University of Nebraska - Lincoln

DigitalCommons@University of Nebraska - Lincoln

Theses and Dissertations in Animal Science

Animal Science Department

8-2018

Utilization of Depth - Enabled Identification and Tracking System to Identify and Track Individual Pigs and Analyse Individual Pig Activity

Jessica Michelle Lancaster

University of Nebraska-Lincoln, jessica-lancaster@live.com

UTILIZATION OF DEPTH – ENABLED IDENTIFICATION AND TRACKING SYSTEM TO IDENTIFY AND TRACK INDIVIDUAL PIGS AND ANALYZE INDIVIDUAL PIG ACTIVITY

by

Jessica M. Lancaster

A THESIS

Presented to the Faculty of

The Graduate College at the University of Nebraska

In Partial Fulfillment of Requirements

For the Degree of Master of Science

Major: Animal Science

Under the Supervision of Professor Ty B. Schmidt

Lincoln, Nebraska

August 2018

UTILIZATION OF DEPTH – ENABLED IDENTIFICATION AND TRACKING SYSTEM TO IDENTIFY AND TRACK INDIVIDUAL PIGS AND ANALYZE INDIVIDUAL PIG ACTIVITY

Jessica Michelle Lancaster, M.S.

University of Nebraska, 2018

Advisor: Ty B. Schmidt

Ensuring the health and wellbeing of pigs is of the utmost importance to the swine industry. There is a need for a real-time system that can identify changes in pig activities and activity patterns to accurately identify compromised pigs. The value of a real-time system is the capability to identify compromised pigs prior to observance of visible clinical symptoms by facility personnel. Therefore, a novel computer vision depth-enabled identification and tracking (DeIT) system was evaluated. Evaluation of 10,544 randomly selected frames indicated a 93.9% accuracy rate for identifying pigs' identity when classified by the system as standing/walking. The accuracy of activities was 99.1% lying, 96.3% standing, 99.3% walking, 86.4% in close proximity to the feeder, and 73.6% in close proximity to the waterer. The average percentage of time spent lying (77.56±1.69%), standing (8.64±1.10%), walking (2.29±0.37%), in close proximity to the feeder (9.93 ± 1.66%), and waterer (0.95±0.28%). Furthermore, m/d walked was 943.1±105.1 m. As the trial progressed, the percentage of time spent lying and time in close proximity to the feeder increased ($P \leq 0.001$; 7.46 and 3.99%, respectively). Time standing and walking decreased (9.82 and 1.53%) from wk 1 thru wk 6. Gender had no effect ($P \geq 0.10$) on percent of time spent lying, standing, walking, in close proximity to the feeder, m/d walked. Barrows spent a greater (P=0.04) percentage of time than gilts in close proximity to the waterer (1.01% vs. 0.89%, respectively). Litter had no effect ($P \geq 0.10$) for time spent lying, standing, in close proximity to the feeder, and

waterer. There was a difference related to the percent of time walking (*P*=0.05) and m/d walked (*P*=0.05) between litters. Results indicate two significant outcomes, 1) proposed DeIT system has the capability and sensitivity to accurately identify, maintain identification, and track the activities of nursery pigs and 2) accuracy of the DeIT system provides the potential to evaluate changes in activity for an extended period of time.

DEDICATION

I dedicate this dissertation to my family. To my father, Mike Lancaster, thank you for always encouraging me to follow my dreams, assuring me everything is going to be okay, and always being only a phone call away. To my mother, Laurie Lancaster, thank you for going on adventures with me, keeping me grounded, and all the support packages I've received over my educational journey. To my older sister, Jamie Lancaster, thank you for always setting an example of excellences, encouraging me to follow my dreams, and reminding me it is my adventure and my choices to make. To my little sister, Jacee Lancaster, thank you for the long talks, keeping me in check, and I'm always here to give you advice. To my grandparents, thank you for encouraging me no matter where I travel and always being there to celebrate my successes. Without the support of my family, this journey would not be possible.

ACKNOWLEDGEMENTS

Growing up in Southern Idaho heading to Corn Belt much less Nebraska was never one of my life goals. However, life has a unique way of putting us exactly where we need to be, and for me that was the University of Nebraska. This experience has been one of the greatest learning opportunities I could have ever imagined. The triumphs, challenges, and life experiences I gained as a Cornhusker will always remain close to my heart.

First, I would like to thank my committee for their endless support, guidance, and time. I have been blessed with a committee that has challenged me to expand my knowledge, think critically and made me a better person. My committee consisted of Dr's Ty Schmidt, Benny Mote, and Steve Jones. I would like to thank Dr. Ty Schmidt for taking a chance on me as a graduate student and providing me the opportunity to coach the meat judging team. To Dr. Benny Mote, thank you for helping me to better understand the swine industry, statistics, and everything in-between. Last but not least, Dr. Steve Jones, thank you for providing me opportunities to work on other projects and serve as a teaching assistant. In addition, I would like to thank Dr. Eric Psota and Mateusz Mittek for all of their work on the camera and technology side.

In addition, I would like to thank the Meat Science Faculty at the University of Nebraska. The guidance, support, knowledge and opportunities provided are far too exhaustive to mention. I would also like to thank Sherri Pitchie for everything she has done for me both inside and outside of the office, Calvin Schrock for all his guidance in the meat lab and Tommi Jones for all of her help in the kitchen and lab.

I have had the opportunity to work with outstanding graduate students here at UNL. I am very thankful for everything they have done for me. I owe a special thank you to Lauren Kett, there is no one I could have ever made it through this process without our forced friendship. Lastly, I would like to thank the meat judging community. To all the students I have had the opportunity to teach or coach, thank you for taking part in this experience with me and teaching me more than I could have ever imagined. To the fellow coaches, thank you for serving as a great support system and always be willing to extend a helping hand.

TABLE OF CONTENTS

LIST OF TABLES……..viii

LIST OF FIGURES………………………………………………….……….…….ix

CHAPTER

I. INTRODUCTION………………………………………………………………1

II. LITERATURE REVIEW…………………………………………………………..3

Swine Health…………………………………………………….……….…….3

Diseases………………………………………….………..……………4

Impact on performance, carcass merit, and economics ……….……..….5

Non-ambulatory issues……………………………………………………..…...7

Impact on performance, carcass merit, and economics ………...……..…8

Determination of morbidity/injury and management …………...……..8

Activity/behaviors of pigs……………………………………………………...…9

Effect of pig activity and time/distance in relation to growth performance and carcass merit……………………..……………………….…………......11

Time eating and d in relation to performance and carcass merit ……………………………...…………………….…………..12

Aggressive behavior……………………………………………………………..14

Utilizing enhanced technology to monitor daily activities of pigs……..……....17

Accurate identification of compromised pigs …..………………………18

Management and benefits…………..……………………………………..19

Use of computer enhanced system to track pig acitivity.……………………......21

Conclusion…………………………………………………………….………31

Literature cited…………………………………………………………….......33

III. EVALUATION OF A NOVEL COMPUTER VISION SYSTEMS' ABILITY TO CONTINUOUSLY IDENTIFY AND TRACK THE ACTIVITIES OF NEWLY WEANED PIGS……………………………………………………………………..……37

Abstract…………………………………..……………………...…..…...37

Introduction………………………………………………………………..…...38

Materials and methods……………………………………………………..….40

Animal and experimental design……………………………………......40

Depth-enabled identification and tracking system ………………..…....40

Accuracy analysis……………………………………………..…...43

Statistical analysis………………………………….……….…...44

Results…………………………………………………………...…………44

Accuracy of identity……………………………….….…..……..44

Classification of activities……………………………...………..45

Time associated with activites.……………………..….………...45

Discussion ……………………………………………….…………...50

Conclusion…………………………………………….…………...55

Literature Cited ……………………………………….…………...57

LIST OF TABLES

1 – Diet fed in the controlled nursery……………………..………..……………….....…59

2 – Identification errors associated with activities and overall DeIT system accuracy of identification of 28 nursery pigs over 42 d, as determined by comparison of DeIT system identification labeling on recorded images and visual observations..................60

3 – Accuracy of DeIT system to identify activity of 28 nursery pigs over 42 d, as determined by comparison of DeIT system identification labeling on recorded images and visual observations...………………………………………………………..…..61

4 – Overall percentage of time associated with activities m/d walked of 28 individual nursery pigs recorded during the first 42 d, as classified by DeIT system………..…...62

5 – Overall percentage of time associated with activities and m/d walked reported by week of 28 individual nursery pigs during the first 42 d, as classified by the DeIT system…...…………………..…………………………………………..…..........63

6 – Overall percentage of time associated with activities and m/d walked reported by gender of 28 individual nursery pigs during the first 42 d, as classified by the DeIT system……………………….……………………………………………..……64

7 – Overall percentage of time associated with activities and m/d walked reported by litter of 28 individual nursery pigs during the first 42 d as classified by the DeIT system……………………...……..………………………………………..….........65

8 – Overall percentage of time associated with activities and m/d walked reported by pen assignment of 28 individual nursery pigs during the first 42 d, as classified by the DeIT system…………………………………………..………….……...….......66

LIST OF FIGURES

1 – Schematic drawing of rooms utilized for the commercial nursery and controlled nursery with pen annotation of the pens utilized in the trials ….......………….……….67

2 – Individual visual identification methods (paint brand, paint pattern, colored/numbered ear tags) utilized to identify newly weaned nursery pigs…..……....68

3 – Image of visual verification of DeIT system's accuracy for determining individual identification. A manual comparison is made between the marker applied by the DeIT system and the colored/numbered ear tags in the pig's ears……………………..…..69

4 – DeIT system activity labels for activities. White circles containing letters indicate the activity the DeIT system is recording for individual pig activity. The colored circle with numbers is representative of the identification the DeIT system has labeled for each pig

……………………………………………………………………………………..70

5 – Recorded identity errors (label swap and loss of DeIT tracking label) observed through manual observation of DeIT system identity labels and visual observation of ear tags utilized for individual identification.………………………...…………...…71

6 – Evaluation of the percentage of time spent lying as reported on a daily basis (highly variable) compared to the percentage of time spent lying as reported on a weekly basis ……………………………………………………...……………….……..72

7 – Evaluation of the percentage of time spent standing as reported on a daily basis (highly variable) compared to the percentage of time spent standing as reported on a weekly basis ……………………………………………………………..………..73

8 – Evaluation of the percentage of time spent walking as reported on a daily basis (highly variable) compared to the percentage of time spent walking as reported on a weekly basis ……………………………………………………………..………..74

9 – Evaluation of the percentage of time spent in close proximity to the feeder as reported on a daily basis (highly variable) compared to the percentage of time spent in close proximity to the feeder as reported on a weekly basis ..……………...………..75

10 – Evaluation of the percentage of time spent in close proximity to the waterer as reported on a daily basis (highly variable) compared to the percentage of time spent in close proximity to the waterer as reported on a weekly basis ..………………....…..76

11 – Evaluation of the m/d walked as reported on a daily basis (highly variable) compared to the m/d walked as reported on a weekly basis …………………………..77

CHAPTER 1

INTRODUCTION

The livestock industry is faced with a fundamental goal of maximizing efficiency and growth while ensuring animal well-being. This production challenge is further amplified as operations increase numbers of animals (operation size) to achieve profits in the industry. Caretaker visual observations have been used as a method to detect deviations in animal health and well-being. Identifying sick, injured or slow growing animals with caretaker visual observations requires the animal to exhibit obvious physical indicators. When the caretaker is present, the time it takes to identify these signals could be improved by finding a more rapid way of identifying sick, injured, or slow growing pigs. Increased observations and extensive resources are needed to identify and monitor all pigs in commercial swine facilities.

Based upon visual observation of clinical symptoms, treatment can be delayed which can delay treatment until pigs are identified with symptoms of illness, injury or stunted growth. Early identification of compromised pigs and appropriate management are an essential step in advancing pig well-being and production efficiencies. Identification and early treatment prior to the observation of clinical symptoms could have many significant benefits: increased effectiveness of treatments, altering management practices of injured pigs, reduction of disease load on a herd and providing insights to management on pathogenic outbreaks. Rated detection of injuries may allow for intervention in a timely manner and can improve pig well-being along with potentially reducing further injury or tissue damage. After resolving the major challenge of identifying sick, injured and growth delayed pigs, more focus can be placed on additional well-being interventions. There is also a need to identify aggressive pigs which negatively impact the well-being of pen mates and could allow for the development of alternative management strategies and improve animal welfare.

The development of a method to rapidly identify pigs that are slow growing or sick would be extremely beneficial to the industry. Rapid and accurate identification of the health status and well-being of pigs would allow for quicker interventions and decrease the impact of injury, disease and stunned performance. Thus, the hypothesis of this research is that a depth-enable identification and tracking (DeIT) system can be used to identify individuals, maintain identification, and classify/track the movement of multiple pigs.

CHAPTER 2

LITERATURE REVIEW

Swine Health:

The swine industry is impacted by viral and bacterial outbreaks and persistent subclinical illnesses that can have devastating results. Initially, a disease outbreak impacts a few farms, as it spreads it impacts a greater number of farms and reaches the point that it can no longer be controlled. Pigs that reach market during or after a disease outbreak will be worth more money because of the decreased supply (Paarlberg 2014). These outbreaks will also impact consumers as they will be faced with purchasing decisions when pork prices increase as a result of decreased pounds of product available (result of slowed growth and increased mortality).

Animal health is a major concern to livestock producers. One concern is the microorganisms (bacteria, virus, fungi, protozoa and microorganisms) that utilize livestock as a source of nutrients and host. Schinckel (1994) utilized 140 barrows (10 – 14 d) to investigate the effects of immune system activation on growth. Barrows were assigned to one of three treatment groups: control (76 barrows), moderate immune challenge (32 barrows) or intense immune challenge (32 barrows). Challenged barrows received antigenic challenge that include lipopolysaccharide, modified live vaccine or killed vaccine, administered between 12 and 84 d of age with moderately challenged barrows receiving five challenges (on d of age 12, 21, 28, 49, 84) and intensely challenged receiving eight challenges (on d of age 12, 21, 28, 35, 42, 49, 63, 84). The challenged (both moderate and intense) barrows required an additional six d to achieve a BW of 104.3 kg and an additional four d to reach 119.8 kg when compared to the unchallenged control barrows. Unchallenged control barrows had 0.96 cm^2 larger loin eye (P = 0.004) than challenged barrows at 32.7 kg, but the difference diminished ($P > 0.1$) when the pigs reached 119.8 kg. Schinckel (1994) indicated that antigenic challenged barrows had a decreased ADG and loin eye are, but if the timeline is extended out, differences diminished.

Diseases:

Porcine Respiratory and Reproductive Syndrome (PRRS) outbreaks reported in the nursery dramatically increased (29.1%) from 2000 to 2012 (United States Department of Agriculture 2017). Porcine Reproductive and Respiratory Syndrome is caused by infection with Porcine Reproductive Respiratory Virus (PRRv). Porcine Reproductive and Respiratory Syndrome is observed in two distinct clinical phases: reproductive impairment of sows and boars and respiratory disease especially post weaning (Aiello and Mays 1998). Transmission of the PRRv is through pig-to-pig contact, as well as through infected manure, birds, mice, and in semen. Pigs infected with PRRv can serve as a persistent source of the infection (three to four months) post outbreak. Clinically infected boars can shed the PRRS virus in semen for 93 d post infection. Sows and gilts inseminated with infected semen displayed clinical symptoms of PRRS, had IgG antibodies to PRRS virus in the blood and reduced conception rates. Reproductive failures are also attributed to sows and gilts infected with PRRv during gestation where increases of 25% in the number of stillborn and mummified piglets, along with an abortion rate of 10% have been reported (Aiello and Mays 1998). Porcine Reproductive Respiratory virus has the ability to cross the placental barrier and infect piglets late in the second or third trimester of a pregnancy and infect neonatal piglets. Infection with PRRv can result in the destruction of mature alveolar macrophages potentially resulting in pulmonary disease (Aiello and Mays 1998). It should be noted that in many cases PRRS occurs in combination with other pathogens making it challenging to determine the true impact of the virus (Holck and Polson 2003).

Another devastating pathogen is Porcine Epidemic Diarrhea Virus (PEDV), which can be transmitted directly (fecal-oral) or indirectly (equipment, transportation, personnel introduced) (Pospischil et al. 2002). Once ingested (contaminated feces), a 3 – 4 d incubation period occurs which allows the virus to replicate in the epithelial cells of the small intestinal villi. There are limited true clinical symptoms associated with PEDV primarily diarrhea and puking in all ages of pigs, with nursery, grower, and finisher pigs being the most susceptible to the virus (Aiello and Mays 1998, Pospischil et al. 2002). Porcine Epidemic Diarrhea Virus has a neonatal mortality of 80% (Aiello and Mays 1998). Finishing pigs may have acute deaths during the viral incubation period and shortly after appearance of clinical symptoms. This is especially prevalent at the end of the finishing period and in stress susceptible breeds (Aiello and Mays 1998). A 100% morbidity is seen in finishing and breeding pigs (Aiello and Mays 1998, Pospischil et al. 2002).

Streptococcus suis is gram a positive bacterium that has been reported to affect both pigs up to 8 wk and finishing pigs. *Streptococcus suis* can be harbored sub-clinically in the tonsillar crypts and serve as a persistent source of contamination. Transmission of *Streptococcus suis* is achieved via pig-to-pig contact with carrier pigs (especially piglets) while type one is endemic to most herds (Aiello and Mays 1998). *Streptococcus suis* is detrimental through the cause of meningitis and arthritis, but can also be manifested through pneumonia, endocarditis, myocarditis, and diseases of the sow's reproductive tract; antibiotics are effective if used early. *Streptococcus suis* has dramatically increased (33.6%) in the nursery phase from 2000 to 2012 (United States Department of Agriculture 2017).

Impact on performance, carcass merit, and economics:

Porcine Reproductive and Respiratory Syndrome (PRRS) results in substantial financial losses to the swine industry. Neumann et al. (2005) reported a potential annual economic impact of

$500.32 due to PRRS. Of this $500.32 million, $250 million is associated with decreased G:F and $243 million in grower pigs. In addition, $63 million is estimated to be attributed to reproductive losses (stillborn pigs and abortions). Broken down, the cost of PRRS/sow is estimated at $255 (Neumann et al. 2005). Holtkamp et al. (2013) reported PRRS costs the swine industry $664 million annually, which was much greater than previously reported numbers. Of this, $140.11 million is associated with animal health costs; $191.86 million is associated with biosecurity related costs, along with $145.82 million associated to other costs (Holtkamp et al. 2013). Utilizing 60 PRRS naïve Choice Genetic Maternal Line gilts (33.6 ± 0.58 kg) randomly assigned to one of two barns, Schweer et al. (2017) investigated the impact of PRRS on growth and carcass parameters. One barn was the control barn and the other was the PRRS challenged barn, both barns had 30 gilts that were assigned to one of five pens. After a 2 wk acclimation period, control pigs were inoculated with 1mL of saline solution and PRRS challenged gilts were inoculated with 1 mL of inoculum containing PRRv (1,000 genomic units of a live field strain of the PRRv, ORF5-RFLP 1-18-14). Gilts were weighed prior to inoculation and then at 7 d intervals until treatment groups reached a targeted average BW of 128 kg. Whole body compositional analysis was conducted at three time points (-1, 42, 80 d post inoculation) using X-ray absorptiometry using procedures described by Suster et al. (2003). Control gilts had a greater (*P* = 0.002) ADG (0.8 kg) compared to PRRv challenged gilts (0.9 kg), which resulted in PRRS challenged gilts requiring an additional 14 d on feed to achieve an average BW of 128 kg. In addition, control gilts had greater tissue accretion (lean 657 vs 568 g/d, protein 131 vs 112 g/d, fat 230 vs 180 g/d, whole body gain 0.92 vs 0.78 kg/d for control and PRRS challenged pigs respectively) over the duration of the trial. The majority of the difference in tissue accretion is contributed to the first 42 d post inoculation (lean 635 vs 491g/d, protein 123 vs 94 g/d, fat 155 vs 108 g/d, whole body gain 0.83 vs 0.63 kg/d for control and PRRv challenged pigs respectively). Differences in carcass characteristics were also observed. Tenth rib back fat depth of control gilts (1.85 cm) was greater (P = 0.005) than the PRRv challenged gilts (1.8 cm) and the lean percentage of the control pigs (55.4%) was greater than the PRRv challenged pigs (56.3%). Schweer et al. (2017) extrapolated PRRv challenged gilts to have an economic impact of $3.47/gilt to achieve the same BW as control pigs, but if gilts were marketed at the same age the economic impact increased to $10.49/gilt. Porcine Epidemic Diarrhea Virus drastically impacted the US pork industry in 2013; it is estimated to have cost the industry between $900 million and $1.8 billion in total loss (Paarlberg 2014). Broken down, the cost of PEDV/sow is estimated at $52.19/female that is breeding age along with $2.36/weaned pig (Neumann et al. 2005).

Non-ambulatory issues:

Non-ambulatory is defined as a pig which unable to stand or is unable to bear weight on at least two legs. Non-ambulatory, injured pigs have an obvious physical injury that is prohibiting the animal from performing normal activities, while non-ambulatory, not injured (NANI) pigs have non-detectable injuries or illness preventing normal activities. It is estimated that 4.9% of pigs identified as morbid are classified as morbid due to lameness issues (United States Department of Agriculture 2017).

Most instances of NANI pigs occur during the relocation of pigs to the abattoir. Utilizing data from five US abattoirs, Sutherland (2008) investigated the health status of NANI pigs at processing. All pigs were classified as ambulatory at the time of arrival. Pigs that became NANI were sorted into an injured pen, tattooed with a unique identification, and a blood sample was taken. Following the identification of a NANI pig, a control pig was also selected, sorted into a control pen, tattooed, and a blood sample was pulled. Sutherland (2008) concluded that there is not a single factor that can be identified as the cause of NANI pigs. Instead it is a combination of feet and leg injuries, infections, ulcers, liver damage, subtle bone injuries, and tissue breakdown.

Impact on performance, carcass merit, and economics:

The majority of the reporting of NANI pigs is reported on pigs at the abattoir. Carr (2005) estimated the economic loss of NANI pigs carcasses to the industry. Using the reported average that 0.5-1% NANI pigs at processing facility are NANI, and factoring in the 100 million pigs processed on an annual basis, there are one million NANI pigs annually. Non-ambulatory, not injured pigs often receive discounts of $10 to $15/pig. In total, NANI pigs can exceed ten million dollars loss of potential profit.

Determination of morbidity/injury and management:

Caretakers are tasked with daily observations and documentation of pig health and well-being. To ensure health and well-being visual observations are conducted at least once a d. Observations include habits (at feeder or at waterer), lying patterns, and clinical symptoms. To observe animals for lameness, caretakers must observe all pigs standing (demonstrating the ability to bear weight) during the observation. In the case of an injured or suspected morbidity, caretakers must determine the appropriate action to take (treatment or euthanasia). Schlooser (2001) reported that on average there is one nursery caretaker/4,000 pigs in the nursery. The ratio of nursery caretaker to nursery pigs' results in very limited time for observations and undoubtedly results in undiagnosed cases of morbidity. Ketchem and Rix (2012) reported the swine industry's morbidity rates (birth to weaning) are greater than 20%. It is estimated the nursery phase is faced with a 3.6% morbidity rate, 47.3% was due to respiratory infection, 22.2% was due to starvation, 13% was due to central nervous system/meningitis, 9.4% wad due to scours, 6.6% was due unknown causes, and 1.7% due to other known causes (United States Department of Agriculture 2017).

Activity/behaviors of pigs:

McGlone and Curtis (1985) investigated the behavior and performance of nursery pigs in pens with hide areas. Pigs were assigned to a control pen (no hide area) or a pen with a hide area (plywood wall with 3 holes cut to allow pigs to enter hide area). Pen activity was recorded by a AVC-3260 camera (Sony Video Products Co., New York) mounted above the pen, hide areas had a transparent top to allow for activity classification. Video recordings were analyzed for mutually exclusive behaviors: attacks, at feeder, lying, or head in hide area. Attacks were classified as acts of aggression involving physical contact (biting/pushing). Activities were recorded using a keyboard activated event recorder (Esterline Angus Model A620X, Esterline Corp., Indianapolis, Indiana) and reported as the number of pigs performing the activity. Pigs that were placed in pens with hide areas had a shorter attack duration that pigs in control pens for attacks happening within 30 minutes (865 sec short attack duration, $P = 0.01$) and within 90 min (1,280 sec short attack duration, $P = 0.06$) of placement into pens. The duration of time pigs spent at the feeder and lying were not different ($P > 0.10$) between treatments. Results suggest that providing hide areas can alter aggressive pig behavior after regrouping (McGlone and Curtis 1985).

It is generally accepted that animal activities serve as an indicator of the state of an animal's health and well-being. Davis et al. (2004) utilized 216 pigs to investigate the effect of weaning age on growth, performance, mortality rate and behavioral indicators of animal welfare of nursery pigs. Two treatments were utilized in the study: pigs weaned 14 d age and pigs weaned at 21 d of age. Pigs from each treatment were assigned to one of three groups based on body weight.

A video surveillance camera was mounted above each pen to monitor pig activity. Observation of video recordings from d 7, 14, 27, 35, 38, 44, and 65 were observed in 2 h increments. Video recordings were manually scored for aggression, time at feeder, time at waterer, lying or movement activities. Aggression included head-to-head knocking, head-to-tail knocking tail biting, ear chewing and aggressive circling. Older pigs weaned at 21 d had a greater ($P < 0.01$) ADG than younger pigs weaned at 14 d. Moreover, the mortality rate was greater (Chi-square, $P < 0.01$) for pigs weaned at 14 d (12% mortality rate) than pigs weaned at 21 d (1% mortality rate). Activity of pigs observed at weaning indicated younger pigs spent less time ($P < 0.05$) lying when compared to older pigs (26.2% and 45.5%, respectively). At 14 d post weaning, younger pigs spent less time ($P < 0.05$) at the waterer than older pigs (1.5% and 4.5% of time, respectively). Results suggest that younger pigs spent decreased time lying when compared to older pigs, which may be the cause of the decreased growth rate and increased mortality when compared to older pigs (Davis et al. 2004).

Utilizing 9,429 pigs (5,989 Large White, 2,908 Landrace, 532 Duroc), Jones et al. (2011) investigated pen dynamics on growth and carcass parameters. Pigs were divided into 353 grower groups that consisted of different pen dynamics including breed (varying ratios of each breed), sex (varying ratios from 0-100% boars and gilts), litter (varying ratio of littermates), and stocking density (varying from 22 to 37 pigs) in each pen. The ratio of Duroc pigs impacted the ADG ($P < 0.001$), while no other breeds were different ($P > 0.10$). Pens that contained a greater ratio of boars had a difference in backfat ($P < 0.02$). Pens that contained less than ten percent boars had greater ADG ($P < 0.05$) than pens containing more than ten percent boars. Pens that contained littermates had greater ADG ($P < 0.001$) and difference ($P < 0.10$) in back fat when compared to pens not containing littermates. Also, the stocking density of the pen had an impact on ADG ($P < 0.001$).

Jones et al. (2011) indicated that the ideal pen composition would be single gender and single litter.

Gonyou et al. (1998) investigate the impact of weaning age on pig behavior utilizing pigs weaned at d 12 ± 2 and d 21 ± 3. Video recordings were collected for 48 h post weaning and then for 3 d through wk 5-6. Instantaneous sampling was used to determine behaviors in the initial 48 h (5 min sampling) and the subsequent wk (8 min sampling). Pigs weaned at 12 d spent less (P = 0.05) time at the feeder when compared to older pigs (3.74% and 6.39% respectively). In addition, younger pigs engaged in more (P = 0.05) social behaviors when compared to older pigs: nosing other pigs (0.28%), chewing other pigs (0.57%), however younger pigs spent less time chewing objects (0.02%) than older pigs. The percentage of time pigs spent at the feeder decreased 4.54% from wk 1 to 1k 6. The percentage of time pigs spent nosing other pigs was the greatest at wk 2 and wk 3 (1.51% and 1.39%, respectively) and decreased in wk 6 (0.47%). Results suggest early weaned pigs spent less time at the feeder and more time participating in social behaviors (Gonyou et al. 1998).

Effect of pig activity and time/distance in relation to growth performance and carcass merit:

There is little to no research looking at the impacts of standing, walking, lying, and time/distance traveled and the relation to performance and carcass characteristics. The amount of time spent lying is mentioned in He et al. (2018), but results are in relation to a feeding treatment. Potential reasons for little research in this area are: activities are challenging to track and the correlation between the activities and performance and carcass merit is unknown.

Sadler et al. (2011) utilized 192 purebred Yorkshire gilts (reduced residual feed intake line and randomly selected controls) to investigate general behavior activities. Two replications of the study were conducted. Each replication had eight pens with 16 pigs/pen (8/genetic line). Gilts were individually marked to maintain identity throughout the test period. Feeding patterns were collected using a Feed Intake Recording Equipment with ACCU-ARM Weigh Race. A single Panasonic WV-CP484 video camera was placed above each pen. Video recordings were started upon placement into the pen, with subsequent video being recorded at 4 wk intervals until the conclusion of the study for a total of four recordings. A total of 576 h of video were analyzed for behaviors, derived from predetermined times (800- 2000 h) based upon time periods when gilts were the most active. Two experienced technicians recorded their observations using Observer Software and scored the video for six mutually exclusive behaviors: (four postures - walking, standing, sitting, lying) and one behavior (at the waterer or unknown). The majority of time (84.2%) for all gilts was spent lying, with standing, walking, and time at the waterer making up the remainder of the time (11.1%, 4.2% and 0.5%, respectively) (Sadler et al. 2011). Aside from the initial recording, gilts from reduced residual feed intake lines spent more time standing ($P = 0.02$), sitting ($P = 0.05$) and active ($P = 0.03$) than the control gilts (Sadler et al. 2011). Sadler et al. (2011) indicated that gilt behaviors differed between the RFI and control gilts.

Time eating and drinking in relation to performance and carcass merit:

Ros-Freixdes et al. (2014) utilized 192 Yorkshire gilts (reduced residual feed intake line and randomly selected controls) to investigate the relationship between behavior and meat quality. Two replications of the study were conducted; each replication had 12 pens with 16 pigs/pen (8/genetic line). Gilts were individually marked to maintain identity throughout the test period. Feeding patterns were collected using a single space electronic feeder. A single Panasonic WV-CP484 video camera was placed above each pen and the video was recorded onto DVDs. Scale activity scores were determined when gilts were weighed using a one to five scoring scale (one -

pigs were calm and had minimal movement up to five - pigs were constantly moving, attempting to escape). Video recordings were started upon placement into the pen, with subsequent video being recorded at 4 wk intervals until the conclusion of the study for a total of four recordings. Sixteen hours of video were analyzed, derived from predetermined times (700-900 and 16-2000 h) when gilts were the most active. Two experienced technicians recorded their observations using Observer Software and scored the video in accordance with behaviors adapted from Bornett, Morgan, Lawrence & Mann (2000). The video was scored for seven behaviors including fights, pushing, bullying, head-knocking, chasing, threatening, and avoidance (Ros-Freixedes et al. 2014). Gilts from reduced residual feed intake lines spent more time ($P \leq 0.05$) at the waterer than the control gilts. The only activity that was different ($P < 0.05$) for carcass parameters was time spent at the feeder and the increased intramuscular fat. Ros-Freixedes et al. (2014) indicated that gilt behaviors did not serve as a good indicator of meat quality, with the exception of time at feeder and intramuscular fat.

He et al. (2018) investigated the behaviors that can indicate slow growing nursery pigs, utilizing 220 pigs randomly assigned to two treatments. Pigs were stratified by weight and gender and assigned to one of two treatments; two eating spaces feeder (7.4 ± 1.7 kg) or five eating spaces feeder (7.3 ± 1.6 kg). The study consisted of two trials with 18 pens/trial, eight pigs/pen. Using video-recording software and a Hi-Res Bullet Camera (Black/White Hi-Res Bullet Cams 2505, Sony, Taiwan) mounted over each of the 18 pens, cameras captured video for the 96 h after pigs were moved into the nursery and again for 24 h on d 21. Pigs were grouped into slow growing or fast-growing categories based on the 170 d BW. Unique patterns were applied to each pig for identification. The 5 min scan sampling method was used to analyze the data for behaviors (time at the feeder, time at the waterer, standing/walking, lying, and fighting). Analysis of 276 images indicated pigs assigned to the 5 – space feeder treatment spent more time at the feeder (*P* = 0.05) and less time standing/walking (*P* = 0.02) than pigs assigned to the two-space feeder treatment. Over the initial four d, pigs increased the time spent at the feeder and lying (*P* < 0.001); after d 21 pigs spent more time at the feeder and lying. Pigs categorized as slow growing spent more time at the waterer (*P* < 0.001) than fast growing pigs. He et al. (2018) indicated that while the trial was effective, it had limitations. Primary issues were related to a stocking density (fewer pigs/pen than industry) and greater space allowance in the trial than in commercial production.

Aggressive behavior:

There are three main factors that will determine the amount of aggression pigs exhibit in commercial housing: amount of regrouping (mixing), method of feeding, and the area provided (Marchant-Forde 2010). McGlone (1985) used 20 pigs (5 barrows, 15 gilts) that were 6 wk of age to identify aggressive and non-aggressive pig behaviors during fighting and non-fighting episodes. Ethograms were used for defining, classifying and observing repeatable behaviors and activities of pigs. Five pigs were placed in each pen, one pig from each pen was then placed in a pen with four new pen mates (pen mates were previously established). Two video cameras (aerial and side views) were used to capture activities and behaviors. In addition to classifying behaviors, fights were also analyzed. For each fight, a winner (showing no submissive behavior during or after fight) and a loser (showing submission during and after the fight) were identified. In some cases, fights were interrupted by a third pig (pushing, biting, or other activity) and ceased after the interruption; these instances were classified as undecided fights. A chi-square test was used to analyze the behaviors. McGlome (1985) evaluated 1,846 behaviors that included 10 fights along with observations in 25 different categories. The fights lasted for 118 ± 42 sec and contained 92 recordable behaviors on average. During fights, biting was different between winners (414 bites) versus losers (216 bites) with the majority of the bites taking place on the ears (55%) and the remaining taking place on the shoulders (23%) and face (17%) (McGlone 1985).

Erhard (1997) utilized 115 pigs (34 + 0.5 kg) to investigate the use of individual pig aggression as a means to reduce the amount of aggression after mixing pigs in a pen. An initial test was conducted by the resident intruder (introduction of a new pig into a pen were another pig is housed) test where an unfamiliar pig is introduced to another pig's pen and the time until the first attack is recorded. This test was conducted on 88 of the pigs (8/litter), and pigs were sorted into high or low aggressiveness categories based on attack times. For logistical reasons, groups of four pigs/litter with the same aggression tendencies were grouped for treatment assignment. At the conclusion of d 2 of resident intruder testing, groups of pigs were assigned to one of three aggressive pen states: high aggression and high aggression, low aggression and low aggression, or high aggression and low aggression. Once the pens were mixed, behavior (threats, head-knocks, biting, chasing, fighting, number of skin lesions and lying preference) was recorded. A clear winner litter and loser litter were determined in 14/15 groupings. The pigs from more dominant litters moved throughout the pen during the trial, while the less dominant litters tended to stay together and avoid interactions with dominant pigs (which reduced the incidence of fighting). Pigs from the litters identified as winners performed 94% of the aggressive behaviors in the first two hours post mixing, with the exception of fighting. Time spent fighting/pig was different for aggression levels in the pens with high aggression and high aggression spending 20.9 sec fighting, low aggression and low aggression 8.2 sec, and high aggression and low aggression 9 sec. Erhard (1997) indicated that whenever possible litters of low aggression are preferred from a welfare perspective. Primary issues were related to application of the mixing of pigs from same litters that did not follow the same group aggression patterns and the inability to determine aggression breakpoints as it is relative to litter (Erhard et al. 1997).

Stookey and Gonyou (1994) utilized 80 pigs (29 kg) assigned to eight like-sex pens, to investigate the impacts of regrouping in finishing pigs. Nine wk post mixing, 72 pigs (9/pen) were assigned to treatment groups that were made up of one of three pen dynamics: control (same pen mates since weaning), mixed (at the start of trial were mixed with new pen mates and stayed there for the duration), or mixed for 24 h (mixed at the start of the trial with new pen mates and then returned to the original pen mates 24 h post mixing). Behavioral observations (recorded on d 1, 2, or 8) were made by an observer sampling activity (lying, time at the feeder, time at the waterer, standing, fighting) taking place in a pen over a 3 min period. On d 1, barrows spent more time standing than gilts ($P < 0.05$) and control pens spent less time fighting than mixed pens ($P < 0.01$). After 24 h, the pigs assigned to the mixed pens for 24 h treatment were regrouped in original pens, resulting in the pigs spending more time at the feeder ($P < 0.01$) and standing ($P < 0.01$), with less time lying ($P < 0.01$). For both d 2 and 8, control and mixed 24 h pens spent less time fighting than mixed pens ($P < 0.01$). The impact of mixing pens resulted in a 0.17 kg/d decrease ($P < 0.05$) in ADG compared to the control pens. Stookey and Gonyou (1994) indicated that pigs should not be mixed into pens with other pigs in the 2 wk prior to harvesting.

Camerlink et al. (2012) utilized 398 crossbred finishing pigs assigned to 50 finishing pens to investigate the relationship between growth rate, oral manipulation, social nosing, and aggression in finishing pigs. Behavior was recorded by manual observation through 2 min instantaneous scan sampling and recorded using Observer 5.0 software package (Noldus Information Technology B.V., Wageningen, The Netherlands) on a hand-held computer. Behaviors recorded were: social nosing (gentle touching or sniffing of pen mate), oral manipulation (nibbling, sucking, chewing part of pen mate including tail, ear, and paws), aggression (pushing, biting or head-nocking pen mates), belly nosing (rubbing belly of a pen mate with the snout), mounting (having front legs on another pig while standing on back legs), and disturbing (disruption of another pig that is not previously listed, i.e. stepping on sleeping pig) (Camerlink et al. 2012). Two behaviors (receiving social nosing and receiving social manipulation) had a positive effect (P = 0.03 and P = 0.01 respectively) on growth. Camerlink et al. (2012) indicated that social behaviors could be considered positive, but additional research is needed on how behaviors can influence growth.

Utilizing enhanced technology to monitor daily activities of pigs:

There are technologies that have been developed specifically for agriculture, but few technologies have been developed for a livestock setting to enhance production practices and animal welfare. The mortality rate of pigs in the nursery is increasing; in 1995 there was a 2.5% mortality rate which increased to 2.6% in 2000, followed by another increase to 2.9% in 2006, with an additional increase to 3.6% mortality rate in 2012 (United States Department of Agriculture 2017). Maes et al. (2001) investigated the timeline of mortalities happening in the growing and finishing phases over a 4 year reporting period, utilizing mortality rates were reported on 1,345,127 pigs in grow-finish barns. The mortality rate increased from 2.57 mortalities/1,000 pig wk in 1996 to 3.57 mortalities/1,000 pig wk in 1999 (Maes et al. 2001). Overall, a greater mortality rate was reported in the late period (wk 11 – end of finishing period) when compared to the mortality rate (2.16 mortalities/1,000 pig wk) in the early period (wk 1 – 10) of the grow-finish operation (Maes et al. 2001). The percentage of mortality occurring in the late growing period is partially larger because pigs identified as morbid in the early wk of the growing phase that do not recover could be reported as mortalities in the late period of the growing phase (Maes et al. 2001).

Sick pigs can pose a challenge through production and may never maximize growth potential. Identifying and treating pigs earlier could help to reduce the loss.

Weimer et al. (2014) investigated the utilization of digital-image evaluation and human evaluation of nursery pig behavior utilizing 1,738 crossbred pigs (6 wk, 25 kg). A camera (Pentax Optio, Golden, Co) was mounted on a base and used to capture images for digital-image evaluation. A human observer entered the pen and crouched down near the gate, the observer then extended a hand straight out toward the center of the pen. Pigs were classified into three categories based on the response to the observer: touch (body part of pig in contact with human observer), oriented (pig facing toward human observer) and not oriented (pig not touching or oriented toward human observer). Pigs that were classified as not oriented could be further classified as standing, sitting, lying, head in feeder, at waterer or in pile with at least one pen mate. Classification was conducted by an observer during the experiment and digital-image evaluation was conducted post experiment. There was no difference ($P > 0.05$) between the classification of the human observer and digital evaluation. Overall, 46.5% of pigs were classified as either touch or oriented; the remaining 53.5% of pigs were classified as not oriented. Of the pigs classified as not oriented, 77.7% were standing and 5% were lying. Results suggest that digital-image analysis is capable of classifying pig behavior, but the time required in labeling behaviors is a limiting factor (Weimer et al. 2014).

Accurate identification of compromised pigs:

Pigs that have altered time spent at the feeder or waterer, or lying patterns as well as pigs that are exhibiting signs of sickness and injury should be further examined for the need of treatment. Lowe (2014) indicated the importance of identifying sick behaviors as occurrence happens days before physical changes like weight loss take place. Pigs that are treated during the early clinical stages allow for greater cure rates and allows the pig to start recovering in a timelier manner (Lowe 2014). Treatment protocols include moving the pig to an isolated or treatment pen (depending on case), keeping accurate treatment records and monitoring response to a treatment. In some instances, euthanasia protocols may need to be utilized on unresponsive animals.

Management and benefits:

One management strategy that is utilized in various livestock industries is reducing variation through grouping animals of similar BW. Animals are weighed using one of two methods: a direct measurement or an indirect measurement. Direct measurements can include utilizing a scale and measuring body parts (body length, shoulder height, heart girth, etc.) as an indicator of BW. Indirect measurements, which are not performed directly on the animal, can include the use of scaled photographs and video imaging. Weighing of pigs does not take place in most commercial pig production and facilities are not designed to easily weigh pigs (Patience and Beaulieu 2006). Furthermore, Meisinger (2003) indicated in the National Pork Quality Benchmark study that two of the five largest concerns to the packers were inconstant weights (first concern) and excessively fat carcasses (fourth concern). Variability of pork carcasses at the packer is estimated to cost $8.08/carcass (Meisinger 2003).

Brandl and Jørgensen (1996) utilized 416 pigs (25 kg), distributed into blocks each containing no littermate (two barrows and two gilts), to evaluate video imaging as a predictor of BW. Pigs were weighed every 3 wk and one half of the pigs were randomly selected for manual measurements (tail to scapula, snout to shoulder, breadth at back, breadth at middle, shoulder width, height at back, and height at shoulder). The study used Scan Beam A/S (1990) equipment

(Scan Beam A/S, Hadund, Denmark) and a recording video camera mounted above the scale outside the weighing area. Results suggested that there ware general relationships between BW and demensional measurements: length of tail to scapula ($r^2 = 0.96$), shoulder width ($r^2 = 0.97$), breadth of middle ($r^2 = 0.97$), and breadth of back ($r^2 = 0.95$) (Brandl and Jørgensen 1996). The greatest correlation ($r^2 = 0.98$) was the comparison betweeen the area a pig's body and the BW of the pig (Brandl and Jørgensen 1996). Brandl and Jørgensen (1996) indicated the recording system was effective, but had limitations. Future research should be conducted to develop automatic algorithms that would allow for the weight estimation of group-housed pigs (Brandl and Jørgensen 1996).

Direct measurements of anatomical locations provide an accurate correlation to body weight. Royal (2017) used 169 market bound pigs to compare the correlation of three body measurements using a measuring tape to record heart circumference and flank-to-flank distances and a marked polyethylene tube to measure heart circumference. The flank-to-flank distance recorded with the tape measure was moderately correlated ($r^2 = 0.38$) to pig body weight prediction. There was a correlation ($r^2 = 0.61, 0.66$) between the polyethylene tube and measuring tape with pig body weight respectively. Royal et al. (2017) indicated the polyethylene tube was a valid tool to determine heart girth measurements as an indicator of BW, but there were limitations. Primary issues were related to limitations around collecting parameters including time required to measure all pigs in commercial barn settings. One alternative to taking physical measurements is farm personnel estimating the weight of pigs via manual observation. Royal et al. (2017) utilized 169 market bound pigs to compared the weight predictions of farm personnel to actual BW. Ten manual observers were divided into two categories: five experienced (more than one year of swine experience) and five inexperienced (less than one year of swine experience and provided training before experiment). Estimation parameters of the 169 had an overall correlation ($r^2 = 0.42$) to the actual weight of the pigs. When observers were asked to predict the weight of pigs with standard weight deviations of 3.3 to 12.2 kg, the correlation decreased ($r^2 = 0.02$) There was no difference ($P > 0.10$) between the observations of the trained and untrained panelists, but this relationship decreased ($r^2 = 0.02$) (Royal et al. 2017). Royal et al. (2017) indicated that personnel estimations of weight were not an accurate method of BW prediction.

Use of computer enhanced system to track pig activity:

In general, video recording technology has been utilized in livestock agriculture as a tool to aid in identifying animals (Kashiha et al. 2013b, Thomasen et al. 2018), monitoring behavior (Gonyou et al. 1998, Davis et al. 2004, Ott et al. 2014) and aggression (McGlone and Curtis 1985, Viazzi et al. 2014), monitoring animal actives (McGlone and Curtis 1985, Kashiha et al. 2013a, Weimer et al. 2014, Zhu et al. 2017, Lassen et al. 2018), providing wt estimates (Wang et al. 2008, Zaragoza 2009, Marinello et al. 2015, Condotta 2017) and providing indications of sickness (Exadaktylos et al. 2008, Weixing et al. 2009).

Maselyne (2016) monitored the time pigs spent at the feeder via video recordings, information transmitted via RFID tags, and intermittent caretaker visual observations. Fifty-nine pigs were identified with high frequency radio frequency identification (HF RFID) transmitters. Tagging pigs with one HF RFID tag/pig was much less accurate (58 - 69%) than when pigs had two HF RFID tags (80 - 83% accurate) (Maselyne et al. 2016). When comparing the visual observations to the HF RFID recordings, the HF RFID system reported at least one reading on 91% of the feeder visits. Of the remaining 8% of reported HF RFID instances of feeder visits, the pigs were doing exploratory behaviors in close proximity to the feeder (Maselyne et al. 2016). The videos were also scored for feeder behaviors, and pigs were classified as eating when the head moved down into the feeder and the eating classification was terminated when the pig lifted the head and traveled away from the feeder (Maselyne et al. 2016). The video footage contained 2,067 visits to the feeder that were all relatively short time duration (14.9% < 5 sec, 30.7% < 10 sec, 53.3% <20 sec, 77% <40 sec) and in close time proximity to each other (Maselyne et al. 2016).

Individually identifying identity and activity of pigs has been reported as a time-consuming task Sadler et al. 2011, Camerlink et al. 2012, Ros-Freixedes et al. 2014). Utilizing 40 pigs (27 + 4.4kg) randomly assigned to four pens, Kashiha et al. (2013) investigated the use of image processing as a means to automatically identify pigs within a pen, using MPEG Recorder Software and a single Panasonic WV-BP330 mounted over each of the four pens with images collected for 12 h/d for 13 d; a total of 156 h of images were collected. To ensure identity of pigs, blue dye marks were applied using specific patterns that were visible to both the camera and human observers. At the conclusion of the 13 d trial, a reference of ID's was manually created as a means of comparison between algorithms created for continuous identification. Analysis of 15,600 identifications determined an average accuracy rate for correctly identifying pigs of 88.7%; 11.3% were not identified, and 1.0% were misidentified. Kashiha et al. (2013) indicated that while the system was effective, but it had limitations. Primary issues were related to pigs not standing in a position that allowed pattern recognition in the image and visual identification patterns faded over time and were no longer identifiable within images. The ability to identify individual animals in a group-housed setting is a tool that can be utilized to further investigate activities and behaviors without the need for manually labeling.

Thomasen et al. (2018) utilized 97 Jersey cows to investigate the use of image processing as a means to automatically identify cows at a feeding table using time-of-flight technology, 19 3D cameras and RFID tags. To ensure the identity of cows, RFID tags recordings were compared to camera observations. Analysis of 6,357 manually labeled images determined an average accuracy rate for correctly identifying cows of 90%; 10% were not identified or were misidentified (Thomasen et al. 2018). Thomasen et al. (2018) indicated that while the system was effective at classifying cow identities ay the feeding table, but the primary limitation was related to incorrect identification.

Ahrdent (2011) investigated the use of image processing as a means to automatically track simulated pigs within a pen utilizing 3 pink toy pigs secured to the top of small, programmable robotic vehicles. MatLab tracking software was used and a single Elphel NC353L camera was mounted over the test area and connected to a Dell Optiplex 760 PC. Images were collected for 8 min; a total of 156 h of images were collected. Each of the simulated pigs was programed to follow a unique route and traveled the opposite direction of simulated pigs on neighboring tracks. The tracks were set at a distance allowing the pig simulations to pass in close proximity to each other and each of the simulations was set to travel at a constant speed of 0.16 m/s. The same testing was completed for three camera lenses (standard lenses, fisheye lenses - no compensation, fisheye lenses - compensation software). The standard lenses allowed for the tracking of all pigs and no correction algorithm was needed, but the field of view was limited to the height of the ceiling. The fisheye lenses also allowed for tracking of all pigs, but without the correction algorithm the pig traveling closest to the perimeter was much smaller than the pigs closer to the center of the pen. The compensation algorithm corrected the size of the pigs to be the same size. Following the robotic trial, the camera was mounted over a pen with three 10 wk old piglets. At the conclusion of the 13 d trial, a reference of ID's was manually created as a means of comparison between algorithms created for continuous identification. The standard lenses allowed for the tracking of all pigs for 17 sec at which point, the field of view is not adequate to view the entire pen space and pigs quickly were out of the field of view. The fisheye lenses allowed for tracking of all pigs, but without the compensation algorithm the three moving pigs were tracked for 34s. The compensation algorithm kept track of three moving pigs for the duration of the trial (8 min). Ahrdent (2011) indicated that while the system shows it is possible to perform a real-time camera vision-based tracking of loose housed pigs, there were limitations. Primary issues were related to the limited field of view of the camera lenses, loss of identification through rapid movements or piling of pigs, and scaling to larger numbers/pen (Ahrendt et al. 2011). Adjustments like the changes in lenses and compensation algorithms make technology more viable in a production setting because it can operate in the environment (Ahrendt et al. 2011).

Ott et al. (2014) investigated the use of video labeling of activity compared to human observations utilizing 40 pigs (27 + 4.0 kg) randomly assigned to four pens. The study used MPEG Recorder Software (Noldus, Wageningen, The Netherlands) and four Panasonic CCD Digital Signal Processing B/W WV-BP300 (Noldus, Wageningen, The Netherlands) mounted over each of the four pens with images collected for 12 h/d for three wk. Human observations were conducted on four 30-min video sessions (recorded on d 1, 4, 8, 11, 15, 18), scan sampling was utilized, and each pig was scored for activity and recorded using Observer XT 10.2 software (Noldus, Wageningen, The Netherlands). Pigs were scored either as inactive or active. The active category was subdivided into three sections: locomotion (walking or running), static activity (time at the feeder, time at the waterer, standing, playing or interacting with pen mates) and locomotion with activity (combination of locomotion and static activity categories) (Ott et al. 2014). At the conclusion of the human observation, the occurrence of each activity (occurrence of activity compared to total occurrences of all activities) was recorded. Automated observations were conducted using similar time points to the human observations, with a mean activity index (based on 30 min sessions/pen) being computed by the software. Analysis of the human observation and automated observations of activity were correlated ($r^2 = 0.92$). Ott et al. (2014) indicated that the system was effective at labeling a mean activity index, but did not label individual behaviors. The ability of an automated system to perform similar tasks as the human observer can be a large resource saver.

Zargoza (2009) investigated the use of image evaluation to determine simple body measurements of pigs. Utilizing 72 individually housed Landrace barrows (57.5 + 7.1 kg) for trial 1 and 144 Landrace barrows (40.6 ± 4.9 kg) randomly assigned to 16 pens. Two methods were utilized for collecting body measurements, direct measurements or photographic measurements (dorsal and lateral views). To provide a dimensional reference to the photographs, a ruler was placed on the back of the barrow for dorsal photographs and on the ribs for lateral photographs. Still photographs were uploaded to Digital Image Basics computer program which utilized the number of pixels that made up each body dimension. A ruler was converted to a pixel to cm ratio to compare the image estimates to the measurements taken on the pigs. Body weights were determined from direct measurements, with measurements obtained through the photographs and calculated weight measurements. Similar r^2 values when comparing live animal measurements to the equation measurements for some parameters (shoulder height $r^2 = 0.84$ and $r^2 = 0.85$, and body volume $r^2 = 0.93$ and $r^2 = 0.94$ for study one and two respectively) while other factors were not similar (body length $r^2 = 0.44$ and $r^2 = 0.26$ and body area $r^2 = 0.63$ and $r^2 = 0.45$ for study one and two respectively). Primary issues were group-housed pigs were difficult to photograph due to activities in the pen, and time between trials impacted the repeatability of the r^2 values (Zaragoza 2009). The direct circumference measurements taken on the pigs compared to the calculated weight of the pigs for chest circumference ($r^2 = 0.93$ and $r^2 = 0.95$ for study one and two respectively). Body weight estimations calculated from live measurements were a more accurate indicators of weight ($r^2 = 0.85$) than measurements determined from lateral photographs ($r^2 = 0.65$). Zargoza (2009) indicated that while the system was effective, there were limitations. Primary issues were related to limitations around collecting parameters including time, labor and restraint of the animal and it would be nearly impossible to collect all measurements on pigs in a commercial setting.

Wang et al. (2006) investigated the use of image processing as a means to automatically determine weights of pigs, utilizing 187 pigs (50-150 kg). The study used a Pentium PC with a frame grabber card for digitizing the images, a VCR, a single Hitachi OEM board level color camera (Hitachi Kokusai Electric America, Woodbury, New York) mounted above the scale, and a ruler was placed horizontally on the center of the back to determine the distance to the wall of the scale in order to evaluate the weight of the pigs (Wang et al. 2006). Image extraction was done using a program written in Visual Basic using the Matrox Imaging Library. The correlation of individual features and body weight was used to determine which feature would be used in a mathematical model for body weight with rear area ($r^2 = 0.96$) being selected as the parameter utilized in the model. Wang et al. (2006) indicated that while the system was around 94% accurate, there were still improvements to be made. Primary areas of improvement were related to improving accuracy, image selection, and ultimately the automation of system.

Condotta (2017) investigated the use of image processing as a means to identify body dimensions of pigs, utilizing 120 pigs (27 + 4.4 kg). MATLAB software and two Microsoft Kinect™ sensors (one mounted over the top of the scale and one on the side of the scale) and images were collected at eight, 12, 16 and 21 wk of age. Two methods were used to analyze the images: automatically generated through the depth map of the sensor (width and height of pig) and manually generated using the color image (remaining measurements: head height, face length, front leg height). To best estimate the weight of the pig, parts of the image that were not the pigs were removed from the image. Also, the head and tail portions of the pigs were removed from the images leaving the shoulder portion, trunk and hind quarter remaining in the image for processing. An equation was utilized to convert the pixels in the image to centimeters. Condotta (2017) used a coefficient of determination above 0.9 for measured dimensions to estimate body weights. Dimensions with coefficient of determinations greater than or equal to 0.9 are total length ($r^2 = 0.92$), length from shoulders to tail ($r^2 = 0.90$), height ($r^2 = 0.93$), depth ($r^2 = 0.95$) and width ($r^2 = 0.94$). Condotta (2017) indicated that the system was effective and did not need the calibration tools that were seen in previous studies. However, primary issues related to bars on the scale prevented automatic measurements by the sensor, and visual identification patterns faded over time and were no longer identifiable within images. Weight estimations using dimensional measurements acquired with the Microsoft Kinect sensors were expanded to include the relationship of volume. Furthermore, utilizing 230 growing finishing pigs, Condotta (2017) investigated the use of image processing as a means to determine BW of pigs, using MatLab software and two Microsoft Kinect™ sensors (one mounted over the top of the scale and one on the side of the scale) and images collected at 8, 12, 16 and 21 wk of age. Depth imaging was used to determine the volume of each pig while digital color RBG images were used to determine animal identification. To best estimate the weight of the pig, parts of the image that were not the pigs were removed from the image. Also, the head and tail portions of the pigs were removed from the image leaving the shoulder portion, trunk and hindquarter remaining in the image. An equation was utilized to convert the pixels in the image to centimeters to determine the height of the animal.

Condotta (2017) used an equation to determine BW based on recorded volume dimensions ($r^2 = 0.995$). A set of test data was analyzed using the equation and calculations were capable of predicting BW within 2.2 kg of recorded BW. Primary issues were related to the lighting in the area where the imaging was taking place (Condotta 2017).

Viazzi et al. (2014) investigated the use of image processing as a means to identify aggressive pigs, utilizing 120 total piglets, separated into five repetitive experiments, Pigs were housed by litter until weaning, at which time the four litters of pigs were mixed together. Viazzi et al. (2014) used a computer with LabVIEW to synchronize the videos from a Guppy F-080C camera and a Guppy GC1350 camera both mounted over each pen and recordings three hours post-mixing and for three hours after the pigs had been mixed for 24 h (a total of 60 h of video was collected). To identify aggressive behaviors, 378 episodes of pig interactions (228 of which were aggressive, 150 were not aggressive) were labeled by a veterinarian. To build the algorithms episodes containing thresholds of activity (low activity: 50% of pigs moving, medium activity: 50 - 80% moving, high activity: 80 - 100% moving) were used as a reference to identify the different activity levels of a pen. The development of the algorithm also utilized motion history image which is an image that looks at how much pigs have moved (the most recent activity is indicated in bright colored pixels, with the older movement being represented by less intensely colored pixels) (Viazzi et al. 2014). Analysis of data determined an average accuracy rate for correctly identifying aggression of pigs of 88.4%. Results suggest that while the system was effective, there were limitations (Viazzi et al. 2014). The primary limitations were related to rapid movement of pigs, which could be classified aggressive even if the movement is only an individual pig; shorter episodes of aggression were not identified; or slow movements of aggression which leaves out instances like tail biting (Viazzi et al. 2014).

Kashiha et al. (2013a) investigated the capability of cameras to automatically monitor water use in group housed pens, utilizing data gathered on 40 grower pigs (25.1 ± 4.4 kg). A Honsberg Magnetic-Inductive MID008 water meter (Honsberg Sensorts and Instraments, Remscheild, Germnay) recorded water usage, and a black and white WVBP330 CCD camera along with Noldus MPEG recorder software. Video was recorded for time periods across a 13 d, a total of 156 h of video were utilized in the analysis. Pigs were classified as at the waterer when the nose of the pig was located on the nipple of the waterer for a time period of 2 sec or longer. Time pigs spent at the waterer had 92% accuracy when compared to water usage data from half hour periods. Results suggest that time at the waterer patterns can be utilized as a predictor of water consumption (Kashiha et al. 2013a).

Zhu et al. (2017) investigated the ability of image processing to classify at the waterer behaviors in pens of pigs using MatLab software and a single Point Grey camera, using seven pigs. Pigs were provided identification during the trial. Over the 5 d period, 140 video segments containing pigs at the waterer were compiled to be evaluated for activity. Pigs were classified at the waterer when there were 20 pixels or less between the nipple waterer and the pig. Results indicated that the system was 90.7% accurate in identifying pigs as at the waterer, with 13 video clips containing misidentifications (Zhu et al. 2017). Overall, results suggested the system was able to identify pigs at the waterer, but small movements could result in activity classification differences (Zhu et al. 2017). The primary issue was any body part of the pig that was within 20 pixels was classified as at the waterer by the system.

Lassen et al. (2018) utilized 97 Jersey cows to investigate the use of image processing as a means to measure individual cow feed intake at a feeding table, using Time of Flight Technology and a 19 3-D cameras and RFID tags. To ensure the identity of cows, RFID tags recordings were compared to camera observations. Feed volume was determined by the cameras determining the height of the feed pile before the cow stated eating and then after the cow was finished eating. No measurements were taken while the cow was eating. Analysis of 14 d of video determined the average feed intake to be 78.1 L/d, with a repeatability of 0.84 for wk and 0.65 for d (Lassen et al. 2018). Lassen et al. (2018) indicated that the system was a repeatable way to measure feed intake, but the system had limitations. The primary issues were the system only classified feed disappearance (did not account for sorting of feed), did not distinguish between two cows eating in the same area on the feed table, and the need for the RFID tags to be matched to the animals for identification.

Marinello et al. (2015) investigated the 3-D technology as a means to determine body dimensions in dairy cattle, utilizing 20 dairy cows. The trial was conducted using SPIP™ software and four Microsoft Kinect™ RCG-depth cameras. Sensors were placed laterally (left and right side) in front of the cow and over the top of the cow, and manual measurements were collected for the same parameters. Images from the top and lateral sensors were combined to provide an estimation of heart girth which was correlated ($r^2 = 0.94$) to body weight. Marinello (2015) indicated that while the system was effective, it has limitations. Primary issues were related to anatomical locations being less pronounced in younger cows (Marinello et al. 2015).

Weixing et al. (2009) utilized 10 Yorkshire pigs assigned to a single pen to evaluate the use of image processing as a means to identify morbid pigs within a pen. A S3C2410 processor, GPRS modem, USB interface, and a single USB camera mounted over each of the pens and images collected for 4 months. Pigs were provided unique identification numbers that were visible to both the camera and human observers. The system identified pigs that had a greater deification rate (> 8 times/d), than the pen average healthy pig (defecated 5 - 6 times/d). At the conclusion of the 4 month trial, the monitoring system identified 37 suspected morbidity cases. Of those 37 pigs, the observation system was capable of identifying 29 pigs that were determined to be clinically morbid. Results suggest that the system was capable of identifying potentially morbid pigs, but manual conformation was needed to determine morbidity (Weixing et al. 2009) indicated the system can identify potentially sick pigs, but manual confirmation is needed to determine sickness.

Exadaktylos et al. (2008) investigated the use of real time recognition to capture the coughing sounds of sick pigs, using a Discrete Fourier Transformer and a Power Spectral Density, utilizing six Belgian Landrace pigs (20-40 kg). Pigs were anesthetized to cause pathologically and chemically induced coughs (inhalation of irritating substances). At the conclusion of the study, a total of 656 sounds were recorded; 231 chemically induced coughs, 291 sick coughs and 149 other sounds (vocalization and environmental). Analysis of 656 sounds determined an average accuracy rate for correctly identifying chemically induced coughs of 13.4%, sick coughs 82.2%, and other coughs 9.72% (Exadaktylos et al. 2008). Exadaktylos et al. (2008) indicated that while the system was effective at identifying real time coughs of challenged pigs, it had more difficulty identifying chemically induced coughs and other sounds. Primary issues were related to a small number of pigs in the trial and adapting the technology to an animal setting (Exadaktylos et al. 2008) .

Conclusion:

There is not a simple solution to combat the fundamental challenge of balancing animal performance and well-being. Morbidity reduces pig growth and can hinder pigs from reaching full growth potential. Reducing morbidity rates can be beneficial to a producer's bottom line, as well as animal well-being. Disease outbreaks including PRRS, PEDV and *Streptococcus suis* have been detrimental to herd inventories and producer bottom lines. Visual health observations require caretakers to detect compromised pigs, within a large number of animals, in a short period of time during daily observations. Addressing animal health concerns at the onset of sick behaviors allows for more timely treatment.

Pigs are social animals that exhibit aggressive behaviors as result of mixing pigs and a result in a decreased ADG. Individual pig behaviors can serve as an indicator of growth and carcass parameters. The consistency of market pigs is highly variable and a concern to the packer. Since scales are infrequently used on pig operations, alternatives have been investigated to predict BW. Physical measurements provide accurate information but are not feasible for large herds and manual predictions are an impractical solution. Technology has been adapted to identify pigs in a group setting, monitor time in close proximity to the feeder or waterer behaviors, provide estimates of live weight, and identify compromised pigs. As such, the object of this research is to evaluate the DeIT system to identify individual pigs, maintain identity throughout monitoring, and classify/track movements of pigs in a group housed system.

Literature Cited

Ahrendt, P., T. Gregersen and H. Karstoft (2011). Development of a real-time computer vision system for tracking loose-housed pigs. Comput. Electron. Agric. 76(2): 169-174.

Aiello, E. and A. E. Mays (1998). The merck veterinary manual. Whitehouse Station, NJ, Merck & Co., INC.

Bornett, H. L. I., C. A. Morgan, A. B. Lawrence and J. Mann (2000). The effect of group housing on feeding patterns and social behaviour of previously individually housed growing pigs. Appl. Anim. Behav. Sci. 70(2): 127-141.

Brandl, N. and E. Jørgensen (1996). Determination of live weight of pigs from dimensions measured using image analysis. Comput. Electron. Agric. 15(1): 57-72.

Camerlink, I., P. Bijma, B. Kemp and J. E. Bolhuis (2012). Relationship between growth rate and oral manipulation, social nosing, and aggression in finishing pigs. Appl. Anim. Behav. Sci. 142(1): 11-17.

Carr, S., J. Gooding, P. Rincker, D. Hamilton, M. Ellis, J. Killefer and F. McKeith (2005). A survey of pork quality of downer pigs. J. Muscle Foods 16(4): 298-305.

Condotta, I. C. F. d. S. (2017). Automatic assess of growing-finishing pigs' weight through depth image analysis, Universidade de São Paulo.

Davis, M., J. Apple, C. Maxwell, S. Arthur, Z. Johnson and M. Dirain (2004). Effect of weaning age and commingling after the nursery phase on growth performance, mortality rate, and behavioral indicators of welfare. Arkansas Animal Science Department Report 2004 522: 160.

Erhard, H. W., M. Mendl and D. D. Ashley (1997). Individual aggressiveness of pigs can be measured and used to reduce aggression after mixing. Appl. Anim. Behav. Sci. 54(2): 137-151.

Exadaktylos, V., M. Silva, J. M. Aerts, C. J. Taylor and D. Berckmans (2008). Real-time recognition of sick pig cough sounds. Comput. Electron. Agric. 63(2): 207-214.

Gonyou, H., E. Beltranena, D. Whittington and J. Patience (1998). The behaviour of pigs weaned at 12 and 21 days of age from weaning to market. Canadian Journal of Animal Science 78(4): 517-523.

He, Y., J. Deen, G. C. Shurson and Y. Z. Li (2018). Behavioral indicators of slow growth in nursery pigs. J. Appl. Anim. Welf. Sci.: 1-11.

Holck, J. and D. Polson (2003). The financial impact of prrs virus. The porcine Reproductive and Respiratory Syndrome compendium. 2nd ed.: National Pork Board: 51-58.

Holtkamp, D. J., J. B. Kliebenstein, E. J. Neumann, J. J. Zimmerman, H. F. Rotto, T. K. Yoder, C. Wang, P. E. Yeske, C. L. Mowrer and C. A. Haley (2013). Assessment of the economic impact of porcine reproductive and respiratory syndrome virus on united states pork producers. J. Swine Health Prod. 21(2): 72-84.

Jones, R. M., R. E. Crump and S. Hermesch (2011). Group characteristics influence growth rate and backfat of commercially raised grower pigs. Anim. Prod. Sci. 51(3): 191-197.

Kashiha, M., C. Bahr, S. A. Haredasht, S. Ott, C. P. Moons, T. A. Niewold, F. O. Ödberg and D. Berckmans (2013a). The automatic monitoring of pigs water use by cameras. Comput. Electron. Agric. 90: 164-169.

Kashiha, M., C. Bahr, S. Ott, C. P. H. Moons, T. A. Niewold, F. O. Ödberg and D. Berckmans (2013b). Automatic identification of marked pigs in a pen using image pattern recognition. Comput. Electron. Agric. 93: 111-120.

Ketchem, R. and M. Rix (2012). Seasonal effects on pig survival rates. National Hog Framber. Fremont, NE.

Lassen, J., J. R. Thomasen, N. W. Hansen, G. G. B. Nielsen, E. Olsen, P. R. B. Stentebjerg, N. W. Hansen and S. Borchersen (2018). Individual measure of intake on in-house commercial dairy cattle using 3d camera system. World Congress on Genetics Applied to Livestock Production, Auckland, New Zealand.

Lowe, J. F. (2014). "Improving sick pig managment." Retrieved 3/15/2018, 2018, from http://www.nationalhogfarmer.com/health/improving-sick-pig-management.

Maes, D., A. Larriestra, J. Deen and R. Morrison (2001). A retrospective study of mortality in grow-finish pigs in a multi-site production system. J. Swine Health Prod. 9(6): 267-273.

Marchant-Forde, J. N. (2010). Social behaviour in swine and its impact on welfare. Proceedings. 21st IPVS Congress.

Marinello, F., A. Pezzuolo, D. Cillis, F. Gasparini and L. Sartori (2015). Application of kinect-sensor for three-dimensional body measurements of cows. Proceedings of "7th European Conference on Precision Livestock Farming, ECPLF.

Maselyne, J., W. Saeys, P. Briene, K. Mertens, J. Vangeyte, B. De Ketelaere, E. F. Hessel, B. Sonck and A. Van Nuffel (2016). Methods to construct feeding visits from rfid registrations of growing-finishing pigs at the feed trough. Comput. Electron. Agric. 128(Supplement C): 9-19.

McGlone, J. J. (1985). A quantitative ethogram of aggressive and submissive behaviors in recently regrouped pigs1. J. Anim. Sci. 61(3): 556-566.

McGlone, J. J. and S. E. Curtis (1985). Behavior and performance of weanling pigs in pens equipped with hide areas. J. Anim. Sci. 60(1): 20-24.

Meisinger, D. J. (2003). The national pork quality benchmarking study. Reciprocal Meat Conference, Columbia, Missouri, American Meat Science Assoication.

Neumann, E. J., J. B. Kliebenstein, C. D. Johnson, J. W. Mabry, E. J. Bush, A. H. Seitzinger, A. L. Green and J. J. Zimmerman (2005). Assessment of the economic impact of porcine reproductive and respiratory syndrome on swine production in the united states. Journal of the American Veterinary Medical Association 227(3): 385-392.

Ott, S., C. P. H. Moons, M. A. Kashiha, C. Bahr, F. A. M. Tuyttens, D. Berckmans and T. A. Niewold (2014). Automated video analysis of pig activity at pen level highly correlates to human observations of behavioural activities. Livestock Science 160(Supplement C): 132-137.

Paarlberg, P. L. (2014). Updated estimated economic welfare impacts of porcine epidemic diarrhea virus (pedv).

Patience, J. and A. Beaulieu (2006). Variation in the finishing barn. Proc. Manitoba Swine Seminar, Manitoba Agric., Food and Rural Initiatives, Manitoba, Canada.

Pospischil, A., A. Stuedli and M. Kiupel (2002). Diagnostic notes: Update on porcine epidemic diarrhea. J. Swine Health Prod. 10(2): 81-85.

Ros-Freixedes, R., L. J. Sadler, S. K. Onteru, R. M. Smith, J. M. Young, A. K. Johnson, S. M. Lonergan, E. Huff-Lonergan, J. C. M. Dekkers and M. F. Rothschild (2014). Relationship between gilt behavior and meat quality using principal component analysis. Meat Science 96(1): 264-269.

Royal, S., J. A. Erceg, J. G. Wiegert, M. T. Knauer and E. van Heugten (2017). Dimensional measurements and visual appraisal as predictors of liveweight of finishing pigs. Midwest Animal Science Meetings. Omaha, Nebraska. 95**:** 192-192.

Sadler, L. J., A. K. Johnson, S. M. Lonergan, D. Nettleton and J. C. M. Dekkers (2011). The effect of selection for residual feed intake on general behavioral activity and the occurrence of lesions in yorkshire gilts. J. Anim. Sci. v. 89(no. 1): pp. 258-266-2011 v.2089 no.2011.

Schinckel, A., L. Clark, A. Grant, G. Stevenson and J. Turek (1994). Evaluation of the effects of immune system activation versus disease on pig growth. Allen D. Leman Swine Conference.

Schlooser, G. E. (2001). "Addressing worforce expectations." Retrieved 3/17/2018, 2018, from http://www.nationalhogfarmer.com/mag/farming_addressing_workforce_expectations.

Schweer, W., K. Schwartz, J. F. Patience, L. Karriker, C. Sparks, M. Weaver, M. Fitzsimmons, T. E. Burkey and N. K. Gabler (2017). Porcine reproductive and respiratory syndrome virus reduces feed efficiency, digestibility, and lean tissue accretion in grow-finish pigs. Trans. Anim. Sci. 1(4): 480-488.

Stookey, J. M. and H. W. Gonyou (1994). The effects of regrouping on behavioral and production parameters in finishing swine. J. Anim. Sci. 72(11): 2804-2811.

Suster, D., B. Leury, E. Ostrowska, K. Butler, D. J. Kerton, J. D. Wark and F. Dunshea (2003). Accuracy of dual energy x-ray absorptiometry (dxa), weight and p2 back fat to predict whole body and carcass composition in pigs within and across experiments.

Sutherland, M. A., K. Erlandson, J. F. Connor, J. L. Salak-Johnson, P. Matzat, J. F. Smith and J. J. McGlone (2008). Health of non-ambulatory, non-injured pigs at processing. Livestock Science 116(1): 237-245.

Thomasen, J. R., J. Lassen, G. G. B. Nielsen, C. Borggard, P. R. B. Stentebjerg, R. H. Hansen, N. W. Hansen and S. Borchersen (2018). Individual cow identification in a commercial herd using 3d camera technology. World Congress of Genetics Applied to Livestock Production, Auckland, New Zealand.

United States Department of Agriculture, U. (2017). Swine 2012: Part iii: Changes in the u.S. Swine industry, 1995-2012. United States Department of Agriculture Animal adn Plant Health Inspection Service. 2018.

Viazzi, S., G. Ismayilova, M. Oczak, L. T. Sonoda, M. Fels, M. Guarino, E. Vranken, J. Hartung, C. Bahr and D. Berckmans (2014). Image feature extraction for classification of aggressive interactions among pigs. Comput. Electron. Agric. 104: 57-62.

Wang, Y., W. Yang, P. Winter and L. Walker (2006). Non-contact sensing of hog weights by machine vision. Applied engineering in agriculture 22(4): 577-582.

Wang, Y., W. Yang, P. Winter and L. Walker (2008). Walk-through weighing of pigs using machine vision and an artificial neural network. Biosystems Engineering 100(1): 117-125.

Weimer, S. L., A. K. Johnson, T. J. Fangman, L. A. Karriker, H. D. Tyler and K. J. Stalder (2014). Article comparison of nursery pig behavior assessed using human observation and digital-image evaluation methodologies. J. Swine Health Prod. 22(3): 116-124.

Weixing, Z., P. Xuefeng, L. Xincheng and Z. Xiaofang (2009). Automated detection of sick pigs based on machine vision. 2009 IEEE International Conference on Intelligent Computing and Intelligent Systems.

Zaragoza, L. E. O. (2009). Evaluation of the accuracy of simple body measurements for live weight prediction in growing-finishing pigs. Animal Science, Universit of Illinois at Urbana-Champaign. Master

Zhu, W.-x., Y.-z. Guo, P.-p. Jiao, C.-h. Ma and C. Chen (2017). Recognition and drinking behaviour analysis of individual pigs based on machine vision. Livestock Science 205: 129-136.

CHAPTER III

EVALUATION OF A NOVEL COMPUTER VISION SYSTEMS' ABILITY TO CONTINUOUSLY IDENTIFY AND TRACK THE ACTIVITIES OF NEWLY WEANED PIGS.

Abstract

Ensuring the health and wellbeing of pigs is of the utmost importance to the swine industry. There is a need for a real-time system that can identify changes in pig activities, as well as activity patterns to accurately identify compromised pigs. The value of a real-time system is the capability to identify compromised pigs prior to observance of visible clinical symptoms by facility personnel during daily checks. Therefore, a novel computer vision system depth-enabled identification and tracking (DeIT) system; was evaluated for its ability to automatically identify, maintain identity and continuously track the activities of group housed pigs. Within a commercial nursery, the DeIT system was installed over a single pen with 15 newly weaned pigs (24 d of age) and images were continuously collected upon introduction of pigs for a period of 5.5 d. Within the Animal Science Complex at the University of Nebraska – Lincoln (UNL), the system was installed over 28 newly weaned pigs (21 d of age) and images were continuously collected upon the introduction of pigs for a period of 42 d. Evaluation of 10,544 randomly selected frames indicated a 93.9% accuracy rate for correctly identifying pigs' identity when classified by the system as standing/walking. Accuracy for activities was determined by evaluating the label of pig activity by the DeIT system in comparison to a manual observation of activity. The accuracy of activities was 99.1% lying, 96.3% standing, 99.3% walking, 86.4% in close proximity to the feeder, and 73.6% in close proximity to the waterer. Activity data generated from the research nursery trial indicated that during the 42 d of the nursery, the average percentage of time spent lying (77.56 ± 1.69%), standing (8.64 ± 1.10%), walking (2.29 ± 0.37%), in close proximity to the feeder (9.93 ± 1.66%), and in close proximity to the waterer (0.95 ± 0.28%). Furthermore, m/d walked was 943.1 ± 105.1

m. Evaluation of the variation associated with activities indicated significant variation between individual pigs. Results indicated that time associated with each activity changed over time ($P \leq$ 0.001). As the trial progressed over time, the percentage of time spent lying and time in close proximity to the feeder increased ($P \leq 0.001$; 7.46 and 3.99%, respectively). Time standing and walking decreased (9.82 and 1.53%) from wk 1 thru wk 6 of the trial. Gender had no effect ($P \geq$ 0.10) on percent of time spent lying, standing, walking, in close proximity to the feeder, m/d walked. Barrows spent a greater ($P = 0.04$) percentage of time than gilts in close proximity to the waterer (1.01% vs. 0.89%, respectively). Litter had no effect ($P \geq 0.10$) for time spent lying, standing, in close proximity to the feeder, and in close proximity to the waterer. There was a difference related to the percent of time walking ($P = 0.05$) and m/d walked ($P = 0.05$) between the four litters. Results indicate two significant outcomes, 1) proposed DeIT computer system has the capability and sensitivity to accurately identify, maintain identification, and track the activities of group housed nursery pigs and 2) accuracy of the DeIT system provides the potential to evaluate changes in activity of nursery pigs for an extended period of time.

Introduction

Over the past 17 years there has been a 1.1% increase in the mortality rate of nursery. The most recent survey in 2012 reported that the rate of mortality within nursery pigs had risen to a rate of 3.6% (United States Department of Agriculture 2017). Maes et al. (2001) investigated the timeline of mortalities happening in the growing and finishing phases over a four-year reporting period, utilizing mortality rates were reported on 1,345,127 pigs in grow-finish barns. The mortality rate of grow-finish pigs increased from 2.57 mortalities/1,000 pig wk in 1996 to 3.57 mortalities/1,000 pig wk in 1999 (Maes et al. 2001). Overall, a greater mortality rate was reported in the late period (wk 11 – end of finishing period) when compared to the mortality rate (2.16

mortalities/1,000 pig wk) in the early period (wk 1 – 10) of the grow-finish operation (Maes et al. 2001). The percentage of mortality occurring in the late growing period is partially larger because pigs identified as morbid in the early wk of the growing phase that do not recover could be reported as mortalities in the late period of the growing phase (Maes et al. 2001). Sick pigs can pose a challenge through production and may never maximize growth potential.

At a time where advanced computer imaging technology is utilized throughout agriculture, there are currently no technologies that have been developed to assist or enhance the ability to monitor, the health and well-being of animals. In general, video recording technology has been utilized in livestock agriculture as a tool to aid in identifying animals (Kashiha et al. 2013b, Thomasen et al. 2018), monitoring behavior (Gonyou et al. 1998, Davis et al. 2004, Ott et al. 2014) and aggression (McGlone and Curtis 1985, Viazzi et al. 2014), monitoring animal actives (McGlone and Curtis 1985, Kashiha et al. 2013a, Weimer et al. 2014, Zhu et al. 2017, Lassen et al. 2018), providing wt estimates (Wang et al. 2008, Zaragoza 2009, Marinello et al. 2015, Condotta 2017) and providing indications of sickness (Exadaktylos et al. 2008, Weixing et al. 2009). Limitations to previous work are limited field of camera view (Ahrendt et al. 2011), challenges in individually identifying pigs (Kashiha et al. 2013, Thomasen et al. 2018), rapid movement of animals (Ahrendt et al. 2011, Viazzi et al. 2014), need for manual comparisons for accuracy (Weixing et al. 2009, Ott et al. 2014), time burden of manual labeling (Zargoza 2009, Weimer et al. 2014), lighting conditions of environment (Condotta 2017), labeling overall activity instead of individual activities (Ahrendt et al. 2011). The development of a method to rapidly identify pigs that are compromised or slow growing would be extremely beneficial to the industry. Rapid and accurate identification of the health status and well-being of pigs would allow for quicker interventions and decrease the impact of injury, disease and stunned performance.

Materials and Methods

Animal and Experimental Design:

All experimental procedures were in compliance with the *Guide for the Care and Use of Agricultural Animals in Research and Teaching*, approved by the University of Nebraska – Lincoln Institutional Animal and Care and Use Committee (IACUC #1409).

Depth-enabled Identification Tracking System:

The DeIT system evaluated consisted of a depth-enabled camera (Kinect v2™, Microsoft, Redmond, WA), PC (NUC, Intel, Santa Clara, CA) and Fantom 4 TB hard drive (Fantom Drives, Torrance, CA). The depth-enabled camera captured color, infrared, and depth images at a rate of approximately 5 frames/sec. Prior to the start of each trial, a manual annotation of pen geometry was conducted to segment pigs from the background. Preliminary testing of the system was accomplished within a within a 1,200 pig commercial nursery facility in Central NE and a controlled nursery trial was conducted at the research nursery facility within the Animal Science Complex (University of Nebraska – Lincoln, Lincoln, NE).

Preliminary testing was conducted within a commercial nursery that consisted of a four-room barn, with 16 pens/room. Pens dimensions were 1.65 m x 2.77 m with a capacity of 20 pigs/pen. Within the facility, a single corner pen within one of the rooms was identified for evaluation of the DeIT system. The depth-enabled camera was mounted above the pen (2.3 m) and connected to a PC (NUC, Intel, Santa Clara, CA), prior to the placement of pigs (Figure 1). The PC was situated directly outside of the pen the room containing the camera. Once installed, the DeIT system was programmed to initiate collection of images upon placement of pigs into the pen. Due to the need for light for the DeIT system to collect images, lights remained on for the duration of the trials. For each trial, 15 newly weaned pigs were randomly selected upon arrival at the facility.

Once selected, pigs were provided a visual individual identification, weighed, and body measurements collected.

During the preliminary testing, three different methods were evaluated as means to maintain and verify individual identity (DeIT and human verification; Figure 2). The first identification method evaluated was sequentially number (1 – 15) paint brands (Stone Manufacturing and Supply Company, Kansas City, MO). Each pig received a numerical paint brand following collection of body measurements. Visual identification of the sequential paint brands by both human observation and the DeIT system were lost 24 h post application. The second identification method evaluated was the use of alternating color (red, blue, and green) and number of strips, each pig was provided a unique visual pattern utilizing livestock spray paint (Prima Tech II Aerosol Marking Spray, Neogen Corporation, Lansing, Michigan). The ability to recognize the color/stripped bar patterns (both via human observation of the DeIT system) was lost 72 h post application. The third identification method evaluated was use of colored/numbered ear tags (Destron Fearing Duflex® Hog Max, South St. Paul, MN). Ear tags were one of five colors (blue, green, red, white or yellow) and one of three number series (1, 22, 333). The color and number ear tag combination were utilized as the DeIT system has the capability to distinguish between the tags. All tags were retained for the duration of the trial. Providing each pig with two tags allowed for identification to be retained if a tag was lost/removed and allowed for easier identification of pigs for the caretaker and DeIT camera system.

Body measurements collected during preliminary testing consisted of heart girth (circumference of the thoracic cavity, immediately posterior to the shoulder), flank girth (circumference of the thoracic cavity, immediately anterior to the hind leg), and body length (top of shoulder blade to base of tail). Immediately following processing pigs were placed in the evaluation pen and the DeIT system captured continuous data. Data collected by the DeIT system during preliminary testing was stored on onsite hard drives and upon completion of preliminary testing were transported to the Perceptual Systems Research Group at the University of Nebraska – Lincoln (Lincoln, NE) for data analysis.

The controlled nursery trial was conducted at the Animal Science Complex (University of Nebraska – Lincoln, Lincoln, NE) is comprised of two rooms with six pens/room (1.22 x 2.13 m). Four pens were selected within a single room of the facility for evaluation of the DeIT system. The depth-enabled camera was mounted (centered across two pens 1 and 2, 3 and 4) above pens (2.4 m) and connected to a PC, prior to the placement of pigs. Computer monitors were situated inside the room, along the wall (Figure 1). The DeIT systems were programmed to initiate collection of images upon placement of pigs. Twenty-eight newly weaned pigs (6.64 ± 1.94 kg) from four litters were stratified by gender, litter, and randomly assigned to one of two pens. Based upon results of the three preliminary commercial trials, ear tags (Destron Fearing Duflex® Hog Max, South St. Paul, MN) were utilized for individual identification, individual identification was maintained using unique colored/numbered ear tag (colors: blue, green, red, white or yellow, numbers: 1, 22, 333). Pigs were provided with ear tags and body measurements collected (heart girth, flank girth and body length) following the same protocol utilized in the preliminary commercial trials. On d 3, additional weight and measurements were recorded. The average of these two weights and measurements were used as the initial weight and measurements for all pigs. Weights and measurements were recorded at 7 d intervals (following d 3 weights and measurements). Immediately following processing pigs were placed in the evaluation pens and the DeIT systems captured continuous data. Every 7 d, hard drives were swapped out and transported to the Perceptual Systems Research Group at the University of Nebraska – Lincoln (Lincoln, NE) for data analysis. On d 23, seven pigs from pen 1 were moved to pen 2 and seven pigs from pen 3 were moved to pen 4. The nursery phase was concluded on d 59 and all pigs were transferred to grow/finisher pens.

All four pens were equipped with a 4 – hole feeder and pigs were offered *ad libitum* access to feed. Diets were formulated to meet or exceed NRC (2012; Table 1). Feed disappearance was measured weekly, on the same 7 d intervals that body measurements were collected pigs were weighed. Two different water systems were utilized. Pen – 1 and Pen – 2 were equipped with the traditional nipple waterer and Pen – 3 and Pen – 4 utilized a cup waterer (VAL-CO, New Holland, PA).

Accuracy Analysis:

Images from the DeIT system recorded in the controlled nursery trial were used to classify the accuracy of the identity and activity classification of the system. The video recordings used for accuracy classification contain an individual marker that corresponded with the color and number series of the pig's ear tags (Figure 3). Individual markers indicate pig identity and activity (Figure 4). The accuracy analysis was conducted on randomly selected frames from videos that represented all pens and d during the nursery phase. An observer manually annotated the video; these annotations were compared to the DeIT system labels.

To determine the accuracy of identity 10,544 data points were utilized. In order to determine the correctness of identity tag colors and numbers had to be identifiable in the randomly selected frames from the captured images. If tags were not identifiable in the randomly selected frame, frames immediately prior and following were utilized to ensure individual identification markers corresponded with the correct pigs. The video recordings were manually scored for two types of errors: label swaps and loss of identification. Label swaps were recorded when individual identification marker by the DeIT system did not correspond with the ear tags of the labeled pig because the marker was labeling a different pig. Loss of identification was recorded when the individual identification marker was labeled in a location that was not in close proximity to the pig (Figure 5). An additional analysis was conducted to determine the accuracy of activity classification the same 10,544 data points. From this 10,544 data points, a total of 10,311 observations were viable due to instances when a pig was outside of manual viewing area of the DeIT identification label was swapped/incorrect.

Statistical Analysis:

Activity data generated was analyzed using the GLIMMIX procedure of SAS (SAS Inst. Inc., Cary, NC). Week, gender and litter were included as fixed effects, pen as a random effect, and individual pig served as the experimental unit. When main effects or interactions were significant ($P \leq 0.05$), specific comparisons were made using the PDIFF option in SAS, 0.06 – 0.10 was considered a tendency. Data is presented as LSMeans ± SEM. Two and three-way interactions were non-significant ($P > 0.10$), thus excluded from the results.

Results

Accuracy of Identity:

Results from the preliminary trials in terms of maintaining identification of the individual pigs was best achieved via using the Destron Fearing Duflex® Hog Max ear tags. Ear tags were retained throughout the 42 d trial and were constantly visible to both human observers and the DeIT system. While use of sequentially numbered paint brands and color-coded bar patterns were a rapid and simple identification methods visible to both the human observer and the DeIT system, neither method retained identification past 72 h. Ability of the human observer and the DeIT system were not able to recognize paint brands ID after 24 h or color-coded bar patterns after 72 h following

Utilizing 10,544 data points manually observed throughout the 6 wk trial, an overall accuracy of identity was 93.9%. More specifically, accuracy of identity for each activity was 99.9% for walking, 99.5% for standing, 94.9% for lying, 99.7% for time at feeder, and 99.95% for time at waterer, (Table 2). Label swaps (DeIT assigned incorrect ID label) contributed 71% of recorded errors with loss of tracking contributing 29% of recorded errors (identification marker was labeled in a location that did not correspond with pig).

Classification of Activities:

Based upon 10,311 data points, overall accuracy was determined to be 96.2%. More specifically, classification of the activity of walking and lying was accurate at a rate of 99.3% and 99.1%, respectively. Classification of in close proximity to the feeder and in close proximity to the waterer was accurate at a rate of 86.4% and 73.6%, respectively (Table 3).

Time associated with activities:

Activity data of the 28 individual pigs indicated that on average, pigs spent 77.56 ± 1.69% of the time lying (minimum = 74.38; maximum = 80.54%), 8.64 ± 1.10% of the time standing (minimum = 6.45; maximum = 10.46%), 2.29 ± 0.37% of time walking (minimum = 2.11; maximum = 3.68%), 9.93 ± 1.66% of time in close proximity to the feeder (minimum = 7.39; maximum = 14.39%), and 0.95 ± 0.28% in close proximity to the waterer (minimum = 0.46; maximum = 1.49%; Table 4). In terms of meters traveled/d, on average pigs walked 692.2 ± 105.1 m/d (minimum = 692.2 m/d; maximum = 1,140.6 m/d).

Time associated with the activities of lying ($P \leq 0.001$), standing ($P \leq 0.001$), walking ($P \leq 0.001$), and in close proximity to the feeder ($P \leq 0.001$) changed over time. The time spent in close proximity to the waterer did not change across the 6 wks ($P = 0.11$). Pigs spent the least ($P \leq 0.001$) percentage of time lying during the 1st wk (72.31 ± 0.56%) of the trial, when compared to wk 2 – 6. During the 2nd and 3rd wk there was no difference in the percent of time lying (77.19% and 79.06%, respectively), but this percent of time was less ($P \leq 0.001$), than time spent lying during the 4th, 5th, and 6th wk (78.66, 79.41, and 79.77%, respectively). In terms of standing, time spent standing decreased from wk 1 – 4 (15.72, 10.22, 8.42, and 5.81%, respectively). There was no difference in the time spent standing during wk 5 and 6 (5.60 and 5.90%, respectively). The percentage of time that pigs spent walking was greatest ($P \leq 0.001$) during wk 1 and 3 (3.72 and 3.61%, respectively), when compared to wk 2, 4, 5, and 6. Time spent standing during the 2nd wk was greater ($P \leq 0.001$) than wk 3, but less ($P \leq 0.001$) than time standing during wk 4 – 6. The time that pigs spent in close proximity to the feeders exhibited a linear decrease ($P \leq 0.001$), with time in close proximity to the feeder during wk 1 was less than ($P \leq 0.001$; 7.26%) the time spent during wk 2 – 6. Time in close proximity to the feeder was less during the 1st wk ($P \leq 0.001$, 8.61 ± 0.48%), when compared to the remaining 5 wks. There was no difference in the time pigs spent in close proximity to the feeder in the 2nd and 3rd wk (8.68 and 8.95%, respectively), but less ($P \leq 0.001$) than the time pigs spent in close proximity to the feeder in the 4th, 5th, and 6th wks of the trial (11.81, 11.76 and 11.25%, respectively). Meanwhile, the percentage of time associated with standing was greatest ($P \leq 0.001$, 15.72 ± 0.32%) during the 1st wk, when compared to all subsequent wks. From wk 2 – 4 wk, there was no difference in time spent standing (P = >0.36), but was 2.4% greater ($P \leq 0.001$) than the time standing during the 5th and 6th wk (8.15 vs. 5.75%, respectively). In addition, the amount of time attributed to walking was the greatest ($P \leq 0.001$, 2.92 ± 0.09%) in 1st and 3rd wks. The percentage of time associated with walking was also greater ($P \leq 0.001$, 2.92 ± 0.09%) in the 2nd wk than the 4th wk, which were greater than the 5th and 6th wk time attributed to walking. The time spent in close proximity to the waterer by the 28 pigs was rather constant with a variation of 0.06% (minimum = 0.46%; maximum = 1.49%). In terms of m/d walked, the greatest ($P \leq 0.001$, 943.08 ± 195.88 m/d) distances were seen in the 1st and 3rd wk. The m/d walked decreased ($P \leq 0.001$, 943.08 ± 195.88 m/d) from the 2nd to the 4th wk, and were greater ($P \leq 0.001$, 943.08 ± 195.88 m/d) than the m/d walked in the 5th and 6th wk. The ADG by wk increased ($P \leq 0.001$, 0.02 kg/d) from the 1st wk to the 6th wk of the trial.

In regards to the effect of gender on percent of time associated with general activities, there was a difference ($P = 0.04$, 0.95 ± 0.06%) for the percentage of time attributed to being in close proximity to the waterer (Table 6). However, there was no difference between genders related to the amount of time spent lying ($P = 0.52$, 77.51 ± 0.47%), standing, ($P = 0.13$, 8.69 ± 0.32%), walking ($P = 0.83$, 2.93 ± 0.11%), time in close proximity to the feeder ($P = 0.53$, 9.92 ± 0.49%), m/d walked ($P = 0.98$, 944.51 ± 223.19 m/d), along with ADG ($P = 0.13$, 0.5 ± 0.03 kg/d). There was a difference ($P = 0.04$,0.95 ± 0.06%) between genders in relation to the time spent in close proximity to the waterer, gilts spent a lesser percentage of time in close proximity to the waterer, when compared to barrows, 0.89% vs. 1.01%, respectively. In terms of time associated with lying, the time gilts (77.18%) and barrows (77.84%) spent lying was not different ($P = 0.52$, 77.51 ± 0.47%). The percentage of time associated with standing was not different ($P = 0.13$, 8.69 ± 0.32%) between genders, with gilts spending 9.03% of time standing while barrows spent 8.34% of time standing. Likewise, the percentage of time associated with walking for gilts was 2.91% and not different ($P = 0.83$, 2.93 ± 0.11%) from barrows that spent 2.94% of time walking. Gender did not have an effect ($P = 0.98$, 944.51 ± 223.19 m/d) on m/d walked as gilts walked 934.50 m/d while barrows walked 954.52 m/d. In regards to ADG over the duration of the trial by gender, gilts were not different (*P* = 0.13, 0.5 ± 0.03 kg/d) from barrows, 0.46 kg/d and 0.54 kg/d respectively.

Time associated with activity was different by litter for the percentage of time spent walking (*P* = 0.05, 2.92 ± 0.18%) and m/d walked (*P* = 0.05, 943.67 ± 353.92 m/d). In terms of the effect of litter on percent of time associated with general activities, there was no difference between litters related to the amount of time spent lying (*P* = 0.12, 77.29 ± 0.75%), standing (*P* = 0.13, 8.75 ± 0.51%), time in close proximity to the feeder (*P* = 0.74, 10.10 ± 0.78%), time in close proximity the waterer (*P* = 0.13, 3.72 ± 0.09%), along with ADG (*P* = 0.19, 0.5 ± 0.04 kg/d; Table 7). Time attributed to walking was greatest (*P* = 0.05, 2.92 ± 0.18%) for litter 1, with the least amount of time attributed to walking for litters 3 and 4. The percentage of time attributed to waking for litter 2, was not different than the other litters. In terms of m/d walked, litter 1 traveled the greatest (*P* = 0.05, 943.67 ± 353.92 m/d) amount, while litters 2 and 4 traveled the fewest m/d. The m/d walked for litter 3 was not different than the m/d walked for litters 1, 2 or 4. In terms of the percent of time associated with lying, there was no difference (*P* = 0.19, 77.29 ± 0.75%) between the litters with a variation of 2.39% of time lying (minimum = 75.88; maximum = 78.27%). Moreover, the percentage of time spent standing by litter was not different (*P* = 0.13, 8.75 ± 0.51%) between the litters with a variation on 1.63% of time (minimum = 8.06, maximum = 9.69%). In terms of the percentage of time associated with being in close proximity to the feeder was not different (*P* = 0.74, 10.10 ± 0.78%) between the litters with a variation on 1.33% for time in close proximity to the feeder (minimum = 9.34; maximum = 10.67%). Furthermore, the percentage of time in close proximity to the waterer was not different (*P* = 0.13, 3.72 ± 0.09%) between the litters, as also indicated by a variation of 0.24% (minimum = 0.84, maximum =

1.08%). Additionally, there was not a difference (*P* = 0.19, 0.5 ± 0.04 kg/d) in terms of ADG between the litters, with a variation of 0.13 kg/d (minimum = 0.42; maximum = 0.55 kg/d).

In terms of the effect of pen assignment on activity, there was a difference in activity for time spent in close proximity to the waterer (*P* = 0.001, 0.94 ± 0.07%) and a tendency for time spent in close proximity to the feeder (*P* = 0.06, 10.05 ± 0.55%). There were no differences between pen assignments for lying (*P* = 0.22, 77.35 ± 0.62%), standing (*P* = 0.52, 8.72 ± 0.43%), walking (*P* = 0.48, 2.91 ± 0.15%), m/d walked (*P* = 0.46, 941.23 ± 42.71 m/d), as well as ADG (*P* = 0.43, 0.5 ± 0.33 kg/d; Table 8). In regards to time spent in close proximity to the waterer by pen assignment, pigs that were transferred to pen 2 spent a greater (*P* = 0.0001, 0.94 ± 0.07%) percentage of time in close proximity to waterer than pigs that remained in pen 1 (0.97% vs. 0.68%, respectively), while pigs that remained in pen 3 spent the a greater percentage of time in close proximity to the waterer when compared to pigs that were moved to pen 4 (1.13% vs. 0.99%, respectively). In terms of time spent in close proximity to the feeder based on pen assignment, pigs that remained in pen 1 tended to spend a greater (*P* = 0.06, 10.05 ± 0.55%) percentage of time in close proximity to the feeder when compared to pigs moved to pen 2 (11.01% vs. 10.24%, respectively), while pigs that were transferred to pen 4 spent a greater amount of time in close proximity to the feeder than pigs that stayed in pen 3 (10.26% vs. 8.70%, respectively). Time associated with lying was not different (*P* = 0.22, 77.35 ± 0.62%) for pen assignment, with little variation (0.85%) between pigs that remained in the initial pens and pigs that were transferred to pens (minimum = 76.43; maximum = 78.05%) for percentage of time spent lying. Moreover, the amount of time attributed to standing was not different (*P* = 0.52, 8.72 ± 0.43%) based on pen assignment with a 0.76% variation (minimum = 8.20; maximum = 8.96%). In terms of percentage of time attributed to walking, there was no difference (*P* = 0.48, 2.91 ± 0.15%) based on pen assignment as indicated by a 0.3% variation between pens (minimum = 2.78; maximum = 3.08%) for percentage of time spent walking. In terms of m/d walked, pen assignment did not have an effect (P = 0.46, 941.23 ± 42.71 m/d) on m/d walked with a variation of 85.35 m/d among pens (minimum = 906.97; maximum = 992.32 m/d). Overall ADG was not different (P = 0.43, 0.5 ± 0.33 kg/d) based on pen assignment, with only 0.04 kg/d variation between pens (minimum = 0.42; maximum = 0.55 kg/d).

Discussion

Individual pig identification is essential to the classification of individual pig activities and behaviors. If pigs are not individually identified, activities and behavior are reported on a pen basis (Ott et al. 2014, Weimer et al. 2014). The first two preliminary nursery trials suggested that paint brands and patterns are not effective for maintaining individual pig identification over a long period of time due to loss of visibility, also reported by Kashiha et al. (2013b). Colored and numbered tags are capable of providing individual identification over extended periods of time.

One of the biggest challenges to ensuring the wellbeing and efficiency of pigs is rapidly and accurately identifying compromised (sick or injured) pigs. However, to date, the only method used by producers to identify compromised pigs is manual observation. Because this method requires the pigs to display obvious signs of injury or illness, there is substantial room for improvement and enhancement, especially in how quickly compromised pigs are identified and treated. In facilities that house several thousand pigs, it is a daunting task to ensure that each pig is visually inspected even so much as once each day, let alone, continuously. Over the past two decades, researchers have attempted to use various methods and technologies for behavioral monitoring of animals (Breuer et al. 2001, Cornou et al. 2008, Stukenborg et al. 2011). Two of the most commonly used technologies are accelerometer data logging devices and video cameras.

Accelerometer-equipped data-logging collars worn around the necks have been used to identify the activities of pigs (Escalante et al. 2013) and to measure the level of locomotion in sows as they approach farrowing (Cornou et al. 2008). By applying machine learning to the data, these systems are able to classify feeding, rooting, walking, lying laterally, and lying sternally with an average accuracy of approximately 75%. Accurate identification of pigs is also essential to the classification of individual activities and behaviors. The 98.6% accuracy of DeIT system in the current study is greater than the 88.7% accuracy reported by Kashiha et al. (2013b). Primary issues reported by Kashiha et al. (2013b) utalizing a MPEG Recorder software and Panasonic WV-330 camera included the loss of visibility of individual identification and the ability of the individual identification to be observed due to the pigs body position in relative proximity to the camera. In the current study the identification errors can be attributed to invariably loss of pig tracking, identity swaps due to dynamic movements, interactions among pigs, and human interactions with pigs in the pen. One challenge in manually determining identity is the duration of the identity error is not accounted for. Results from the research nursery trial only considered if the identity was correct or incorrect. The DeIT system utilized deep machine learning to correct identifications the next time the tag is visible.

Activity data generated during the research nursery trial suggest that the DeIT camera system is capable of accurately identifying pig activities at a rate of 96.2%. While a 96.2% overall activity accuracy rate was achieved, the most frequent errors were attributed to time in close proximity to the feeder (86.4% accurate) and time in close proximity to the waterer (73.6% accurate). The accuracy percentage of identifying pigs standing (96.3%) in the nursery is greater than the percentage reported by Kashiha et al. (20 14). Both studies had classification challenges when identifying pigs that pile together and overlap, in addition Kashiha et al (2014) noted the inherent error of identifying activities. Part of the difference in the two studies could be attributed to Kashiha et al (2014) not utilizing visual identification on pigs (all ellipsoid tracking), the classification of all locomotion (includes exploratory and social behaviors), and the scan sampling of video recorded during periods of daylight. A similar challenge with reporting time at waterer was observed in Zhu et al. (2017), where any body part of the pig being in close proximity (as determined by distance in pixels) was classified as being at the waterer. The DeIT system labeling of the orientation of the pigs aids in reducing the instances labeled as at the waterer due to close proximity of any body part. The challenge with classifying time at the feeder or time at the waterer is pig activity is determined by the proximity of a pig to the location of the feeder or waterer. Therefore, the activity percentage reported is not true water consumption or feed disappearance. However, a correlation ($r^2 = 0.92$) between the overall duration of time pigs spend at the waterer and water meter measurements was reported by Kashiha et al. (2013a). The incorporation of water usage could be an avenue to improve the accuracy of time at the waterer classifications. The accuracy percentage (94.9%) of identifying pigs as lying in the current study is less than the accuracy percentage (95.8 ± 2%) reported by Nasirahmadi et al. (2015). Key differences can be attributed to Nasirahmadi et al. (2015) utilizing time frames where a large percentage of pigs were lying, the initial start weight (30 kg), duration of trial (15 d) and the challenges with the camera in the environment (sight restrictions and dirt/waste reduced visibility). The controlled nursery study and the study by Nasirahmadi et al. (2015) kept the lights on during the recording period to increase the visibility of the pigs. Manual labeling of pig activity has been evaluated in several studies (Sadler et al. 2011, Camerlink et al. 2012, Ros-Freixedes et al. 2014, Weimer et al. 2014) and utilized in the research nursery trial to determine the accuracy to activity labeling by the DeIT system. The classification of 10,311 time points was conducted for determining accuracy of activity labeling by the DeIT system, the large amount of time required to perform manual labeling was reported by Weimer et al. (2014). When manually determining pig activity there were two main challenges; 1) the video recordings labeled by the DeIT system utilized were cropped in the file conversion process, if pigs were on the very edges of the pen pigs could be out of view of the manual observer 2) accuracy of activity was recorded using randomly selected data points and viewed as still frames, this does not take into account the rapid time in which errors are corrected by the DeIT system.

The utilization of the percentage of time pigs spend doing each activity allows for comparisons of activity data across studies, regardless of the amount of time observed in the trial. The average percentage of time pigs spent lying in research nursery trial (77.56%) was less than the 84.2% of time reported by Sadler et al. (2011). Sadler et al. (2011) utilized two genetic lines (low residual feed intake and control) and collected activity observations using a four wk interval while the current study utilized pigs of similar genetic background and continuous monitoring of activity. The percentage of time spent in close proximity to the feeder (9.93%) in the current study is less than the time spent at the feeder (11.6 and 10.5%) reported by (Gonyou et al. 1998). Both the current study and Gonyou et al. (1998) reported activity over a similar time period, however key differences are the sampling technique of pig activity and the differences in treatment. The current study utilized pigs of similar age and continuous analysis to determine pig activity while Gonyou et al. (1998) utilized two treatment ages of pigs (weaned at 12 and 21 d of age) and three d video recordings to determine pig activity. The percentage of time pigs spend in close proximity to the waterer in the research nursery trial (0.95%) is less than the percentage of time (1.7-3.5%) reported by (Davis et al. 2004). The current study and Lind et al. (2005) recorded the distance pigs traveled. Both studies were able to track the distance pigs traveled and noted the impact of small changes in movement as a challenge for recording walking. However, there were differences including the utilization of mini pigs that were 18 months of age and conducting the observation post injection for a set window of time (Lind et al. 2005), while the current study utilized 21 d old pigs and continuous monitoring. A major difference is the activity data reported in the current study is the percentage of time are calculated using continuous data collection while previous studies have utilized interval observations (Gonyou et al. 1998, Sadler et al. 2011, Camerlink et al. 2012, Ros-Freixedes et al. 2014, He et al. 2018). There is a large variability in the activity of individual pigs. Due to the variability in daily activity and between individual pigs caution should be taken when reporting activity data collected over a short period of time. Changes in activity patterns can be partially attributed to human interaction (weighing, feeding, cleaning), however there are changes in activities that occur that cannot be linked to management practices. Pigs' daily activity is largely variable but analyzing by weekly activity reduces variability. For activities like lying that make up a large portion of daily activities, utilizing a weekly average reduces the noise attributed to fluctuation in daily activities (Figure 6). A similar reduction in noise is seen by analyzing standing activity data by wk instead of on a daily basis (Figure 7), as the largest portions of a pigs' daily activity can be attributed to either lying or standing. Activities that comprise the remaining percentages of daily activity (walking; Figure 8, in close proximity to feeder; Figure 9, and in close proximity to waterer; Figure 10) contain less noise as a result of a smaller range. Moreover, when analyzing m/d walked evaluating on a weekly basis helps to remove visible peaks and valleys as a result of human interaction to give a more accurate estimate of pig activity (Figure 11). Results demonstrate that averaging time associated with daily activities reduces the variability of the activities.

Activity data generated indicated time lying and in close proximity to the feeder increased over time (7.46% and 3.99%, respectively), similar to He et al. (2018), while Gonyou et al. (1998) reported a decrease in time in close proximity to the feeder over time (4.54%). The continuous monitoring of pig activity in the current study takes into consideration pigs in close proximity to the feeder throughout the trial, while the percentages reported by (Gonyou et al. 1998, He et al. 2018) considers time pigs spent at the feeder during sampling periods. The manual observation of activities utilized to evaluate activity suggests time spent in close proximity to the feeder patterns (number of visits and duration of visits) vary greatly among pigs, which was also noted by Maselyne et al. (2016). The short duration of activities like time in close proximity to the feeder and time in close proximity to the waterer, may result in observation over a window of time not fully accounting for time at the feeder and time at the waterer. Differences in time barrows and gilts spent standing was reported by Stookey and Gonyou (1994) utilizing 80 nursery pigs. Barrows spent two less minutes standing/h than gilts and spent 25% more time in close proximity to the feeder than gilts. Differences reported or lack thereof for gender in the controlled nursery could be attributed to changes in pen dynamic as a result of mixing genders and the lack of controls (single gender or litter pens).

Conclusions

Results of this study indicated the DeIT system is able to accurately identify, maintain identification and continuously track the activities of newly weaned nursery pigs. To our knowledge the controlled nursery trial is the longest duration of continuous nursery pig activity monitoring. The collection of continuous activity data allows for the analysis of activity patterns outside of windows of time traditionally included in random sampling or sampling of periods of high activity. The DeIT system is capable of detecting activity difference across time, among litters, and genders. The detection of changes in activity over time can be beneficial as a baseline to detect illness or injury. Future work should be conducted on larger sample sizes in an effort to better understand differences. The incorporation of feed consumption and water usage data would serve as a valuable tool when classifying pigs in close proximity to the feeder and in close proximity to the waterer. These variables could serve as valuable indicators of changes in activity and growth patterns of pigs. The DeIT system serves as a valuable method of automatically identifying individual pigs and activities of nursery pigs, which could serve as a valuable tool to the swine industry.

LITURATURE CITED

Breuer, K.B., Beattie, V.E., Dunne, L.M., Slade, E.C., Davies, Z., Mercer, J.T., Rance, K.A., Sneddon, I.A., Sutcliffe, M.E.M., Edwards, S.A. (2001). Validation and development of a behavioural test to predict the predisposition of growing pigs to perform harmful social behaviour such as tail biting. Proceeding of the British Society of Animal Science 50.

Camerlink, I., P. Bijma, B. Kemp and J. E. Bolhuis (2012). Relationship between growth rate and oral manipulation, social nosing, and aggression in finishing pigs. Appl. Anim. Behav. Sci. 142(1): 11-17.

Cornou, C., Vinther J., and Kristensen, A.R. (2008). Automatic detection of oestrus and health disorders using data from electronic sow feeders. Livest Sci 118:262-71.

Davis, M., J. Apple, C. Maxwell, S. Arthur, Z. Johnson and M. Dirain (2004). Effect of weaning age and commingling after the nursery phase on growth performance, mortality rate, and behavioral indicators of welfare. Arkansas Animal Science Department Report 2004 522: 160.

Escalante, H. J., Rodriguez, S. V., Cordero, J., Kristensen, A. R., and Cornou, C. (2013). Sow-activity classification from acceleration patterns: A machine learning approach. Computers and Electronics in Agriculture, Vol. 93, pp. 17–26.

Gonyou, H., E. Beltranena, D. Whittington and J. Patience (1998). The behaviour of pigs weaned at 12 and 21 days of age from weaning to market. Canadian Journal of Animal Science 78(4): 517-523.

He, Y., J. Deen, G. C. Shurson and Y. Z. Li (2018). Behavioral indicators of slow growth in nursery pigs. J. Appl. Anim. Welf. Sci.: 1-11.

Kashiha, M., C. Bahr, S. A. Haredasht, S. Ott, C. P. Moons, T. A. Niewold, F. O. Ödberg and D. Berckmans (2013a). The automatic monitoring of pigs water use by cameras. Comput. Electron. Agric. 90: 164-169.

Kashiha, M., C. Bahr, S. Ott, C. P. H. Moons, T. A. Niewold, F. O. Ödberg and D. Berckmans (2013b). Automatic identification of marked pigs in a pen using image pattern recognition. Comput. Electron. Agric. 93: 111-120.

Kashiha, M. A., C. Bahr, S. Ott, C. P. Moons, T. A. Niewold, F. Tuyttens and D. Berckmans (2014). Automatic monitoring of pig locomotion using image analysis. Livestock Science 159: 141-148.

Lind, N. M., M. Vinther, R. P. Hemmingsen and A. K. Hansen (2005). Validation of a digital video tracking system for recording pig locomotor behaviour. Journal of Neuroscience Methods 143(2): 123-132.

Maes, D., A. Larriestra, J. Deen and R. Morrison (2001). A retrospective study of mortality in grow-finish pigs in a multi-site production system. J. Swine Health Prod. 9(6): 267-273.

Nasirahmadi, A., U. Richter, O. Hensel, S. Edwards and B. Sturm (2015). Using machine vision for investigation of changes in pig group lying patterns. Comput. Electron. Agric. 119(Supplement C): 184-190.

Ott, S., C. P. H. Moons, M. A. Kashiha, C. Bahr, F. A. M. Tuyttens, D. Berckmans and T. A. Niewold (2014). Automated video analysis of pig activity at pen level highly correlates to human observations of behavioural activities. Livestock Science 160(Supplement C): 132-137.

Ros-Freixedes, R., L. J. Sadler, S. K. Onteru, R. M. Smith, J. M. Young, A. K. Johnson, S. M. Lonergan, E. Huff-Lonergan, J. C. M. Dekkers and M. F. Rothschild (2014). Relationship between gilt behavior and meat quality using principal component analysis. Meat Science 96(1): 264-269.

Sadler, L. J., A. K. Johnson, S. M. Lonergan, D. Nettleton and J. C. M. Dekkers (2011). The effect of selection for residual feed intake on general behavioral activity and the occurrence of lesions in yorkshire gilts. J. Anim. Sci. v. 89(no. 1): pp. 258-266-2011 v.2089 no.2011.

Stookey, J. M. and H. W. Gonyou (1994). The effects of regrouping on behavioral and production parameters in finishing swine. J. Anim. Sci. 72(11): 2804-2811.

Stukenborg, A., Traulsen, I., Puppe, B., Presuhn, U., Krieter, J. (2011). Agonistic behaviour after mixing in pigs under commercial farm conditions. Appl. Anim. Behav. Sci. 129 (1), 28–35.

United States Department of Agriculture, U. (2017). Swine 2012: Part iii: Changes in the u.S. Swine industry, 1995-2012. United States Department of Agriculture Animal adn Plant Health Inspection Service. 2018.

Weimer, S. L., A. K. Johnson, T. J. Fangman, L. A. Karriker, H. D. Tyler and K. J. Stalder (2014). Article comparison of nursery pig behavior assessed using human observation and digital-image evaluation methodologies. J. Swine Health Prod. 22(3): 116-124.

Zhu, W., Y.. Guo, P. Jiao, C. Ma and C. Chen (2017). Recognition and drinking behaviour analysis of individual pigs based on machine vision. Livestock Science 205: 129-136.

Table 1. Diets fed in the controlled nursery.

Ingredient[1]	Prestarter	Nursery 1	Nursery 2	Medicated Nursery 2[2]	Grower 1	Grower 2
Corn	43	43.6	60	57	68.5	74.6
Soybean Meal, 47.5%	14.7	32	33.8	34.8	26	20.3
Dried Whey	22.5	15	-	-	-	-
Tallow	-	-	-	-	3	3
Fish Meal	8	4	-	-	-	-
Animal Plasma	6	-	-	-	-	-
Corn Oil	3	3	3	3	-	-
Dicalcium Phosphate	0.4	1	1.7	1.7	0.7	0.35
Limestone	0.25	0.35	0.6	0.3	1	1
Salt	0.3	0.3	0.3	0.3	0.3	0.3
F-G-N Swine Vitamin Premix[3]	0.25	0.25	0.25	0.15	0.2	0.2
Swine TM Premix[4]	0.15	0.15	0.15	0.15	0.15	0.15
Mecadox	1		-	-	-	-
Zinc Oxide	0.4	0.3	-	-	-	-
DL-Methionine	0.05	0.025	0.025	0.025	-	-
L-lysine HCL	-	-	0.04	0.04	0.13	0.12
Denegard	-	-	-	0.18	-	-
Aureomycin 50	-	-	-	0.4	-	-
Phytase	-	-	-	-	0.02	0.02
Analyzed Composition, %						
Net Energy	2,631	2,534	2,515	2,531	2,585	2,628
Crude Protein	16.69	20.02	17.92	17.95	15.31	13.33
Lysine	1.33	1.21	1.03	1.03	0.91	0.77

[1] All ingredients reported on an a percentage as fed basis
[2] Medicated Nursery 2 diet included Denegard and Auromycin 50
[3] Vitamin Premix ingredients: Vitamin A, Vitamin D, Vitamin E, Vitamin K, Niacin, Panothenic Acid, Riboflavin, Vitamin B12
[4] Swine TM Premix ingredients: Copper, Iodine, Iron, Manganese, Selenium, Zinc

Table 2. Identification errors associated with activities and overall DeIT system accuracy of identification of 28 nursery pigs over 42 d, as determined by comparison of DeIT system identification labeling on recorded images and visual observations.

	Identification Error (%)		
Activity x ID[1]	Label Swap[2]	No Label[3]	% Correctly Identified[4]
Walking	0.13	0.02	99.85
Standing	0.37	0.12	99.51
Lying	3.65	1.41	94.94
At the Feeder[5]	0.15	0.19	99.66
At the Waterer[6]	0.02	0.03	99.95
Overall Accuracy of ID (%)	4.32	1.77	93.91

[1] Activity of individual pig when DeIT system incorrectly identified a pig (% of identification error)

[2] Label swap identification error was determined as the percentage of error due to identification labels not being applied, lost track in an individual pig.

[3] ID Switch was determined as the percentage of error due to identification labels being incorrectly assigned.

[4] Rate of individual identification labels correctly applied by the DeIT, verified by visual observations of 10,544 randomly selected images across 42 d within the nursery facility.

[5] At the feeder is classified by pigs being in close proximity to the feeder.

[6] At the waterer is classified by pigs being in close proximity to the waterer

Table 3. Accuracy of DeIT system to identify activity of 28 nursery pigs over 42 d, as determined by comparison of DeIT system identification labeling on recorded images and visual observations.

	Correct Activity[1]	Total Activity[2]	Accuracy (% correct)
Walking	937	944	99.3
Standing	1,279	1,328	96.3
Lying	6,133	6,187	99.1
At the Feeder[3]	1,414	1,636	86.4
At the Waterer[4]	159	216	73.6
Overall Accuracy	9,922	10,311	96.2

[1] Number of observations for activity (walking, standing, lying, at the feeder, or at the waterer) correctly determined by DeIT system.
[2] Number of observations for activity (walking, standing, lying, at the feeder, or at the waterer) as determined by visual evaluation of activity.
[3] At the feeder is classified by pigs being in close proximity to the feeder.

[4] At the waterer is classified by pigs being in close proximity to the waterer.

Table 4. Overall percentage of time associated with activities and m/d walked of 28 individual nursery pigs recorded during the first 42 d, in the nursery research facility as classified by DeIT system.

ID	Gender	Percent of time over 42 d					
		Lying	Standing	Walking	At Feeder[1]	At Waterer[2]	m/d walked
AB1	Barrow	76.02	6.64	2.31	14.39	0.64	768.3
AB22	Barrow	76.41	9.66	2.59	10.52	0.82	870.5
AG1	Gilt	79.58	8.18	2.97	8.61	0.66	960.1
AG22	Barrow	74.77	10.33	2.90	11.00	0.99	951.7
AG333	Gilt	77.20	9.71	3.04	9.58	0.46	963.9
AR1	Barrow	77.56	9.25	2.77	9.29	1.13	912.7
AR22	Gilt	80.54	7.03	2.69	8.99	0.74	858.2
AR333	Barrow	78.60	9.08	2.82	8.43	1.07	913.2
AW1	Barrow	75.95	10.35	3.61	9.24	0.85	1,140.6
AW22	Gilt	76.05	7.78	2.47	13.04	0.66	815.5
AW333	Gilt	77.09	7.77	2.57	12.01	0.55	832.3
AY1	Gilt	74.38	10.18	3.68	11.21	0.54	1,124.8
AY22	Gilt	74.48	10.46	2.99	11.18	0.90	954.8
AY333	Barrow	75.68	8.68	3.11	11.49	1.03	1,017.3
BB1	Gilt	78.95	7.42	2.69	10.16	0.77	875.2
BB2	Gilt	78.96	6.45	2.11	11.59	0.89	692.2
BG1	Gilt	79.24	7.92	3.08	8.40	1.35	966.1
BG22	Barrow	79.79	8.37	3.03	7.39	1.41	963.5
BG333	Barrow	78.47	8.70	3.14	8.73	0.96	1,016.6
BR1	Gilt	79.15	9.16	3.05	7.69	0.95	974.3
BR22	Gilt	79.08	7.38	2.75	10.91	0.89	908.8
BR333	Barrow	75.81	9.38	3.41	10.47	0.92	1,082.1
BW1	Barrow	78.66	8.79	3.11	7.94	1.49	992.0
BW22	Gilt	78.37	8.52	3.17	8.56	1.37	1,044.4
BW33	Gilt	77.72	8.90	2.86	9.37	1.15	936.3
BY1	Gilt	76.84	8.75	3.47	9.84	1.09	1,099.7
BY22	Gilt	78.93	7.85	2.91	8.95	1.35	945.6
BY333	Barrow	78.47	9.12	2.54	9.00	0.85	825.8
Mean		77.56	8.64	2.29	9.93	0.95	943.1
Min		74.38	6.45	2.11	7.39	0.46	692.2
Max		80.54	10.46	3.68	14.39	1.49	1,140.6
StDev		1.69	1.10	0.37	1.66	0.28	105.1

[1] Percent of time at the feeder is reported as the percent of time that a pig was within the annotated area of the pen associated with the feeder.

[2] Percent of time at the waterer is reported as the percent of time that a pig was within the annotated area of the pen associated with the waterer.

Table 5. Overall percentage of time associated with activities and m/d walked reported by week of 28 individual nursery pigs during the first 42 d, as classified by the DeIT system.

		Percent of time over 42 d					
Week	ADG	Lying	Standing	Walking	At Feeder[1]	At Waterer[2]	m/d walked
One	0.22[a]	72.31[a]	15.72[a]	3.72[a]	7.26[a]	0.95	1,195.76[a]
Two	0.33[b]	77.19[b]	10.22[b]	3.05[b]	8.68[b]	0.86	990.85[b]
Three	0.44[c]	79.06[bc]	8.42[c]	3.61[a]	8.95[b]	0.97	1,219.60[a]
Four	0.61[d]	78.66[c]	5.81[d]	2.66[c]	11.81[c]	1.06	819.53[c]
Five	0.66[e]	79.41[c]	5.60[e]	2.29[d]	11.76[c]	0.91	731.21[d]
Six	0.75[f]	79.77[c]	5.90[e]	2.19[d]	11.25[c]	0.89	701.53[d]
P-value	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	0.11	≤0.001
SEM	0.02	0.56	0.32	0.09	0.48	0.06	195.88

[1] Percent of time at the feeder is reported as the percent of time that a pig was within the annotated area of the pen associated with the feeder.

[2] Percent of time at the waterer is reported as the percent of time that a pig was within the annotated area of the pen associated with the waterer.

Table 6. Overall percentage of time associated with activities and m/d walked reported by gender of 28 individual nursery pigs during the first 42 d, as classified by the DeIT system.

			Percent of time over 42 d					
Gender	n	ADG[1]	Lying	Standing	Walking	At Feeder[2]	At Waterer[3]	m/d walked
Barrows	12	0.46	77.18	9.03	2.94	9.83	1.01a	954.52
Gilts	16	0.54	77.84	8.34	2.91	10.01	0.89b	934.50
P – value		0.13	0.52	0.13	0.83	0.53	0.04	0.98
SEM		0.03	0.47	0.32	0.11	0.49	0.06	223.19

[1] ADG reported as a weekly average

[2] Percent of time at the feeder is reported as the percent of time that a pig was within the annotated area of the pen associated with the feeder.

[3] Percent of time at the waterer is reported as the percent of time that a pig was within the annotated area of the pen associated with the waterer.

Table 7. Overall percentage of time associated with activities and m/d walked reported by litter of 28 individual nursery pigs during the first 42 d, as classified by the DeIT system.

			Percent of time over 42 d					
Litter[1]	n	ADG	Lying	Standing	Walking	At Feeder[2]	At Waterer[3]	m/d walked
L1	8	0.42	75.88	9.69	3.21[a]	10.36	0.85	1,031.11[a]
L2	6	0.50	78.11	8.06	2.70[b]	10.04	1.08	878.25[b]
L3	8	0.52	78.27	8.45	2.99[ab]	9.34	0.95	962.70[ab]
L4	6	0.55	76.89	8.81	2.79[b]	10.67	0.84	902.62[b]
P-value		0.19	0.12	0.13	0.05	0.74	0.13	0.05
SEM		0.04	0.75	0.51	0.18	0.78	0.09	353.92

[1] Dams were same genetic line. Sires were from pooled Duroc semen.
[2]Percent of time at the feeder is reported as the percent of time that a pig was within the annotated area of the pen associated with the feeder.
[3] Percent of time at the waterer is reported as the percent of time that a pig was within the annotated area of the pen associated with the waterer.

Table 8. Overall percentage of time associated with activities and m/d walked reported by pen assignment of 28 individual nursery pigs during the first 42 d, as classified by the DeIT system.

			Percent of time over 42 d					
Pen	n	ADG	Lying	Standing	Walking	At Feeder[1]	At Waterer[2]	m/d walked
1 – 1[3]	7	0.49	76.43	8.96	2.92	11.01[y]	0.68[a]	939.80
1 – 2[4]	7	0.52	77.20	8.80	2.78	10.24[xy]	0.97[b]	906.97
3 – 3[5]	7	0.46	78.05	8.93	3.08	8.70[x]	1.13[c]	992.32
3 – 4[6]	7	0.52	77.70	8.20	2.86	10.26[xy]	0.99[b]	925.83
	P – value	0.43	0.22	0.52	0.48	0.06	0.001	0.46
	SEM	0.33	0.62	0.43	0.15	0.55	0.07	42.71

[1] Percent of time at the feeder is reported as the percent of time that a pig was within the annotated area of the pen associated with the feeder.

[2] Percent of time at the waterer is reported as the percent of time that a pig was within the annotated area of the pen associated with the waterer.

[3] Pigs assigned to pen 1 (d 1 – 23), stayed in pen 1 for remainder of nursery phase

[4] Pigs assigned to pen 1 (d 1 – 23), moved to pen 2 on d 23 for remainder of nursery phase

[5] Pigs assigned to pen 3 (d 1 – 23), stayed in pen 3 for remainder of nursery phase

[6] Pigs assigned to pen 3 (d 1 – 23), moved to pen 2 on d 23 for remainder of nursery phase

Figure 1. Schematic drawing of rooms utilized for the commercial nursery and controlled nursery with pen annotation of the pens utilized in the trials.

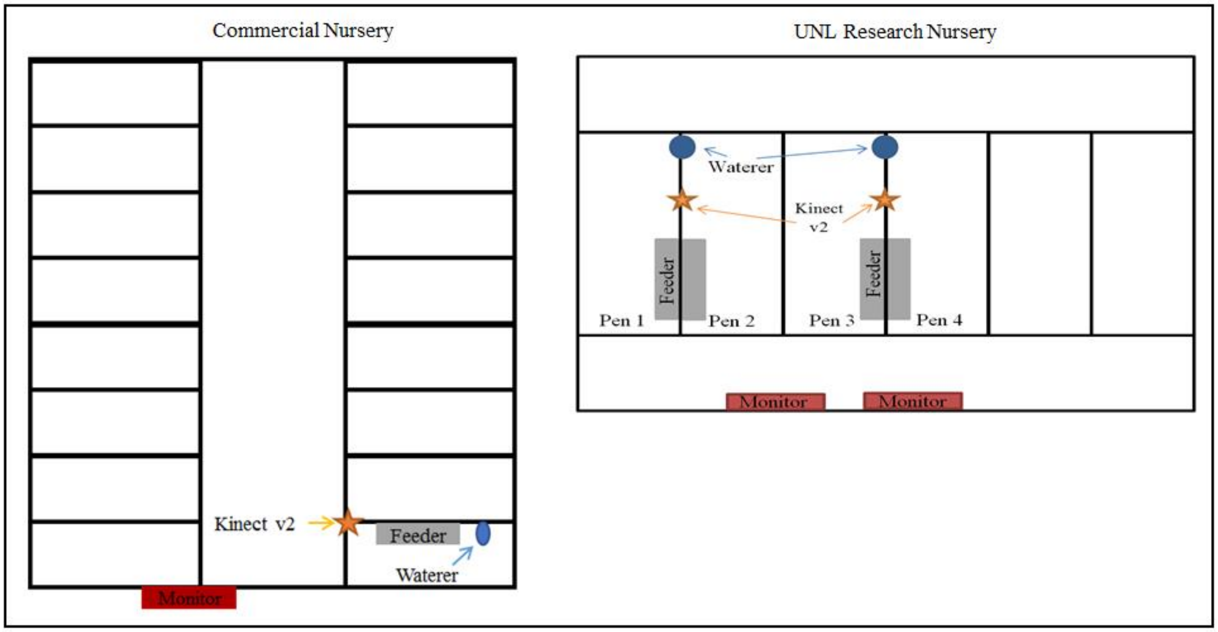

Figure 2. Individual visual identification methods (paint brand, paint pattern, colored/numbered ear tags) utilized to identify newly weaned nursery pigs.

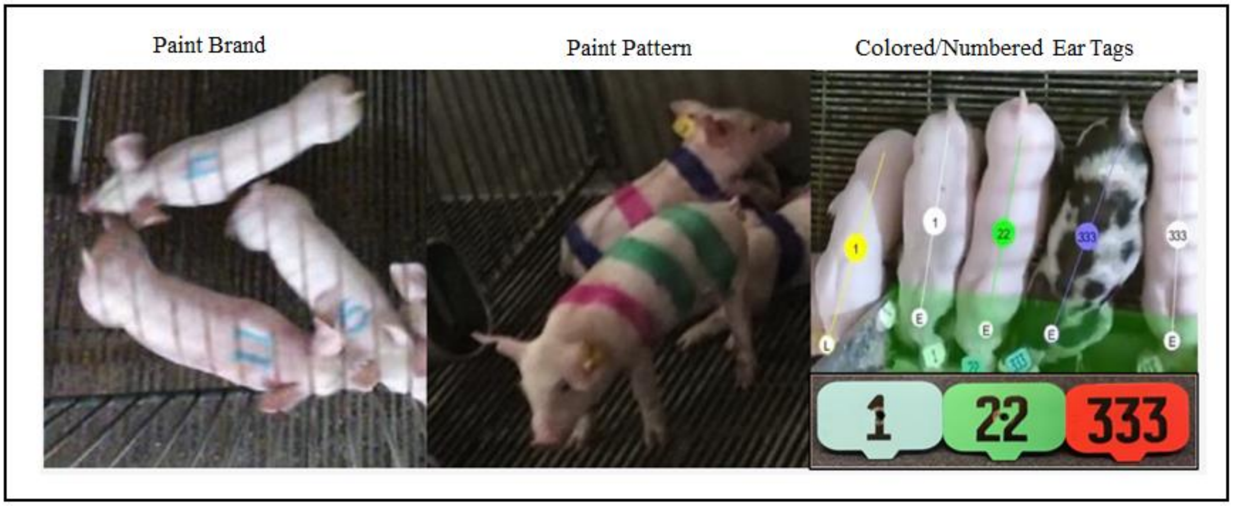

Figure 3. Image of visual verification of DeIT system's accuracy for determining individual identification. A manual comparison is made between the marker applied by the DeIT system and the colored/numbered ear tags in the pig's ears.

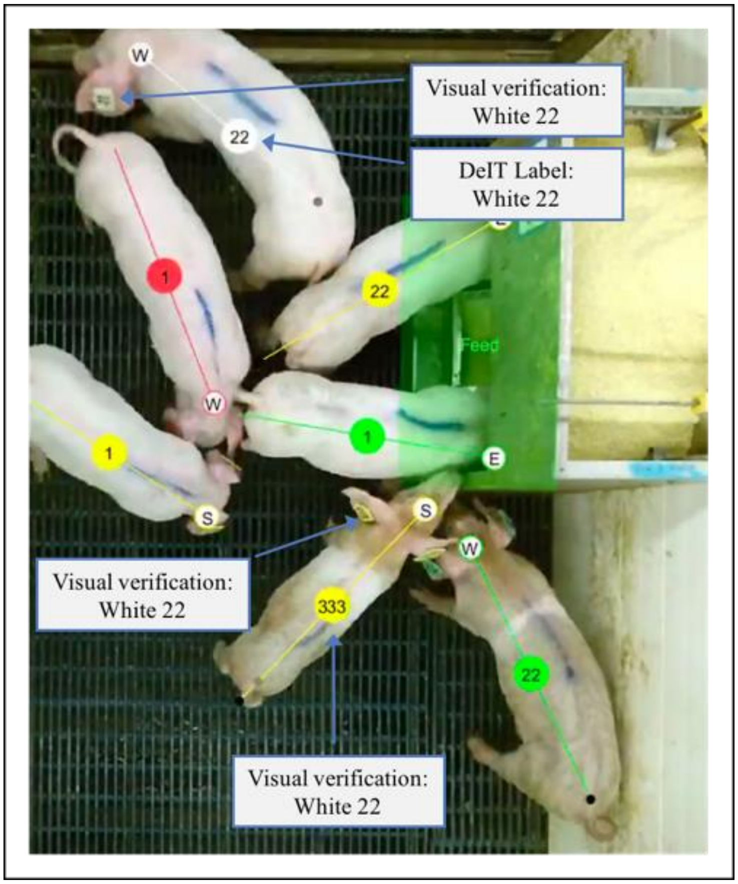

Figure 4. DeIT system activity labels for activities. White circles containing letters indicate the activity the DeIT system is recording for individual pig activity. The colored circle with numbers is representative of the identification the DeIT system has labeled for each pig.

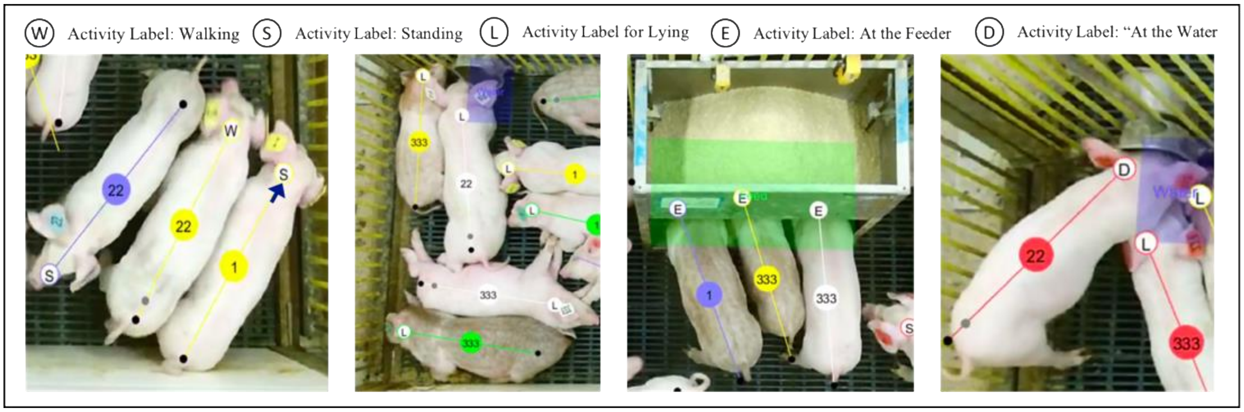

Figure 5. Recorded identity errors (label swap and loss of DeIT tracking label) observed through manual observation of DeIT system identity labels and visual observation of ear tags utilized for individual identification.

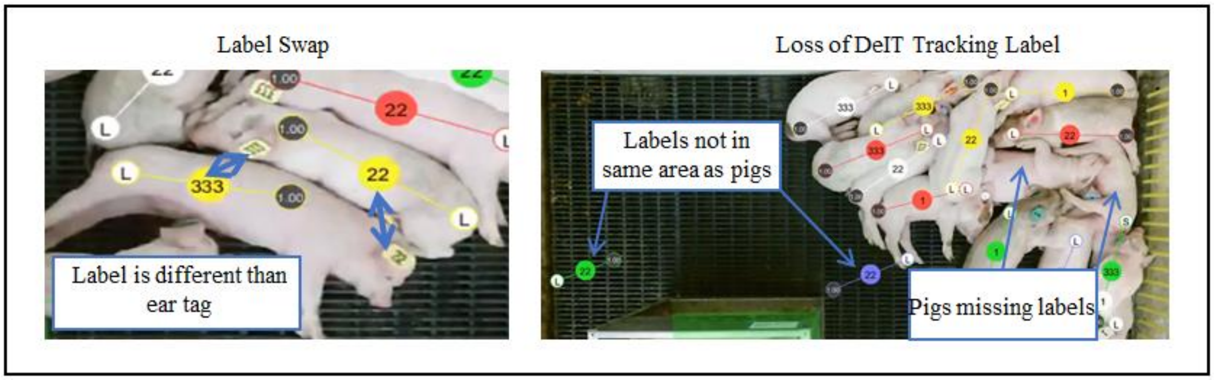

Figure 6. Evaluation of the percentage of time spent lying as reported on a daily basis (highly variable) compared to the percentage of time spent lying as reported on a weekly basis.

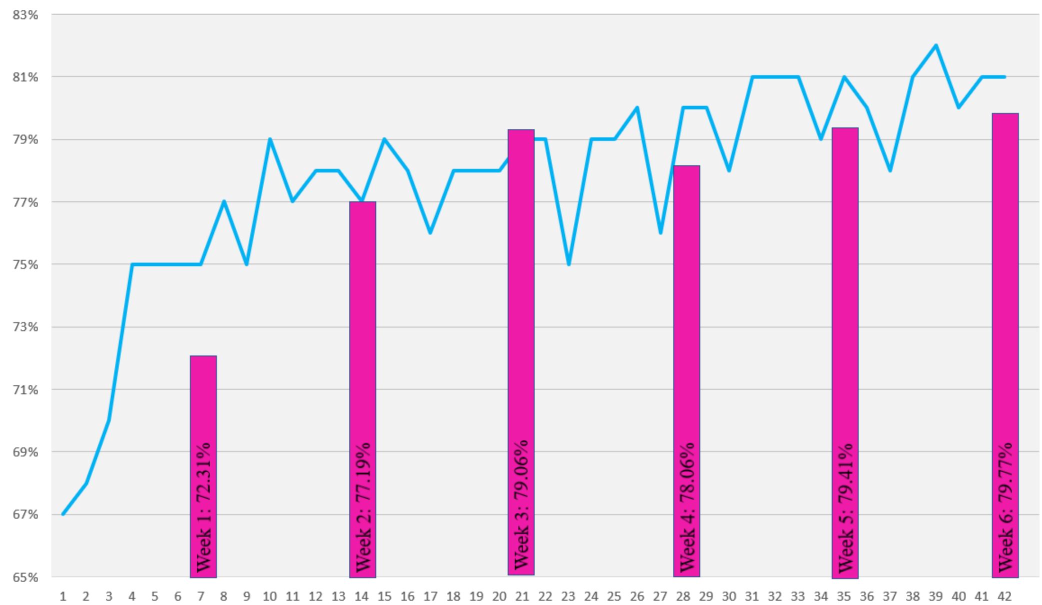

Figure 7. Evaluation of the percentage of time spent standing as reported on a daily basis (highly variable) compared to the percentage of time spent standing as reported on a weekly basis.

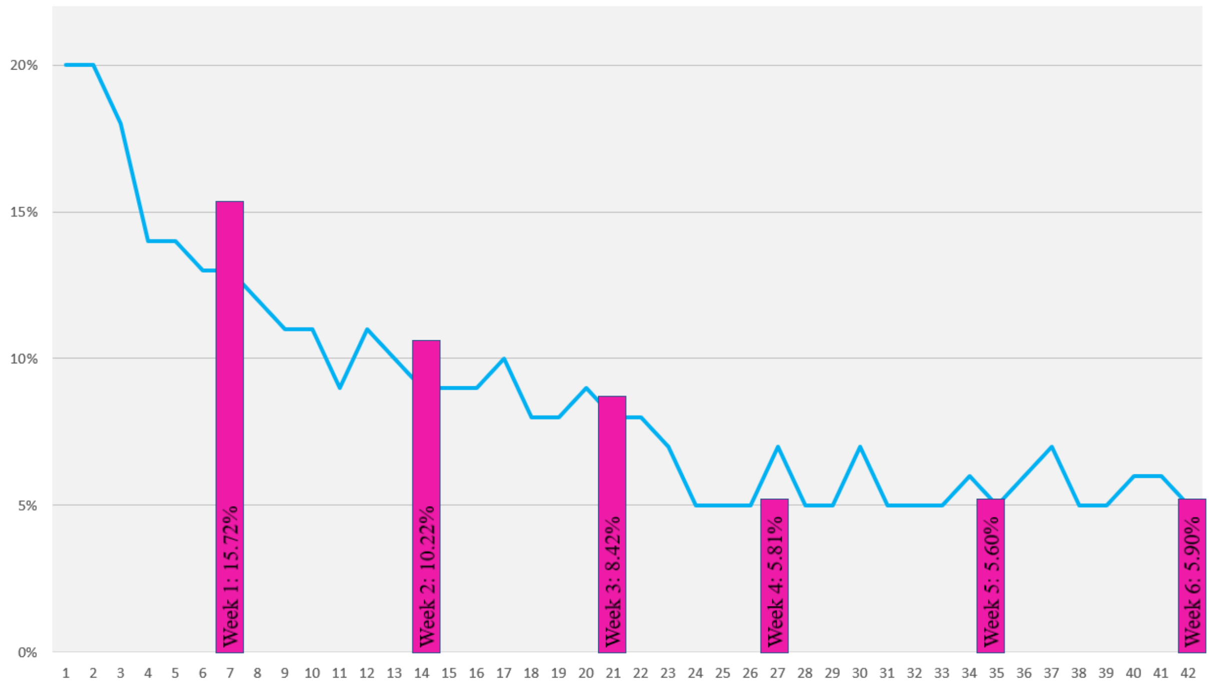

Figure 8. Evaluation of the percentage of time spent walking as reported on a daily basis (highly variable) compared to the percentage of time spent walking as reported on a weekly basis.

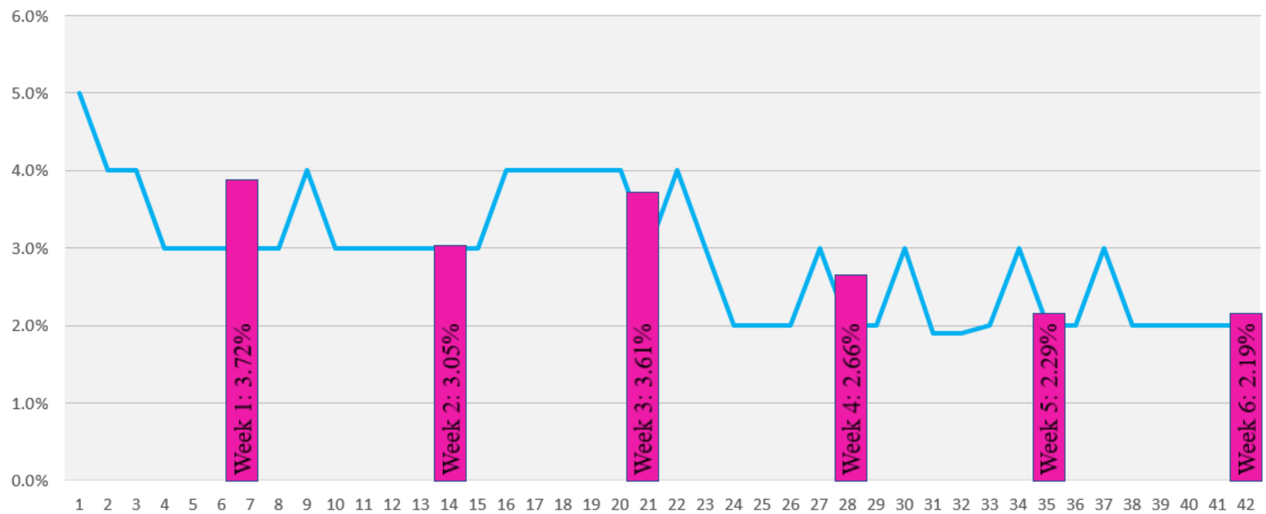

Figure 9. Evaluation of the percentage of time spent in close proximity to the feeder as reported on a daily basis (highly variable) compared to the percentage of in close proximity to the feeder as reported on a weekly basis.

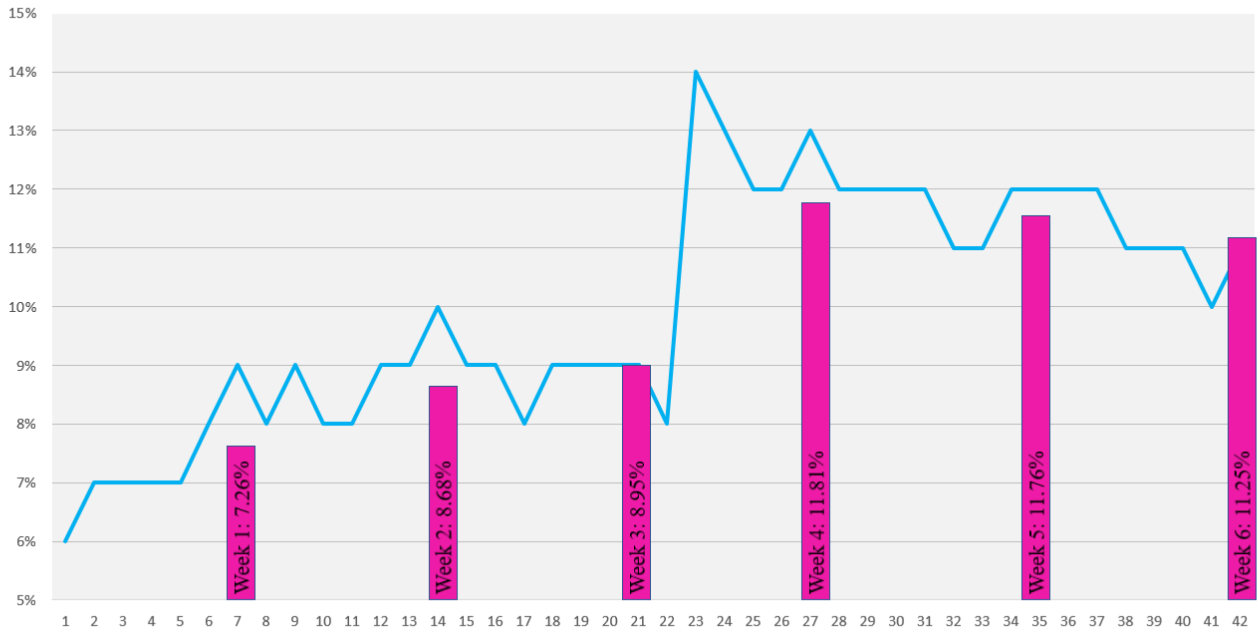

Figure 10. Evaluation of the percentage of time spent in close proximity to the waterer as reported on a daily basis (highly variable) compared to the percentage of time spent in close proximity to the waterer as reported on a weekly basis.

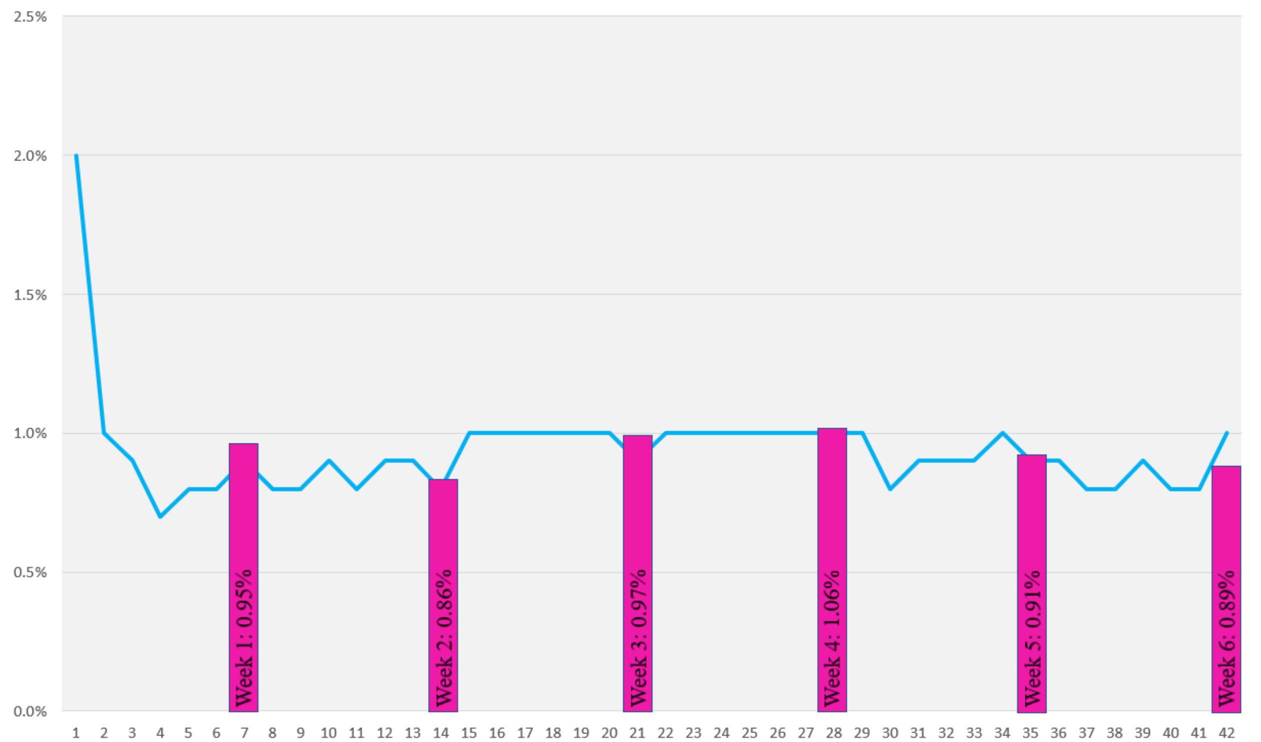

Figure 11. Evaluation of the m/d walked as reported on a daily basis (highly variable) compared to the m/d walked as reported on a weekly basis.