity levels were relatively small (Table 3) and all humidity levels were generally within a range considered to have little if any impact on the pig. Differences in temperature and humidity levels on the trailer during the journey may reflect an increased volume of air movement through the trailer on the long compared to the short journeys.

Live Weights and Transport Losses

Descriptive statistics for pig live weights and transport losses are presented in Table 4 with the equivalent data for each of the four trials being given in Appendix Tables 5, 6, 7, and 8, respectively. The average live weight of the 17,652 pigs transported in the 954 test compartments was 124.7 ± 4.38 kg and ranged from 111.7 kg to 134.7 kg (Table 4). The average live weight of pigs transported in the test compartments (Table 3) was similar ($P > 0.05$) for the short and long journey time treatments (125.0 and 124.2 kg, respectively).

On average, total transport losses were 0.24% (Table 4), which is relatively low compared to other data collected in previous studies carried out within the same production system as used in the current study. For example, Ritter et al. (2007) evaluated the effects of distance moved during loading and floor space on the trailer and found the incidence of total transport losses on arrival was 1.47%, with 0.52% dead and 0.95% non-ambulatory pigs.

The production system in question has made a number of improvements to facility design and to pig handling, loading, and transportation procedures in an attempt to minimize transport losses. This has included an increased use of large group sizes to facilitate the pre-sorting of pigs on the day prior to transport, a procedure that was used for the majority of pigs in this study. Johnson et al. (2009) reported that pigs loaded from large, pre-sorted pens had much lower transport losses than pigs from small pens that were sorted at the time of loading. It was not the purpose of the current study, nor was it possible, to determine the precise reasons for the substantial reduction in transport losses achieved by this production system. A significant number of the improvements in transportation procedures was based on research carried out within the system in question, much of which was funded by NPB. Although not directly relevant to the current study, this dramatic reduction in transport losses within this system is testimony to the value of using a research-based approach to solving such problems.

Effects of Journey Time and Transport Floor Space on Physical Indicators of Stress

The approach used to create the floor space treatments in this study involved varying the number of animals per compartment with no adjustment of compartment size, which resulted in any effect of floor space being confounded with the effect of the number of pigs per compartment. However, this is the approach that would be used under commercial conditions to adjust the floor space per pig on the trailer.

Effects of journey time and transport floor space on physical indicators of stress measured at the time the pigs were unloaded at the plant are summarized in Table 5. There was an interaction between journey time and floor space treatments ($P < 0.01$) for the frequency of open-mouth breathing. For long journeys, there was no difference ($P > 0.05$) between the floor space treatment means for the frequency of open-mouthed breathing. In contrast, on short journeys pigs transported at the lowest two floor spaces (0.396 and 0.415 m^2/pig) had a higher incidence of open-mouth breathing than those transported at the three greatest floor spaces (0.462, 0.489, and 0.570 m^2/pig).

The frequency of skin discoloration was greater ($P < 0.0005$) for pigs transported on short compared to long journeys (2.08 vs. 1.30%) and was also greater ($P < 0.0001$) for the two lowest floor spaces compared to the three greatest floor spaces evaluated (Table 5). The incidence of pigs exhibiting muscle tremors was very low ($\leq$ 0.11%) and there was no effect ($P > 0.05$) of either floor space or journey time on this parameter (Table 5).

Indicators of stress, such as open-mouth breathing and skin discoloration, exhibited by the pig at the time of unloading at the plant are the result of the stressors experienced by the animal up to that point in the transportation process. These stressors include those occurring at the farm during loading, on the trailer during the journey, and at the plant from arrival until the end of the unloading process. Ritter et al. (2007) showed that the frequency of open-mouth breathing was particularly high immediately after pigs were loaded onto the trailer at the farm. Ritter et al. (2006b) also showed that the majority of pigs exhibiting physical indicators of stress (defined as open-mouth breathing, skin discoloration, or both) after loading at the farm had completely recovered during a 3-hour journey and exhibited none of these indicators after unloading at the plant. The results of the current study, when combined with those of Ritter et al. (2007), suggest that pigs transported on short journeys may not have sufficient time to recover from the stress of loading at the farm before being unloaded at the plant. In addition, these results suggest that the increased incidence of open-mouth breathing for pigs on short journeys is exacerbated by low floor space levels on the trailer. Thus, the results of the current study suggest that the combination of low floor space and short journey times results in the pigs being more stressed during unloading at the plant and, in theory, this would predispose these animals to a higher incidence of stress-related problems.

Effects of Journey Time and Transport Floor Space on Transport Losses

The effects of journey time and transport floor space on the incidence of transport losses are summarized in Table 5. There was no effect ($P < 0.05$) of either journey time or floor space on the incidence of dead and non-ambulatory injured pigs, or on total transport losses. There was a trend ($P = 0.08$) for dead pigs at the plant to be influenced by transport floor space with the lowest floor space (0.396 m^2/pig) having the highest incidence. However, the incidence of dead on arrival for the next two most restrictive floor spaces (0.415 and 0.437 m^2/pig) was zero and there was no clear relationship between floor space and the incidence of dead pigs. There was an interaction ($P = 0.05$) between journey time and floor space for the incidence of non-ambulatory non-injured pigs (Table 5). There was no effect ($P > 0.05$) of journey time on the incidence on non-ambulatory non-injured pigs for the lowest (0.396 m^2/pig) and the three highest (0.462, 0.489, and 0.520 m^2/pig) floor spaces evaluated. However, for two of the lower floor spaces (0.415 and 0.437 m^2/pig), the incidence of non-ambulatory non-injured pigs was greater for the short compared to the long journey time. These results, when combined with those for the physical indicators of stress, suggest that the incidence of stress-related problems and losses may be greater on short journeys at low floor spaces. However, care must be taken when interpreting these results as the treatment differences were relatively small and there was no effect of journey time or floor space on total losses.

The lack of an effect of journey time on total transport losses is somewhat surprising given the greater frequency of indicators of stress after unloading at the plant in the pigs transported on the short compared to the long journeys already discussed. Numerically, total losses were greater for the short compared to the long journey times (0.29 vs. 0.21%, respectively), however, this difference was not statistically significant ($P = 0.12$). A much larger study than the current one would be needed to clearly establish any effect of short journey times on transport losses.

A number of controlled studies that have shown that reduced floor space on the trailer is associated with relatively high transport losses. For example, Ritter et al. (2006b) showed that total transport losses were higher for pigs transported at a floor space of 0.39 m^2/pig (total transport losses of 0.88%) compared to 0.48 m^2/pig (total transport losses of 0.36%). In addition, Ritter et al. (2007) showed that total transport losses were increased at floor spaces of 0.396 and 0.415 m^2/pig compared to higher levels (0.489 and 0.520 m^2/pig). Therefore, the results of this study with respect to the effects of floor space on total transport losses were unexpected and not in line with other studies carried out in the system used for the current experiment. As previously discussed, the major difference between the current study and the previous ones was in the absolute level of losses experienced. Thus, total transport losses were 1.08% and 1.47%, respectively, in the studies of Ritter et al. (2006b and 2007) compared to 0.24% in the current study. At such a low level of losses it will be difficult to find any factor that would reduce losses further.

Discussion:

Total transport losses for this study were very low, averaging around 0.24% of pigs transported. There was no effect of journey time or floor space on total transport losses. There was an interaction between journey time and floor space for the incidence of non-ambulatory non-injured pigs which suggested that the incidence of stress-related losses was greater on short than on long journeys at low floor spaces. Differences in the incidence of physical indicators of stress suggest that pigs transported for short journey times (< 40 mins) may be more stressed after unloading at the plant than pigs transported for 3 h, particularly those kept at low floor spaces on the trailer. However – somewhat unexpectedly – these differences did not translate into a higher incidence of total transport losses. Some of the results of this experiment were indeed unusual and might have been due to effects of factors that were specific to the pork-production system in which the study was conducted and which have not yet been identified. Subsequent efforts should be made to identify any such factors. Encouragingly, the results of this study suggest that it is possible to transport pigs under commercial conditions in the US with very low losses.

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Figure 1. Diagram of the trailer.

<table>
<tr><td rowspan="2">Front / Top 1*</td><td rowspan="2">Top 2*</td><td rowspan="2">Top 3*</td><td rowspan="2">Top 4</td><td>Rear / Top 5</td></tr>
<tr><td>Loading Ramp</td></tr>
<tr><td rowspan="2">Front / Bottom 1*</td><td rowspan="2">Bottom 2*</td><td rowspan="2">Bottom 3*</td><td rowspan="2">Bottom 4</td><td>Rear / Bottom 5</td></tr>
<tr><td>Rear / Bottom 6</td></tr>
</table>

* Test compartments

Table 1. Trailer compartment dimensions and transport floor space treatments[1].

		Floor space treatment, m²/pig											
		0.396		0.415		0.437		0.462		0.489		0.520	
	Area, m²	No. pigs	Actual floor space, m²/pig	No. pigs	Actual floor space, m²/pig	No. pigs	Actual floor space, m²/pig	No. pigs	Actual floor space, m²/pig	No. pigs	Actual floor space, m²/pig	No. pigs	Actual floor space, m²/pig
Trailer design 1[2]													
Top deck													
Compartment 1	7.433	19	0.391	18	0.413	17	0.437	16	0.465	15	0.496	14	0.531
Compartment 2	8.257	21	0.393	20	0.413	19	0.435	18	0.459	17	0.486	16	0.516
Compartment 3	9.255	23	0.402	22	0.421	21	0.441	20	0.463	19	0.487	18	0.514
Bottom deck													
Compartment 1	7.433	19	0.391	18	0.413	17	0.437	16	0.465	15	0.496	14	0.531
Compartment 2	8.257	21	0.393	20	0.413	19	0.435	18	0.459	17	0.486	16	0.516
Compartment 3	9.255	23	0.402	22	0.421	21	0.441	20	0.463	19	0.487	18	0.514
Trailer design 2[2]													
Top deck													
Compartment 1	7.618	19	0.401	18	0.423	17	0.448	16	0.468	15	0.508	14	0.544
Compartment 2	11.520	29	0.397	28	0.411	26	0.443	25	0.461	24	0.480	22	0.524
Compartment 3	6.503	17	0.383	16	0.406	15	0.434	14	0.465	13	0.500	12	0.542
Bottom deck													
Compartment 1	7.618	19	0.401	18	0.423	17	0.448	16	0.476	15	0.508	14	0.544
Compartment 2	11.520	29	0.397	28	0.411	26	0.443	25	0.461	24	0.480	22	0.524
Compartment 3	6.503	17	0.383	16	0.406	15	0.434	14	0.465	13	0.500	13	0.500

[1]Compartments were numbered consecutively from the front to the rear of the trailer (Figure 1).

[2]Trailer design 1 was used for loads in Trial 1 (number of loads = 40). Trailer design 2 was used for loads in Trials 2, 3, and 4 (number of loads = 120).

Table 2. Descriptive statistics for transport event times and temperature and humidity levels on the trailer during transport.

Event	Number of loads	Mean	Standard deviation	Minimum	Maximum
Number of loads transported per day	-	3.8	0.59	2.0	4.0
Event times, min					
Loading	160	42.1	10.29	17.0	75.0
Waiting at the farm[1]	160	4.7	3.17	0.0	20.0
Journey	160	107.1	74.17	20.0	223.0
Waiting at the plant[2]	160	21.2	17.89	3.0	107.0
Unloading	160	24.2	9.71	12.0	67.0
Total time[3]	160	199.0	85.92	81.0	363.0
Temperature in the trailer by event, °C					
Loading	160	11.2	10.10	-13.2	29.4
Waiting at the farm[1]	160	15.8	7.39	2.0	30.0
Journey	160	13.8	8.93	-4.1	30.5
Waiting at the plant[2]	160	16.0	8.13	-2.0	30.8
Unloading	160	15.2	7.80	-0.8	31.5
Overall average[3]	160	13.7	9.07	-13.2	31.5
Relative humidity in the trailer by event, %					
Loading	160	69.2	17.63	26.9	100.0
Waiting at the farm[1]	160	74.4	13.02	35.7	99.8
Journey	160	58.0	14.16	25.8	100.0
Waiting at the plant[2]	160	54.4	14.87	24.3	99.9
Unloading	160	52.1	15.03	24.1	96.1
Overall average[3]	160	59.7	16.29	24.1	100.0

[1]From the end of loading to the beginning of the journey.
[2]From arrival at the plant to the start of unloading.
[3]From the beginning of loading at the farm to the end of unloading at the plant.

Table 3. Least-squares means for the effects of journey time on transport event times, temperature and humidity levels on the trailer, and pig live weight during transport.

Item	Journey time		SEM	*P*-value
	Short	Long		
Number of observations	80	80	-	-
Event times, min				
Loading	41.1	43.3	1.30	0.08
Waiting at the farm[1]	4.5	5.0	0.36	0.38
Journey	34.3	180.7	1.12	<0.0001
Waiting at the plant[2]	16.8	26.3	2.29	0.001
Unloading	21.4	27.0	1.01	0.0002
Total time[3]	117.7	281.4	3.17	<0.0001
Temperature in the trailer by event, °C				
Loading	12.0	12.0	0.61	0.95
Waiting at the farm[1]	17.5	17.6	0.43	0.96
Journey	15.2	14.2	0.49	<0.001
Waiting at the plant[2]	16.1	16.4	0.46	0.43
Unloading	16.2	16.9	0.48	0.09
Overall average[3]	14.6	14.4	0.50	0.60
Relative humidity in the trailer by event, %				
Loading	68.7	68.3	1.70	0.65
Waiting at the farm[1]	73.8	72.6	1.83	0.36
Journey	59.7	54.9	1.75	<0.0001
Waiting at the plant[2]	57.1	50.7	1.96	<0.0001
Unloading	54.8	48.5	2.05	<0.0001
Overall average[3]	62.0	56.2	1.67	<0.0001
Average live weight of pigs, kg	125.0	124.2	0.537	0.06

[1]From the end of loading to the beginning of the journey.
[2]From arrival at the plant to the start of unloading.
[3]From the beginning of loading at the farm to the end of unloading at the plant.

Table 4. Descriptive statistics for average live weight and transport losses.

Event	Number of loads	Mean	Standard deviation	Minimum	Maximum
Average live weight, kg[1]	160	124.7	4.38	111.7	134.7
Transport losses at the plant, %					
Dead	160	0.04	0.183	0.00	1.04
Non-ambulatory injured	160	0.05	0.195	0.00	0.98
Non ambulatory, non-injured	160	0.16	0.408	0.00	1.88
Total losses[2]	160	0.24	0.497	0.00	2.12

[1]Based on the compartment weight for a total of 17,652 pigs that were transported in 954 test compartments.
[2]Total losses = dead on arrival + non-ambulatory injured + non-ambulatory non-injured.

Table 5. Least square means for the effects of transport floor space and journey time on the incidence of transport losses, open-mouthed breathing, and skin discoloration observed during unloading.

	Floor space (FS); m^2/pig								Journey time (JT)				FS x JT
Item	0.396	0.415	0.437	0.462	0.489	0.520	SEM	*P*-value	Short	Long	SEM	*P*-value	*P*-value
Number of observations[1]	157	159	156	157	159	155	-	-	80	80	-	-	-
Physical indicators of stress, %													
Open mouthed breathing													
Short journey time	2.08^{a}	1.49^{ab}	1.17^{bc}	0.57^{de}	0.91^{cd}	0.61^{cde}	0.260	-	-	-	-	-	0.003
Long journey time	0.43^{de}	0.06^{e}	0.16^{e}	0.28^{e}	0.07^{e}	0.13^{e}	-	-	-	-	-	-	
Skin discoloration	2.49^{a}	2.12^{ab}	1.68^{bc}	1.16^{c}	1.35^{c}	1.33^{c}	0.281	<0.0001	2.08^{a}	1.30^{b}	0.216	0.0005	0.70
Muscle tremors	0.03	0.03	0.06	0.09	0.11	0.05	0.047	0.88	0.07	0.06	0.025	0.49	0.47
Transport losses, %													
Dead	0.11	0.00	0.00	0.08	0.00	0.03	0.037	0.08	0.04	0.03	0.020	0.52	0.99
Non-ambulatory, total	0.20	0.21	0.24	0.25	0.21	0.15	0.084	0.95	0.24	0.18	0.047	0.14	0.09
Non-ambulatory injured	0.07	0.07	0.02	0.06	0.04	0.03	0.041	0.92	0.05	0.04	0.026	0.73	0.85
Non-ambulatory non-injured													
Short journey time	0.22^{bcd}	0.27^{cd}	0.36^{d}	0.09^{abc}	0.10^{abcd}	0.08^{abc}	0.107	-	-	-	-	-	0.05
Long journey time	0.05^{ab}	0.00^{a}	0.08^{abc}	0.29^{abcd}	0.24^{abcd}	0.16^{abcd}	-	-	-	-	-	-	-
Total losses[2]	0.32	0.21	0.24	0.33	0.21	0.19	0.092	0.70	0.29	0.21	0.054	0.12	0.15

^{a,b,c,d,e}Means with differing superscripts within a row differ by ($P < 0.05$).

[1]Experimental unit for floor space treatment was trailer compartment. Experimental unit for journey time treatment was trailer load of pigs.

[2]Total losses = dead on arrival + non-ambulatory injured + non-ambulatory non-injured.

APPENDICES

Appendix Table 1. Descriptive statistics for transport event times and temperature and humidity levels on the trailer during transport for Trial 1.

Event	Number of loads	Mean	Standard deviation	Minimum	Maximum
Number of loads transported per day	-	4.0	0.0	4.0	4.0
Event times, min					
Loading	40	41.7	12.05	17.0	71.0
Waiting at the farm[1]	40	6.5	3.39	2.0	18.0
Journey	40	100.4	74.50	20.0	223.0
Waiting at the plant[2]	40	20.3	17.56	6.0	107.0
Unloading	40	28.5	10.46	17.0	63.0
Total time[3]	40	197.4	84.47	95.0	317.0
Temperature in the trailer by event, °C					
Loading	40	1.3	5.05	-13.2	23.3
Waiting at the farm[1]	40	8.9	2.33	2.0	15.5
Journey	40	3.8	3.80	-4.1	15.9
Waiting at the plant[2]	40	7.4	4.18	-2.0	15.2
Unloading	40	8.0	3.84	-0.8	23.3
Overall average[3]	40	4.4	4.75	-13.2	23.3
Relative humidity in the trailer by event, %					
Loading	40	51.5	11.31	26.9	76.6
Waiting at the farm[1]	40	66.1	7.71	39.5	79.6
Journey	40	51.5	9.23	33.1	82.6
Waiting at the plant[2]	40	49.2	8.79	32.4	71.8
Unloading	40	46.5	10.70	24.8	73.7
Overall average[3]	40	50.9	10.33	24.8	82.6

[1]From the end of loading to the beginning of the journey.
[2]From arrival at the plant to the start of unloading.
[3]From the beginning of loading at the farm to the end of unloading at the plant.

Appendix Table 2. Descriptive statistics for transport event times and temperature and humidity levels on the trailer during transport for Trial 2.

Event	Number of loads	Mean	Standard deviation	Minimum	Maximum
Number of loads transported per day	-	3.6	0.84	2.0	4.0
Event times, min					
Loading	36	45.4	9.31	32.0	70.0
Waiting at the farm[1]	36	4.5	3.66	0.0	20.0
Journey	36	111.4	73.14	30.0	199.0
Waiting at the plant[2]	36	22.1	17.82	3.0	85.0
Unloading	36	22.6	6.34	14.0	38.0
Total time[3]	36	205.9	84.71	105.0	323.0
Temperature in the trailer by event, °C					
Loading	36	7.2	6.95	-12.5	19.8
Waiting at the farm[1]	36	13.5	4.00	6.0	21.1
Journey	36	10.2	4.97	-0.3	21.1
Waiting at the plant[2]	36	13.5	4.29	0.8	22.4
Unloading	36	12.8	4.39	1.7	22.8
Overall average[3]	36	10.2	5.73	-12.5	22.8
Relative humidity in the trailer by event, %					
Loading	36	66.7	16.17	31.7	100.0
Waiting at the farm[1]	36	73.8	15.02	35.7	99.8
Journey	36	48.1	14.38	29.8	99.8
Waiting at the plant[2]	36	47.2	15.82	26.5	89.4
Unloading	36	43.7	16.45	24.6	85.9
Overall average[3]	36	52.1	17.50	24.6	100.0

[1]From the end of loading to the beginning of the journey.
[2]From arrival at the plant to the start of unloading.
[3]From the beginning of loading at the farm to the end of unloading at the plant.

Appendix Table 3. Descriptive statistics for transport event times and temperature and humidity levels on the trailer during transport for Trial 3.

Event	Number of loads	Mean	Standard deviation	Minimum	Maximum
Number of loads transported per day	-	3.6	0.81	2.0	4.0
Event times, min					
Loading	40	36.8	8.03	25.0	61.0
Waiting at the farm[1]	40	4.4	2.61	0.0	11.0
Journey	40	105.2	79.11	23.0	201.0
Waiting at the plant[2]	40	20.8	19.00	5.0	103.0
Unloading	40	24.2	10.69	12.0	67.0
Total time[3]	40	191.3	91.47	81.0	348.0
Temperature in the trailer by event, °C					
Loading	40	18.3	3.98	9.0	26.9
Waiting at the farm[1]	40	21.9	2.71	16.7	27.2
Journey	40	20.3	2.93	13.1	27.5
Waiting at the plant[2]	40	21.6	2.97	15.7	28.5
Unloading	40	21.2	3.28	12.9	28.7
Overall average[3]	40	20.2	3.37	9.0	28.7
Relative humidity in the trailer by event, %					
Loading	40	75.3	14.28	34.8	99.3
Waiting at the farm[1]	40	77.1	15.00	43.7	99.3
Journey	40	60.8	14.51	25.8	99.3
Waiting at the plant[2]	40	57.7	14.67	24.3	80.6
Unloading	40	55.4	16.14	24.1	82.8
Overall average[3]	40	62.9	16.22	24.1	99.3

[1]From the end of loading to the beginning of the journey.
[2]From arrival at the plant to the start of unloading.
[3]From the beginning of loading at the farm to the end of unloading at the plant.

Appendix Table 4. Descriptive statistics for transport event times and temperature and humidity levels on the trailer during transport for Trial 4.

Event	Number of loads	Mean	Standard deviation	Minimum	Maximum
Number of loads transported per day	-	4.0	0.00	4.0	4.0
Event times, min					
Loading	44	44.4	9.50	26.0	75.0
Waiting at the farm[1]	44	3.4	2.26	0.0	9.0
Journey	44	111.0	72.16	27.0	195.0
Waiting at the plant[2]	44	21.8	17.76	5.0	80.0
Unloading	44	21.6	9.34	12.0	47.0
Total time[3]	44	201.9	85.39	99.0	363.0
Temperature in the trailer by event, °C					
Loading	44	22.2	3.36	14.2	29.4
Waiting at the farm[1]	44	25.4	2.50	20.3	30.0
Journey	44	23.3	2.43	16.5	30.5
Waiting at the plant[2]	44	24.9	3.08	18.0	30.8
Unloading	44	24.5	2.89	18.8	31.5
Overall average[3]	44	23.4	2.91	14.2	31.5
Relative humidity in the trailer by event, %					
Loading	44	82.2	8.6	53.2	100.0
Waiting at the farm[1]	44	81.4	9.92	53.5	96.8
Journey	44	63.3	13.37	28.5	100.0
Waiting at the plant[2]	44	54.4	18.27	26.0	99.9
Unloading	44	57.7	14.53	26.2	96.1
Overall average[3]	44	66.1	16.20	26.0	100.0

[1]From the end of loading to the beginning of the journey.
[2]From arrival at the plant to the start of unloading.
[3]From the beginning of loading at the farm to the end of unloading at the plant.

Appendix Table 5. Descriptive statistics for average live weight and transport losses for Trial 1.

Event	Number of loads	Mean	Standard deviation	Minimum	Maximum
Average live weight of pigs, kg[1]	40	128.2	3.43	120.2	134.7
Transport losses at the plant, %					
Dead on arrival	40	0.04	0.195	0.00	1.04
Non-ambulatory injured	40	0.08	0.244	0.00	0.93
Non ambulatory non-injured	40	0.30	0.522	0.00	1.88
Total losses[2]	40	0.42	0.606	0.00	2.12

[1]For the 4,467 pigs that were transported in 236 test compartments.

[2]Total losses = dead on arrival + non-ambulatory injured + non-ambulatory non-injured.

Appendix Table 6. Descriptive statistics for average live weight and transport losses for Trial 2.

Event	Number of loads	Mean	Standard deviation	Minimum	Maximum
Average live weight of pigs, kg[1]	36	123.6	3.74	117.3	134.4
Transport losses at the plant, %					
Dead on arrival	36	0.00	-	0.00	0.00
Non-ambulatory injured	36	0.07	0.228	0.00	0.88
Non ambulatory non-injured	36	0.18	0.444	0.00	1.85
Total losses[2]	36	0.25	0.473	0.00	1.85

[1]For the 3,972 pigs that were transported in 215 test compartments.

[2]Total losses = dead on arrival + non-ambulatory injured + non-ambulatory non-injured.

Appendix Table 7. Descriptive statistics for average live weigh and transport losses Trial 3.

Event	Number of loads	Mean	Standard deviation	Minimum	Maximum
Average live weight of pigs, kg[1]	40	122.2	3.15	114.0	129.2
Transport losses at the plant, %					
Dead on arrival	40	0.02	0.139	0.00	0.88
Non-ambulatory injured	40	0.02	0.155	0.00	0.98
Non ambulatory non-injured	40	0.05	0.285	0.00	1.80
Total losses[2]	40	0.09	0.345	0.00	1.80

[1]For the 3,972 pigs that were transported in 215 test compartments.
[2]Total losses = dead on arrival + non-ambulatory injured + non-ambulatory non-injured.

Appendix Table 8. Descriptive statistics for average live weigh and transport losses for Trial 4.

Event	Number of loads	Mean	Standard deviation	Minimum	Maximum
Average live weight of pigs, kg[1]	44	124.5	4.65	111.7	134.7
Transport losses at the plant, %					
Dead on arrival	44	0.08	0.263	0.00	1.04
Non-ambulatory injured	44	0.02	0.141	0.00	0.93
Non ambulatory non-injured	44	0.11	0.309	0.00	1.11
Total losses[2]	44	0.22	0.485	0.00	1.90

[1]For the 4,807 pigs that were transported in 260 test compartments.
[2]Total losses = dead on arrival + non-ambulatory injured + non-ambulatory non-injured.