The Relationships Between the Performance of Injurious Pecking and Behavioural and Physical Traits in Domestic Turkeys

by

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The Relationships Between the Performance of Injurious Pecking and Behavioural and Physical Traits in Domestic Turkeys

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This thesis is an investigation of the relationships between the performance of injurious pecking and other behavioural and physical traits in domestic turkeys. Injurious pecking is a serious concern for the welfare and productivity of domestic turkeys, as a large proportion of the mortalities and culls in commercial flocks show injurious pecking damage. There are three distinct types of injurious pecking in turkeys: head pecking, severe feather pecking, and cannibalism; however, the development and causation of this damaging behaviour in turkeys is still poorly understood. The first research study in this thesis investigated the development of injurious pecking damage in relation to physical characteristics, such as body weight, leg health, and the snood length of growing male turkeys. This study showed that male turkeys develop more injurious pecking damage and poorer leg health over time. Yet, head pecking damage showed no correlation with body weight and snood length in domestic male turkeys. The validation study of data accelerometers for detecting turkey steps determined that this technology is best suited to evaluate the relationship between activity levels and injurious pecking in turkeys under small-scale research settings. The next study used temporal pattern analysis and a conventional behavioural assessment to identify differences in the behavioural organization of head pecking, severe feather pecking, and non-damaging gentle feather
pecking. Both analyses identified similar differences in the structure of active behaviours and gentle feather pecking among pecking types, yet gave conflicting results on the organization of feeding and foraging behaviour for turkeys engaged in head, severe, or gentle feather pecking. The final study was an initial step for determining if morphological differences in beak shape influence the injurious pecking behaviour of individual turkeys. This research used landmark-based geometric morphometrics to establish that beak shape shows a wide phenotypic variation between male and female domestic turkeys at both 6 and 18.5 weeks of age. This morphological study provides a foundation for future genetics and behavioural research to evaluate the heritability of beak shape in domestic turkeys and to identify differences in potential capacity for injurious pecking damage between the distinct beak shape phenotypes.
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From 2007 to 2015, Canadian turkey production has shifted from lighter turkeys (<11.0 kg) towards greater production of heavier turkeys (≥11.0 kg) to meet the growing consumer demand for processed turkey products, such as breast meat from heavier and mature turkeys (Morris, 2008; CFIA, 2016). Heavier turkeys grown to a later age require a greater feed investment per turkey and therefore, a producer will incur a greater financial loss if that turkey is culled or dies before it can be slaughtered. In modern day turkey production, injurious pecking represents a serious concern to the welfare and productivity of domestic turkeys, as a large proportion of the mortalities and culls in commercial flocks show injurious pecking damage (Hocking, 1993; Sherwin et al., 1999; Duggan et al., 2014).

Beak-related behaviour, which includes pecking of the environment and flock mates, makes up a large proportion of the daily time budget of domestic turkeys (Hughes and Grigor, 1996). Turkeys can gently feather peck the plumage of their flock mates causing no damage to the pecked bird (Savory, 1995; Hughes and Grigor, 1996). Alternatively, turkeys can cause damage to the plumage and/or tissue of another turkey through injurious pecking. In domestic turkeys, injurious pecking is defined as one of three types of damaging pecking behaviours: head pecking, severe feather pecking, and cannibalism (Savory, 1995; Sherwin et al., 1999). The tissue damage and removal of feathers from injurious pecking can be painful for the recipient and can hinder the pecked turkey’s normal behavioural patterns (Gentle and Hunter, 1991). For instance, feather loss from
injurious pecking can reduce a turkey’s ability to thermoregulate, causing the pecked
turkey to consume more feed to compensate for increased heat loss due to reduced
plumage cover (Appleby, 2004).

The different types of injurious pecking in turkeys can be distinguished by differences in
the development, causation, and targeted areas (Savory, 1995; Sherwin et al., 1999).
Head pecking is regarded as an act of aggression used to establish dominance, and is
directed at the head, neck, and/or snood of another turkey (Savory, 1995; Moinard et al.,
2001; Buchwalder and Huber-Eicher, 2003). In contrast, severe feather pecking and
cannibalism are considered re-directed foraging behaviour due to a lack of suitable
environmental complexity (Martrenchar, 1999; Sherwin et al., 1999). Turkeys target
severe feather pecking at the back, wings, and/or tail of another turkey, which results in
plumage and/or tissue damage that can be accompanied by the removal of feathers from
the pecked bird (Savory, 1995). Following head pecking or severe feather pecking,
turkeys will occasionally engage in cannibalistic pecking, which can spread rapidly
throughout a flock (Hale and Schein, 1962). Cannibalism refers to the continued pecking
of the skin of another turkey resulting in tissue damage, bleeding, and the possible
removal of tissue by the acting turkey (Hale and Schein, 1962; Savory, 1995).

Current strategies to mitigate injurious pecking damage in commercial turkey flocks
include environmental and dietary approaches, such as environmental enrichment
(Sherwin et al., 1999; Martrenchar et al., 2001), reduced stocking densities (Gill and
Leighton, 1984; Leighton et al., 1985; Buchwalder and Huber-Eicher, 2004), lower light
intensities (Lewis et al., 1998a; Moinard et al., 2001), and the feeding of high fibre forage (Hale and Schein, 1962; Hamilton and Keenie, 1997; Sherwin et al., 1999). Day-old turkeys also undergo physical alterations at the hatchery, such as infrared beak treatment and snood removal, to reduce the potential for the beak to inflict pecking damage (Krautwald-Junghanns et al., 2011a) and to remove a frequently targeted area for pecking damage in male turkeys (Freeman, 1987). Public perception of beak treatment as a painful procedure resulting in the loss of sensation in the beak tip, has led to legislative efforts in several countries towards discontinuing this commercial practice in poultry (Grigor et al., 1995; Fiks-van Nieker and de Jong, 2007). However, there is concern within the industry that current strategies alone will not prevent pecking damage from increasing in modern turkey flocks if beak treatment is phased out of commercial practice.

In contrast to other poultry species, the existing research on injurious pecking in domestic turkeys is still relatively sparse. Mitigation strategies and hypotheses about factors contributing to injurious pecking in turkeys have primarily relied on studies of damaging pecking behaviour in laying hens. Therefore, any attempts to reduce injurious pecking based on research in chickens will have limited success until a better foundation of knowledge is established on the development and maintenance of this behaviour in turkeys.

To create a better understanding of injurious pecking behaviour in turkeys, this thesis was designed to examine the relationships between the performance of injurious pecking
and other behavioural and physical traits in domestic turkeys. One study investigated the development of injurious pecking damage in relation to physical characteristics, such as body weight, leg health, and the snood length of growing male turkeys (Chapter Four). An evaluation of data accelerometers for activity monitoring in turkeys was undertaken to determine if this technology could be applied to assess the relationship between activity levels and injurious pecking (Chapter Five). Using temporal pattern (T-pattern) analysis, fundamental research was performed to identify differences in the behavioural organization of two forms of injurious pecking (head pecking and severe feather pecking), and non-damaging, investigatory gentle feather pecking (Chapter Six). Finally, a multidisciplinary approach was used to evaluate phenotypic beak shape variation in domestic turkeys to determine the potential to genetically select for specific beak shape phenotypes as an alternative to beak treatment (Chapter Seven).
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Chapter Two. Literature Review - Injurious Pecking in Domestic Turkeys:
Development, Causes, and Potential Solutions

Abstract

Injurious pecking is a serious concern for commercial turkey production and welfare. The behaviour is thought to represent re-directed ground foraging; however; the development and causes are poorly understood with little supporting literature. In the initial development of the behaviour, early lighting regimes and social facilitation might play contributing roles. Other factors, such as the availability of foraging material, diet composition, stocking densities, and group dynamics might also affect levels of injurious pecking. Given that commercial turkeys are group housed, alternative breeding strategies, like group selection based on social effects, might successfully reduce mortalities from pecking without detracting selection pressure from economic traits. However, to better suit their behavioural needs, any genetic attempts to adapt turkeys to perform less injurious pecking should be done in combination with environmental and dietary improvements.

Introduction

Injurious pecking is a significant welfare concern for raising turkeys in commercial facilities. The resulting injuries are responsible for the majority of culls and are a leading cause of mortality in adult turkeys (Hocking, 1993; Sherwin et al., 1999; Duggan et al.,
2014). Very little is known about the development of, and relationships between, the multiple factors influencing this abnormal behaviour in turkeys. Research in laying hens has provided the basis for knowledge on pecking in group-housed poultry and this has been extrapolated to other domestic poultry. However, any attempts to reduce injurious pecking in turkeys will likely have limited success until the causation of the behaviour in this species is better understood.

To best assess strategies to decrease injurious pecking, we need to clarify the different types exhibited by turkeys (head pecking, severe feather pecking, and cannibalism) and the factors contributing to the development, such as the environment, genetics, and nutrition. With this information it should be possible to design strategies to reduce injurious pecking to lead to improvements in both welfare and production.

**Defining injurious pecking**

Injurious pecking in turkeys can be divided into three types of problem behaviours: head pecking, severe feather pecking, and cannibalism. All three types have a negative impact on the welfare of the commercial turkey (Denbow et al., 1984; Sherwin et al., 1999). The first, head pecking (or aggressive pecking) is a form of aggression that typically follows a social disturbance, and is often used to retain dominance (Savory, 1995; Moinard et al., 2001). This type of pecking is usually directed at the head, neck and/or snood of subordinate turkeys (Buchwalder and Huber-Eicher, 2003).
In contrast, feather pecking involves the repeated pecking or plucking of another turkey's plumage, usually targeting feathers on the back, tail, base of the tail, and the wings. It sometimes includes the removal and consumption of the feathers (Savory, 1995). Since there are several ways a turkey might peck another, difficulty arises in distinguishing between the different types of pecking behaviour. Feather pecking is not always destructive and can be a form of social preening (Savory, 1995; Jendral and Robinson, 2004). Gentle pecking of another turkey is a mild, social, investigatory behaviour directed at food particles or debris on the plumage (Savory, 1995; Hughes and Grigor, 1996). When pecking becomes more forceful, concluding with the removal and possible consumption of pulled feathers, the behaviour is considered severe. Severe feather pecking often results in plumage damage and feather loss to the pecked turkey, and the recipient turkey responding with a distressed vocalization and moving away to escape further pecking (Denbow et al., 1984; Savory, 1995).

If bleeding occurs at the site of feather pecking, cannibalism often develops (Hale and Schein, 1962). Cannibalism in poultry refers to the repeated pecking of the exposed skin of another turkey, leading to hemorrhaging, and the removal of blood and tissue, which may then be consumed by the pecking turkey (Hale and Schein, 1962; Savory, 1995). Cannibalism can also manifest independently of feather pecking following aggressive pecking of denuded areas or the feet (Ensminger, 1992; Savory, 1995). All three forms of injurious pecking contribute significantly to animal suffering and production inefficiency in turkey rearing and must be addressed (Hocking, 1993; Sherwin et al., 1999).
Development of injurious pecking

Early lighting environment and environmental stability

There is no consensus as to the reasons that social preening becomes destructive. It might be related to a mismatch between the behavioural needs of the growing turkey and features of the early environment (Hughes and Grigor, 1996; Sherwin et al., 1999). In the first week of life, the appearance of ultraviolet (UV) feather markings on the wings and tails are temporally and spatially linked to the onset and initial targets of damaging pecking (Sherwin and Devereux, 1999; Moinard et al., 2001). Most commercial facilities operate under fluorescent or incandescent lighting with a minimal UV content, so the distorted appearance of emerging UV feathers in young turkeys might become targets for investigatory pecking (Moinard and Sherwin, 1999).

Frequent fluctuations in the early environment of chickens have also been linked with the initial appearance of feather pecking and could potentially have a similar impact in turkeys (Ensminger, 1992; Jendral and Robinson, 2004). In chickens, rough handling or disruptive events, like frequent changes to staff, temperature, or diet, can increase flock nervousness and cause turkeys to exhibit a heightened fear response (Ensminger, 1992; Jendral and Robinson, 2004). Similarly, fearful turkeys might also develop feather pecking as a coping mechanism to respond to environmental stress (Hughes and Duncan, 1972).
Sex differences and social facilitation

The highly stratified social structure of domestic turkeys mirrors their wild counterparts with males using head pecking, when fighting other toms, to establish dominance or breeding access (Watts and Stockes, 1971; Buchholz, 1997). In domestic flocks, head pecking is consistently lower in hens compared to toms, which becomes more aggressive following sexual maturity (Leighton et al., 1985; Buchholz, 1997; Buchwalder and Huber-Eicher, 2003). Busayi et al. (2006) showed males engaged in the highest levels of damaging feather pecking and pulling at three weeks of age, whereas females exhibited the most injurious pecking at nine weeks. However, their study terminated at nine weeks of age, far before sexual maturity, and inconsistent pecking terminology provides doubt that the pecking observed was damaging and not social preening.

Insight from wild turkey behaviour might also explain why social facilitation plays a significant role in the development of injurious pecking in commercial turkeys. In the wild, head pecking is learned by young turkeys as a fighting technique used by mature turkeys to determine the ‘pecking order’ (Watts and Stockes, 1971; Buchholz, 1997). In commercial environments, social learning is thought to facilitate the spread of damaging pecking (Sherwin and Kelland, 1998; Sherwin et al., 1999). Taking into consideration how injurious pecking is learned, if producers isolate individual ‘peckers’ when pecking is observed, then the spread of this negative behaviour through the entire flock might be
Causes of injurious pecking

There are several hypotheses as to why domestic poultry injuriously peck. There is consensus that head pecking is an act of aggression (Savory, 1995; Moinard et al., 2001). Alternatively, research in turkeys considers severe feather pecking and cannibalism to represent the re-directed ground pecking of foraging behaviour (Martrenchar, 1999; Sherwin et al., 1999). It was suggested that both feather pecking and cannibalism occur due to a lack of environmental stimuli in barren housing systems and an inherent tendency to peck. This need to peck is shaped by both genetic and nutritional variables. Severe feather pecking was previously proposed to represent frustration in both jungle fowl and domestic chickens, which occurs when a bird is prevented from performing other highly motivated behaviours, such as dust bathing (Vestergaard et al., 1993). Newer research by Dixon et al. (2008) in laying hens challenged the role of dust bathing in facilitating domestic poultry to feather peck. This research showed that the motor patterns of foraging pecks in laying hens were almost identical to the behavioural sequence of feather pecking. Rodenburg et al. (2004) has also suggested that severe feather pecking in poultry reflects an overexpressed motivation for social exploration in large flocks of unfamiliar birds. While this explanation would link the appearance of gentle feather pecking in young chickens to high levels of severe pecking in later life, this theory has yet to be tested in turkeys and therefore, re-directed foraging is considered the underlying motivation in turkeys.
An inherent need to peck

Taking re-directed foraging as a major cause of severe feather pecking and cannibalism in turkeys, research began to investigate the precise mechanisms shaping the behavioural switch between foraging and damaging pecking. Hughes and Duncan (1972) proposed that poultry have a highly substitutable ‘pecking requirement’ so when an appropriate foraging material is unavailable, poultry will re-direct investigative behaviour from feeding to the destructive pecking of other birds. However, an inherent need to peck might be too simplistic to explain this abnormal behaviour. Hughes and Grigor (1996) noted that turkeys spent a large amount of time pecking other turkeys, even when foraging material was available. The type of forage provided might not have satisfied turkey preference, but likely the notion of a pre-determined pecking requirement is more complex (Hughes and Grigor, 1996; Busayi et al., 2006). It appears that severe feather pecking and cannibalism, like all forms of injurious pecking in turkeys, are controlled by multiple influences from the environment, diet, and underlying genetic make-up (Martrenchar, 1999; Sherwin et al., 1999).

Environmental causes

Commercial environments are markedly different from the natural environment of the wild turkey. In the wild, turkey flocks will vary in size throughout the year and can be found in a diverse range of habitats, including dense woods and open grasslands (Watts...
and Stockes, 1971; Hawkins et al., 2001). In comparison, commercial facilities generally consist of an open area barn with feeders, drinkers, a litter floor, and the lighting and ventilation provided either artificially in fully-enclosed barns or artificially and naturally if the barn is curtain-sided (Duggan et al., 2014). Research suggests outbreaks of injurious pecking can be primarily attributed to a lack of suitable environmental features in commercial settings hindering the performance of a turkey's normal behavioural repertoire (Hughes and Grigor, 1996; Sherwin et al., 1999; Jendral and Robinson, 2004). These deficiencies in commercial environments can include a lack of foraging or exploratory substrate and a nutritionally unsuitable diet or inappropriate feed form.

Environmental conditions that cause stress, such as high stocking densities or inappropriate lighting, might also lead to outbreaks of severe feather pecking and cannibalism within turkey flocks (Leighton et al., 1985; Classen et al., 1994). Leighton et al. (1985) suggested that severe bouts of feather pecking and pulling in female turkeys were more frequent when nine-week old females were assigned the smallest floor space in grower pens (140 cm$^2$/turkey, range: 140-232 cm$^2$/turkey) after previously being brooded in pens with the largest space allowance (93 cm$^2$/turkey, range: 56-93 cm$^2$/turkey). Although in larger flocks (>600 turkeys), Martrenchar et al. (1999) showed that stocking density (range – females: 100-160 cm$^2$/turkey, males: 150-400 cm$^2$/turkey) did not influence the percentage of total activity male or female turkeys spent pecking one another. Denbow et al. (1984) and Hughes et al. (1997) suggested that in the standard, large flock sizes of >100 turkeys in commercial barns, social hierarchy is too difficult to establish so feather pecking and cannibalism likely operate independently of
group size. Inappropriate lighting schedules, such as an unbalanced short/long day length or a sudden change in photoperiod, have also been shown to increase the frequency of injurious pecking in male turkeys (Classen et al., 1994; Vermette et al., 2016). Other aspects of farm management, such as poor ventilation, inappropriate humidity levels, constantly fluctuating or extreme temperatures, or irritation from flies or ectoparasities can additionally heighten stress and contribute to damaging pecking in turkey flocks. The presence of dead turkeys or turkeys with leg problems (e.g., footpad swelling, arthritis, or deviated toes) is also thought to elicit injurious pecking in flocks as injured/dead turkeys act as a target for destructive pecking behaviour (Hughes and Duncan, 1972; Ensminger, 1992; Jendral and Robinson, 2004; Allain et al., 2013).

Like feather and cannibalistic pecking, head pecking in turkeys is also influenced by the frequency of environmental disturbances and stocking density (Gill and Leighton, 1984; Classen et al., 1994; Buchwalder and Huber-Eicher, 2003). Both female and male turkeys will perform head pecking after an environmental disturbance, possibly to restore the pre-existing dominance hierarchy and settle the flock (Gill and Leighton, 1984; Cunningham et al., 1992; Buchwalder and Huber-Eicher, 2003). This suggests that head pecking and its resulting injuries will be more prominent in commercial flocks that are exposed to frequent changes to husbandry or the environment (Classen et al., 1994; Buchwalder and Huber-Eicher, 2003). Gill and Leighton (1984) showed poorer feather scores for adult male turkeys when kept at higher population densities, likely reflecting increased aggression between sexually mature males. Martrenchar (1999) suggested high stocking densities is likely a major contributing factor in the high
incidence of injurious pecking in commercial barns, especially within male flocks.

However, unlike the other forms of injurious pecking, rates of aggressive head pecking in turkeys are affected by bird familiarity. The level of familiarity between group members also has a significant, negative correlation with the rate of agonistic pecking and fighting amongst turkey toms in both wild and domestic populations (Watts and Stockes, 1971; Buchwalder and Huber-Eicher, 2003, 2004, 2005a). Buchwalder and Huber-Eicher (2003) noted that domestic male turkeys will use aggressive pecking against unfamiliar individuals in group sizes containing as few as four males, especially at higher stocking densities (1.2 m$^2$/turkey vs. 3.6 m$^2$/turkey). Buchwalder and Huber-Eicher (2005a) also showed that group size impacted the amount of head pecking initially displayed towards an unfamiliar turkey. In this study, small groups of 12-week old males (6 turkeys/pen) engaged in more head pecking (20.3 ± 15.6 head pecks; mean ± standard deviation) towards an unfamiliar male than larger groups of male turkeys (30 turkeys/pen; 5.0 ± 5.7 head pecks). Buchwalder and Huber-Eicher (2005a) also suggested that the high level of head pecking in large commercial flocks might actually reflect continuous attempts to establish stable hierarchies among the large number of turkeys.

*Genetic causes*

Genetic selection against injurious pecking has never been documented in turkeys. This means that only direct comparisons between traditional lines and modern turkeys can tell
us about the relationship between genetics and injurious pecking (Busayi et al., 2006). Under the same environmental conditions, modern lines showed a higher propensity for severe feather pecking and pulling in contrast to the traditional lines. Since traditional lines displayed fewer injuries from severe feather pecking, the likelihood of cannibalism was lower (Busayi et al., 2006). However, the numerous confounding variables in this investigation prevent meaningful insights. Many authors suggest that breeding programs selecting for larger and faster-growing poultry have unintentionally selected for higher rates of aggression and destructive pecking (Flock et al., 2006; Rodenburg and Turner, 2012). Unfortunately, no knowledge currently exists of the specific traits affected by turkey breeding that have contributed to a higher incidence of injurious pecking in modern flocks.

*The role of diet*

Numerous studies have found correlations between diet form, feeding frequency, or ingredients and injurious pecking in turkeys (Hale and Schein, 1962; Hughes and Grigor, 1996; Hamilton and Kennie, 1997). The physical structure of feed and the amount of distributed food can have considerable effects on rates of damaging pecking, and several studies found that turkeys switched to a crumble or mash diet spent more time feeding, feather pecked less, and had better plumage cover compared to turkeys fed pelleted diets (Hale and Schein, 1962; Hamilton and Kennie, 1997). After switching turkeys from pellets to mash, and simultaneously increasing the fiber content from 5 to 22%, Hale and Schein (1962) also found fewer turkeys with denuded areas. Hamilton
and Kennie (1997) found that providing feed *ad libitum* to growing turkeys reduced injuries from severe feather pecking in comparison to feed-restricted turkeys. Sherwin et al. (1999) showed the scattering of rough-cut wheat straw to non-beak trimmed, male turkeys led to fewer wing, tail, and head pecking injuries. However, Mirabito et al. (2003) found the addition of whole wheat to the turkey feed had no effect on feather pecking, which illustrates the importance of choosing appropriate high fiber forage delivered in a form suited to turkey preference (Hale and Schein, 1962; Hughes and Grigor, 1996). If dietary requirements are not met, turkeys might re-direct highly motivated beak-related behaviour from foraging to damaging pecking (Hughes and Grigor, 1996).

**Mitigating the problem**

*Current practices: anatomical alterations and light reductions*

Beak trimming (or treatment) in turkeys is presently performed with infrared lasers immediately following hatching to reduce the damage caused by injurious pecking (Krautwald- Junghanns et al., 2011a). Compared to conventional hot-blade beak trimming, infrared laser trimming prevents open wounds, decreases operator error in trimming length, and produces fewer behavioural changes post-amputation by allowing the beak tip to gradually wear away (Dennis et al., 2009). However, concerns still exist over beak trimming as a mutilating procedure performed without analgesia (Grigor et al., 1995). Krautwald-Junghanns et al. (2011a) found that a high number of the turkeys
(12.8% of males and 13.8% of females) still suffered from skin injuries, such as pecking wounds, even when housed with other turkeys that had been infrared trimmed. It has been suggested in laying hens that beak trimming might actually increase the incidence of feather pecking and cannibalism, which might also apply to turkeys (Gentle et al., 1982; Leighton et al., 1985). Frustrated by the physical difficulty in grasping feathers, beak-trimmed poultry might experience a heightened motivation to continue feather pecking and pulling until the action is complete.

Other common management practices used in turkey rearing to decrease pecking include lowering light intensities and snood removal. Similar to beak trimming, these also have welfare implications beyond influencing pecking rates. Very low light intensities (<5 lux at eye level) are often used to reduce injurious pecking, but can also lead to the development of eye abnormalities, including blindness and musculoskeletal disorders (Siopes et al., 1984; Lewis et al., 1998a). Sherwin (1998) also showed turkeys were relatively averse to very low light intensities and chose to spend less time in <1 lux chambers than chambers with 5, 10, or 25 lux light levels. An additional disadvantage of a dark rearing environment is it might hinder staff from recognizing injured and lame turkeys (Jendral and Robinson, 2004). Another common management procedure is the removal of the snood from male turkeys, a process usually performed in the hatchery. Removal prevents the snood becoming a target for aggressive head pecking and deters cannibalism. Done incorrectly, this amputation might become chronically painful (Freeman, 1987). Concern over trading one welfare concern for another has fostered interest in developing less drastic alternatives, such as genetic selection for gentler
turkeys, environmental enrichment, and changes to diet, to reduce injurious pecking in turkeys (Grigor et al., 1995; Sherwin et al., 1999; Moinard et al., 2001).

Use of genetic selection

Until recently, genetic selection in turkeys has focused on a limited number of traits that improve profitability such as improvements in body weight, feed conversion, breast meat yield, and egg production (Wood, 2009). Increased consumer pressure is shifting breeding efforts to direct quantitative genetic selection for livability or indirect selection for social effects and selection against injurious pecking in group-housed poultry (Muir, 1996; Moore et al., 1997; Flock et al., 2006; Rodenburg and Turner, 2012). There have been no reports on breeding against negative social behaviours in turkeys and previous genetic improvement programs in meat poultry show mixed success using survival as a selection parameter (Havenstein et al., 2007). Newer research in turkeys indicated a low to moderate heritability for survival (0.14 ± 0.07) and this information could provide a basis for future selection against injurious pecking (Quinton et al., 2011).

Damaging pecking can result in death so another strategy to reduce injurious pecking in laying hens has focused on selection to reduce mortality based on a social effects model (Muir, 1996; Rodenburg et al., 2009). This model successfully decreased damaging pecking in lines of laying hens through group selection for survival without sacrificing productivity (Craig and Muir, 1996; Cheng and Muir, 2005; Ellen et al., 2007). The success shown in the laying hens could conceivably be replicated in turkeys and merits
research. Genetic selection has great potential to improve the lives of livestock, although Rodenburg and Turner (2012) warned that genetic selection will only achieve dramatic improvements to animal welfare when accompanied by environmental changes to better suit the species’ natural behavioural repertoire.

Group selection for improved physical condition, such as better plumage coverage, might also reduce injuries from severe feather pecking and cannibalism in turkeys. Busayi et al. (2006) showed traditional line turkeys with better feather coverage experienced fewer pecking injuries than modern turkeys under identical environmental conditions. Research is still needed to clarify the association between plumage quality and injurious pecking injuries within a line. Only then can plumage coverage be used as selection criteria for improved turkey welfare.

*Environment and light changes*

A focus of research into pecking in turkeys has been the relationship between damaging pecking and light intensity, photoperiod, and light source. The definition of the light source is important as it highlights such parameters as the use of an incandescent or fluorescent bulb, the visible light spectrum, and whether or not the light source contains UV radiation (Lewis et al., 1998a,b; Sherwin and Devereux, 1999; Sherwin et al., 1999). Reduced light levels (<10 lux) have been standard industry practice to manage feather pecking in turkeys for many years, since research substantiated the role of higher light levels (≥ 10 lux for ≥ 12 hours) in increasing injurious pecking (Lewis et al., 1998a,b;
Martrenchar et al., 2001). The use of intermittent lighting schedules to reduce injurious pecking in turkeys was only moderately successful (Lewis et al., 1998b). Intermittent lighting operates by providing a varied program of multiple, brief light periods throughout the day to increase the value of performing highly-motivated, light based maintenance behaviours - like feeding and drinking - instead of engaging in injurious pecking during the scarce lighting periods (e.g., 8(1Light:2Dark), 8(1L:1D):8D, or 2(2L:3D):2L:12D, Lewis et al., 1998b; Sherwin et al., 1999).

The source of light can have an effect on pecking in turkeys with fewer tail and wing injuries displayed under fluorescent compared to incandescent lighting (Sherwin, 1999; Moinard et al., 2001). Moinard et al. (2001) showed that turkeys perceived fluorescent lighting to be less bright than incandescent due to the differences in spectral intensity. The incandescent light spectrum has a higher percentage of red wavelengths (70% red light) compared to fluorescent light (10% red light) (Lewis and Morris, 2000). This difference might alter a turkey's visual perception of the environment and increase the motivation to peck (Gill and Leighton, 1984). Research conducted in fully-enclosed housing also suggested the inclusion of UV light from hatching prevented the initial development of injurious pecking in turkeys (Moinard et al., 2001). Moinard and Sherwin (1999) speculated that pen mates resort to damaging pecking if they are unable to display and read plumage signals normally so communication breaks down. The lack of UV light might also inhibits turkeys from properly interacting with the available forage so they negatively re-direct frustration into the pecking of others (Sherwin and Devereux, 1999; Moinard et al., 2001). Conversely, Duggan et al. (2014) found turkeys
in curtain-sided barns exposed to natural UV light had worse feather scores and higher mortality than fully-enclosed facilities without supplemental UV. The lack of UV light during early turkey development is undoubtedly linked to the onset of damaging pecking, but the relationship between UV lighting and injurious pecking in adult turkeys is still unclear and requires further research.

Altering the environment through the use of visual barriers and novel objects can also decrease feather pecking. An example of visual barrier enrichment was the use of four suspended, plywood boards to divide the open barn space into quarters (Sherwin et al., 1999; Moinard et al., 2001). Although the welfare benefits of visual barriers were not specifically tested, they demonstrated that turkey poults suffered significantly fewer wing, head, and tail pecking injuries when provided supplementary visual barriers, UV radiation, and novel objects (Sherwin et al., 1999; Moinard et al., 2001). Visual barriers might act to reduce injurious pecking by preventing the spread of this negative behaviour through social facilitation or by providing an escape for turkeys being pecked (Sherwin et al., 1999). Martrenchar et al. (2001) found levels of injurious pecking amongst both male and female turkeys were higher in un-enriched pens than in pens containing straw bales and reflective 15 cm x 20 cm metal sheets. Conversely, Duggan et al. (2014) attempted to decrease feather pecking by adding coloured plastic balls to the floors of large flocks. No differences in feather pecking behaviour were observed between control groups and turkeys with supplementary ball enrichment. Although this particular enrichment was unsuccessful, the majority of the preliminary research in turkeys suggests enrichment chosen by bird preference can effectively deter injurious
pecking and therefore, warrants further testing (Sherwin et al., 1999; Martrenchar et al., 2001).

Dietary changes

There is evidence to suggest that dietary changes can prevent outbreaks of feather pecking in some circumstances. Specifically, the availability and type of forage substrates appear to influence the rate of injurious pecking. Some dietary factors that have been shown to decrease pecking include the feeding of crumble or mash (rather than pellets), supplementary dietary salt, \textit{ad libitum} feed, and the use of high fiber foraging substrates (Hale and Schein, 1962; Hamilton and Kennie, 1997; Sherwin et al., 1999; Berger, 2006). Hughes and Grigor (1996) suggested that bulkier, high fiber diets for turkeys, delivered in part by scattering, would increase foraging and decrease destructive pecking. Further research is required into dietary consequences of feed composition, form, and distribution on abnormal pecking behaviour in turkeys. For instance, species-specific research is needed to test if the addition of dietary salt and other trace elements in turkey feed results in less cannibalism within flocks. Although these proposed solutions could potentially increase production costs, the welfare benefits of decreasing unnecessary mortalities from damaging pecking should outweigh the costs of these dietary changes.

While head pecking is primarily a reflection of social organization and environmental disturbance, the two other types of injurious pecking in turkeys, severe feather pecking
and cannibalism, appear to be multi-factorial products of genetics, environment, and nutrition. To develop practical solutions, further research is required to clearly understand the development and maintenance of injurious pecking. Group genetic selection using social effects might offer a promising alternative to the current mitigation methods without excessive costs or compromises to production or welfare. The multifactorial nature of injurious pecking suggests genetic improvements will be limited without environmental and nutritional adjustments to support the behavioural needs of domestic turkeys.
Chapter Three. Thesis Objectives and Hypotheses

The overall aim of this thesis was to examine the relationships between the performance of injurious pecking and other behavioural and physical traits in domestic turkeys. The objective of the first study (Chapter Four) was to determine whether body weight variation within groups, leg health, and sexual ornamentation was predictive of injurious pecking damage in male turkeys. Wild sexually mature male turkeys rely on variation in physical characteristics, such as body weight and snood length, to evaluate the potential for injury in male-to-male combat using head pecking. However, variations in body weight and snood length within flocks have not been examined as contributing factors to outbreaks of head pecking in domestic male turkeys. Therefore, I hypothesized that groups of sexually mature domestic turkeys composed of more uniformly sized males would perform more head pecking than groups with clearer distinctions in body weight and snood length.

In this study, I also hypothesized that turkeys with poorer leg health would have more skin and plumage damage from severe feather pecking and cannibalism than turkeys with good leg health and normal gaits. Like injurious pecking, lameness is a leading cause of poor welfare in commercial turkey flocks with severely lame turkeys becoming the targets of severe feather pecking and cannibalism from flock mates. However, no studies prior to this research had tracked the development of lameness and injurious pecking damage in domestic turkeys over time.
The existing literature suggests that flock disturbances increase turkey activity levels and lead to outbreaks of injurious pecking. To measure the activity of individual turkeys within flocks, the objective of the second study (Chapter Five) was to validate the use of HOBO Pendant® data loggers for automated step detection for two ages of male turkeys. I hypothesized that the HOBO loggers could detect the stepping activity of these turkeys with high sensitivity and little error.

Since the majority of information regarding the development and causation of injurious pecking in turkeys has been adopted from laying hen research, I wanted to explore whether organizational differences exist between behavioural sequences of injurious pecking and non-damaging gentle feather pecking. The aim of the third study (Chapter Six) was to identify differences in the behavioural distribution and organization of head pecking, severe feather pecking, and gentle feather pecking in male turkeys using two analytical methods: detection of temporal patterns (T-patterns) and conventional qualitative assessment of behavioural frequencies and durations. I hypothesized that sequences of severe feather pecking and head pecking would occur in more structured, yet less frequent and variable behavioural patterns than sequences of gentle feather pecking.

The final study in this thesis was designed as an initial step in determining whether genetic approaches could be used to produce beak shape morphologies in turkeys that would reduce the need for beak treatment. The objective of this study (Chapter Seven) was to evaluate the phenotypic variation in beak shape using landmark-based geometric
morphometrics and to determine if age, sex, or beak size had an effect on the beak shape variation in domestic turkeys. I hypothesized that turkey beak shape would show both a large phenotypic and genetic variation. A large genetic variation in beak shape would suggest that a possibility exists to breed for beak shape phenotypes with a reduced ability to cause pecking damage.
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Chapter Four. Changes in Leg Health, Skin, and Plumage Condition in Domestic Male Turkeys of Varying Body Weights

Abstract

Injurious pecking in turkeys is a serious welfare and economic concern in commercial production. Yet, very little is known about the development of this behaviour, and whether it relates to physical characteristics of the turkey. The objective of this study was to investigate the relationships among group variation in body weight, snood length, leg health, and skin and plumage damage over time in adult male turkeys. At 11 weeks of age, 50 male turkeys were allocated to one of three treatments based on body weight: HEAVY (8.22 ± 0.11 kg), AVERAGE (7.54 ± 0.11 kg), or LIGHT (7.14 ± 0.11 kg; mean ± standard error of the mean (SEM)). Turkeys were housed in groups of 8-10 with two replicates per treatment. They were weighed and scored weekly for plumage and skin condition (separate scores for head, neck, back, wings, and tail) and leg health (gait, footpad health and cleanliness, and number and severity of deviated toes). The data were divided into three time periods: 11-13, 14-17, and 18-21 weeks of age, and analyzed with a mixed model procedure and principal components analysis in SAS. With time, gaits worsened (Live Gait: $F_{2,65} = 14.72, P < 0.0001$, Video Gait: $F_{1,43} = 3.15, P = 0.083$) and turkeys had more deviated toes ($F_{2,71} = 177.10, P < 0.0001$) and a greater severity of toe deviations ($F_{2,112} = 75.15, P < 0.0001$) across all weight treatments. All turkeys showed worse footpad cleanliness over time ($F_{2,162} = 12.01, P < 0.001$), which might have contributed to the increase in footpad health problems ($F_{2,69} = 15.58, P < 0.0001$).
Pecking injuries to the head ($F_{1,66} = 17.71, P < 0.0001$) and neck ($F_{1,46} = 4.40, P = 0.042$) became more prevalent after the first period, whereas pecking injuries to the back ($t_{48} = -4.37, P < 0.0001$) increased in the final period. Damage to the tails of these turkeys also increased significantly in the final period ($t_{51} = -6.80, P < 0.0001$). Snood length did not vary between treatments and showed no association to the head and neck condition of these turkeys. As turkeys matured, signs of injurious pecking increased while leg health deteriorated. However, group variation in early body weights was not predictive of these turkeys’ leg health, snood length, or skin and plumage damage later in life.

**Introduction**

A significant proportion of mortalities and culls in growing turkeys show signs of injurious pecking suggesting that this behaviour contributes to economic loss and diminished welfare in commercial production (Sherwin et al., 1999; Chapter 2). Injurious pecking in turkeys can be classified into three distinct types: head pecking, severe feather pecking, and cannibalism, based on differences in the development, causation, and targeted areas (Savory, 1995; Chapter 2). Head pecking is considered an act of aggression and is typically directed at the head, snood, and/or neck of a targeted turkey (Savory, 1995; Buchwalder and Huber-Eicher, 2003). In contrast, severe feather pecking and cannibalism are thought to represent re-directed foraging due to a lack of suitable environmental complexity (Martrenchar, 1999; Sherwin et al., 1999). In order to decrease the prevalence and damage from injurious pecking, there needs to be a better understanding of the relationships between this behaviour and other behavioural and
physical traits in turkeys. Little empirical data exist on the causes of injurious pecking in turkeys due to the difficulty of studying this behaviour in the very large groups typical of commercial housing (Duggan et al., 2014).

Similar to injurious pecking, lameness is a leading cause of decreased productivity and welfare in commercial turkey flocks (Dibner et al., 2007; Ferket et al., 2009). Lameness is multifactorial in nature and there are a large number of environmental, genetic, and health problems that can cause a turkey to display impaired movement (Dibner et al., 2007). A number of musculoskeletal disorders can result in lameness in turkeys, including: crooked/deviated toes (Buffington et al., 1975), inflamed or infected leg joints (Riddell, 1980; Julian, 1985), fractures or deformations of leg bone and cartilage (Riddell, 1980; Crespo et al., 1999), tissue lesions (Julian, 1984), and contact dermatitis of the hocks or footpads (Krautwald-Junghanns et al., 2011b). In addition to impaired mobility, severely lame turkeys can experience chronic pain and become the targets of injurious pecking, specifically severe feather pecking and cannibalism, by flock mates (Duncan et al., 1991; Dibner et al., 2007; Ferket et al., 2009; Hocking and Wu, 2013). Post-mortem evaluations by Allain et al. (2013) found that injurious pecking injuries were positively correlated with the presence of deviated toes and swelling of the leg joints and footpads in turkeys on the slaughter-line. To date, several studies have examined factors influencing the appearance of lameness or pecking injuries independently (e.g., Riddel et al., 1980; Hughes and Grigor, 1996; Sherwin et al., 1999; Krautwald-Junghanns et al., 2011b). However, no research has simultaneously tracked
the development of severe pecking damage and leg health problems through a turkey’s lifetime.

Group variation in male body weight and sexual ornamentation might also contribute to rates of injurious pecking – specifically head pecking. In the wild, female turkeys will select males to breed based on physical indicators of fighting ability and physical condition, such as the quality of sexual ornamentation and body size (Watts and Stockes, 1971; Buchholz, 1997). Buchholz (1997) showed that sexually mature wild male turkeys rely primarily on variation in snood length amongst competing males to avoid aggressive encounters when the potential for injury outweighs the fitness benefits. The size of secondary sexual ornamentation, such as snood and spur length, appear to be positively correlated with body weight in sexually mature wild males, which is also thought to indicate a higher breeding status and resource holding capacity (Buchholz, 1997; Badyaev et al., 1998). Therefore, groups of sexually mature male turkeys with greater variation in body weight and snood length are expected to engage in fewer aggressive interactions, such as head pecking, to establish the dominance hierarchy than groups of similarly proportioned males. Flock uniformity in body weight is frequently recorded in commercial turkeys to assess feed efficiency and overall health. However, the relationship between body weight uniformity and aggressive pecking in domestic turkeys is unknown and therefore, merits research.

The aim of our study was to determine whether body weight variation within groups, sexual ornamentation, and leg health was predictive of injurious pecking damage in
domestic male turkeys. We hypothesized that groups composed of more uniformly sized, sexually mature male turkeys would show higher levels of aggression and engage in more head pecking than groups with more clear distinctions in body weight. We also hypothesized that turkeys with poorer gaits would have more skin and plumage damage from severe feather pecking and cannibalism than turkeys with normal gaits and good leg condition.

Materials and Methods

The University of Guelph’s Animal Care Committee approved all procedures used in this study (Animal Utilization Protocol #1850) in accordance with guidelines outlined by the University of Guelph Animal Care Policy and the Canadian Council for Animal Care (CCAC, 2009).

Animals and housing

Sixty commercial male turkeys were beak treated via infrared laser at one day of age in the hatchery and vaccinated with B1B1 Newcastle disease vaccine at five and nine weeks of age. At one week of age, the turkeys were individually marked with numbered, silver tab-end wing tags (Ketchum Mfg. Co. Inc., Lake Luzerne, NY, USA). The turkeys were housed in pens within a single room in a power-ventilated, closed-sided barn for the duration of the study. Initially, the turkeys were housed in two pens of 30 turkeys (1.83 x 2.36 m, length x width). At 11 weeks of age, the turkeys were allocated to six
identical pens (1.83 x 2.36 m) by weight (see study treatments) with 8-10 turkeys per pen. Each pen was bedded with kiln-dried pine shavings 10 cm deep. The bedding was changed bi-weekly throughout the study and shavings were added as necessary. Chlorinated water was provided ad libitum via a seven-nipple drinker line. Feed was available ad libitum to the turkeys from a 10 kg hanging tube feeder in each pen. From day one to 20, the turkeys were fed a standard pre-starter diet (metabolizable energy, ME: 2847.58 kcal/kg; crude fiber, CF: 2.94%; crude protein, CP: 28.11%). From day 21 to 42, the turkeys were fed a standard grower diet (ME: 3023.38 kcal/kg, CF: 2.90%, CP: 24.17%), then a finisher diet (ME: 4494.26 kcal/kg, CF: 1.98%, CP: 18.66%) from day 43 onwards. The turkeys were housed under 20 lux incandescent light under a schedule of 23Light(L):1Dark(D) for the first two days, 20L:4D from three to five days, 18L:6D from six to nine days, and then 16L:8D from 10 days of age onwards. During the study, the mean ambient temperature was 21.4°C (range: 16.7-30.8°C). Ten turkeys were found dead or were culled (due to yolk sac infection in two poults) prior to the start of the trial at 11 weeks of age. Between 11-21 weeks of ages, five turkeys were found dead or were culled due to the placement of wrongly sexed females (two turkeys) or humeral fractures (three turkeys). None of the mortalities in this study were due to injurious pecking.

Study treatments

At 11 weeks of age, the turkeys were weighed using a digital strain gauge scale with a readability of ± 5g (Mettler-Toledo Inc., Mississauga, ON, Canada) and based on their
body weight, they were allocated to one of two weight categories: LIGHT (≤7.643 kg) or HEAVY (>7.643 kg). The turkeys were then sorted into one of three pen treatments based on body weight:

(i) LIGHT,
(ii) HEAVY, and
(iii) AVERAGE (composed of ½ LIGHT and ½ HEAVY turkeys)

with two pen replicates for each treatment and 8-10 turkeys per pen. The pen treatments were randomly distributed within the room.

Turkey body scoring

The following measures were collected on each turkey weekly over a two-hour period from 11-21 weeks of age: body weight, Live Gait score, footpad health and cleanliness, number and severity of toe deviations, and the condition of the plumage and skin. Two observers each scored half of the weekly measures during the study with the exception of footpad health and cleanliness, which was scored by a single trained observer. Both observers were blind to the weight treatment of the pens. Inter- and intra-observer reliabilities were tested at 11, 16, and 20 weeks of age by independently scoring 10 live turkeys or by re-scoring photos of 10 turkeys. Mean weighted kappa coefficients showed moderate to very good agreement between observers with an agreement of 0.55 for Live Gait, 0.91 and 0.77 for the number and severity of deviated toes, and 0.73, 0.83, 0.78, 0.70, and 0.71 for the scores of head, neck, back, wings, and tail condition respectively (Altman, 1991). The intra-observer reliabilities for the two observers also showed

1 7.643kg was the mean body weight among the fifty 11-week old male turkeys.
moderate to very good agreement from pairwise comparisons between the three ages for the weekly scores (Altman, 1991). For the first observer, the mean weighted kappa coefficients were 0.71 for Live Gait, 1 and 0.89 for the number and severity of deviated toes, and 0.87, 0.83, 0.45, 0.74, and 0.50 for the head, neck, back, wings, and tail condition scores. The mean weighted kappa coefficients for the second observer were 0.56 for Live Gait, 0.70 and 1 for the number and severity of deviated toes, and for the plumage and skin condition scores: 0.73 (head), 0.86 (neck), 0.61 (back), 0.69 (wings), and 0.58 (tail).

**Turkey weight and gait scoring**

After the turkeys were weighed using the scale described above, their walking ability was assessed in two ways: live (‘Live Gait’) and via video for later scoring by an expert technician (‘Video Gait’). Gait was scored for each turkey on a minimum of six steps taken in their home pen. Live Gait was scored using the 6-point system (0-5) developed by Kestin et al. (1992), which has been previously used to evaluate walking ability in turkeys (Martrenchar et al., 1999). A score of zero denoted a turkey that walked normally with no detectable abnormality, was in full command of where it was headed, and was able to deviate quickly to avoid colliding with other turkeys. A score of five denoted a turkey that was incapable of standing on its feet and was only able to move around by crawling on its shanks or using its wings for assistance (Kestin et al., 1992).
For Video Gait, the turkeys were filmed at 12, 16, and 20 weeks of age using a Sony® HDR-XR150 120GB AVCHD Handycam Camcorder 4.1MP (Sony Electronics, San Diego, CA, USA) while being simultaneously scored for Live Gait. Video Gait was scored for each turkey by an expert technician from the video footage using the gait scoring system from Quinton et al. (2011) (J. McCurdy, Kitchener, ON, Canada, personal communication). Using this 6-point system (1-6) designed for breeder turkeys, walking ability in the males was scored from one (fluid motion with no structural leg defects, very good to excellent pitch and balance, no weakness in hock or hip strength, and low outward leg angulation) to six (poor motion, poor to good pitch and balance, weak to very weak hock or hip strength, severe leg angulation, and a slight to severely bowed or twisted leg structure).

*Footpad health and cleanliness*

Footpad health and cleanliness were assessed by lifting a turkey’s foot off the ground one at a time, while an assisting technician temporarily restrained the turkey. Both the footpad health and cleanliness scores for a turkey reflected the most severe condition apparent on either foot. Footpad health was scored using a 10-point scale (0-9) for assessing footpad dermatitis in turkeys through visual observation (Allain et al., 2013). This scoring system accounted for the severity of footpad inflammation and lesion(s) along with the affected surface area (<25%, 25-50%, or >50%). A score of zero denoted a turkey with no visible footpad lesions whereas a maximum score of nine denoted a turkey in which >50% of the footpad showed a depressed lesion and ulceration with or
without a thick, dark, adherent scab (Allain et al., 2013). Footpad cleanliness was scored using a 4-point scale (0-3) based on the appearance of each of the turkey’s feet (footpads, toes, and nails; Table 4.1).

**Number and severity of deviated toes**

The number and severity of deviated toes were scored by examining the dorsal surface of a turkey’s feet. The severity of toe deviations of the three forward-facing digits (II-IV) was scored using a 3-point scale (0-2; Figure 4.1). A score of zero was given if there were no deviations from the normal, straight extension at the tarsometatarsus joint and/or along the digit’s phalanges on either foot. A score of one denoted a slight toe deviation with one or more digits curved less than 45º. The highest score of two implied a severe toe deviation was present meaning one or more digits was curved 45º or more from the expected straight extension at the tarsometatarsus joint and/or along the digit’s phalanges (Figure 4.1). If a turkey had more than one affected toe, the score reflected the severity of the most deviated toe on either foot. The number of deviated toes was scored on a 7-point scale (score of zero = no deviated toes, score of six = digits II-IV deviated on both feet).

**Plumage and skin condition**

Plumage and skin condition were scored for five separate regions: the head, neck, wings, back, and tail. The head region was designated as the skull, including the snood, and
ending at the base of the skull at the first cervical vertebrae. The neck region was classified as the area between the first cervical vertebrae and the furcula. The wings region was classified as the area from the shoulder joints to the terminal phalanges. The back region was classified as the area on the dorsal side of the turkey along the backbone beginning at the furcula, extending between the shoulder joints, and ending at the base of the tail. The tail region included the feathers and tissues of the tail and cloacal region.

The 4-point score (0-3) for head condition was adapted from Tauson et al. (2005), a scheme that has been previously applied to evaluate turkeys (Duggan et al., 2014; Table 4.2). The neck, wings, back, and tail regions were each scored using a 6-point scoring scheme (0-5) by Morrissey et al. (2014). A score of zero meant that region of the turkey’s body was completely covered in plumage. A score of five implied that >50% of the feathers were missing from that region and there was blood and/or tissue damage.

*Measuring snood length*

During the final scoring session at 21 weeks of age, the retracted snood length of each turkey was measured using a digital caliper with a 0.01 mm resolution (World Precision Instruments, Sarasota, USA; Buchholz, 1997). Turkeys typically retracted their snoods during handling so this state of the snood was chosen for ease of measurement. This snood measure was deemed appropriate for our analysis given that retracted snood length in male turkeys has been shown to be highly correlated to stretched snood length,
which is the distended condition of the snood during aggressive displays (Buchholz, 1997).

**Statistical Analysis**

To facilitate analyses, the study was divided into three time periods: 11-13, 14-17, and 18-21 weeks of age. Results are reported as raw means and standard errors of the mean (SEM) with the exception of weight treatment × period estimates, which are presented as least square (LS) means ± SEM. Data for each of the 16 untransformed turkey body scores were analyzed using a generalized linear mixed model procedure (Proc Glimmix) in SAS (SAS 9.2, 2007) using pen as the experimental unit. Fixed effects included period, weight treatment, and interactions between weight treatment × period. Pen within weight treatment was the first random effect. The second random effect accounted for repeated measurements on the turkeys within each pen and weight treatment over the three periods. Each measure was fitted to the model using a Cholesky parameterization of the unstructured covariance matrices for that measure. Orthogonal contrasts were used to compare results between periods and weight treatments × period through t-tests for differences of LS means. Satterthwaite approximations were used to determine the denominator degrees of freedom for these models. Significant effects were detected at $P < 0.05$ and the tendency of an effect was interpreted when the $P$-value was $< 0.10$. 


Correlation coefficients were determined between the two gait scoring schemes and among snood length and the condition scores for the head and neck using Spearman rank-order correlation procedures (Proc Corr) using the data of all 50 turkeys without reference to weight treatment. To test the correlation between the two gait scoring schemes, Video and Live Gait scores were transformed into one of three categories of gait deformities: ‘normal’ (score of one), ‘mild’ (score of two) or ‘severe’ (score of three). Turkeys scored from zero to 0.5 for Live Gait or between one and 2.5 for Video Gait were classified as having a ‘normal’ gait and given a score of one. Live Gait scores from one to 2.5 and Video Gait scores from three to 4.5 were categorized as ‘mild’ gait abnormalities and scored as two. Finally, ‘severe’ gait impairments (score of three) were Live Gait scores from three to five and Video Gait scores between five and six.

A principal components (PC) analysis (Proc Princomp without rotation) was used to determine the structure of the data set and associations among the 14 untransformed weekly measures of turkey body scores (excluding Video Gait scores and retracted snood length, due to unequal number of observations for these variables compared to the weekly measures). Only eigenvector factor loadings of the weekly measures \( \geq 0.40 \) were considered significant for interpretation in the results.

**Results**

**Effect of body weight treatment on turkey body scores**
Body weight treatment tended to influence the body weight of these male turkeys during the trial with pens of HEAVY male turkeys tending to have higher body weights on average than pens of AVERAGE or LIGHT males. Pens of AVERAGE male turkeys also tended to have a higher mean body weight than pens of LIGHT males during the trial ($F_{2,3} = 6.37, P = 0.085$; Figure 4.2). However, body weight treatments alone did not have an effect on changes in gait score (Live Gait: $F_{2,3} = 0.19, P = 0.84$, Video Gait: $F_{2,44} = 0.96, P = 0.39$), footpad health ($F_{2,3} = 0.53, P = 0.63$) or cleanliness ($F_{2,3} = 0.26, P = 0.79$), the number ($F_{2,3} = 0.23, P = 0.81$) or severity ($F_{2,48} = 1.05, P = 0.36$) of deviated toes, or the plumage and skin condition scores for the head ($F_{2,46} = 0.61, P = 0.55$), neck ($F_{2,49} = 0.23, P = 0.79$), back ($F_{2,51} = 0.68, P = 0.51$), wings ($F_{2,59} = 0.02, P = 0.98$), or tail ($F_{2,57} = 1.11, P = 0.34$) regions over time.

**Relationship between time period and turkey body scores**

**Body weight**

The three treatment groups based on initial weight variation had the following mean values for body weights at the start of the trial: HEAVY (8.22 ± 0.11 kg), AVERAGE (7.54 ± 0.11 kg), and LIGHT (7.14 ± 0.11 kg). The weights of all the turkeys increased during the trial ($F_{2,221} = 1541.53, P < 0.0001$; Figure 4.2) with the most significant increase after period one ($F_{1,173} = 2343.17, P < 0.0001$).

**Gait**
Live Gait and Video Gait scores were not correlated ($\rho = 0.074$, $P = 0.39$) so were treated separately, and the untransformed values were used for further analysis. Across all weight treatments, the mean Live Gait and Video Gait scores were $0.39 \pm 0.02$ (range: 1-4) and $2.77 \pm 0.07$ (range: 0-3) respectively during the trial. Across all weight treatments, the Live Gait scores for all turkeys increased over time ($F_{2,65} = 14.72$, $P < 0.0001$), yet showed the most significant increase after period one ($F_{1,70} = 28.92$, $P < 0.0001$; Figure 4.3a). Throughout the trial, the Video Gait scores for all weight treatments did not significantly differ ($F_{2,43} = 2.00$, $P = 0.15$). However, the Video Gait scores tended to be lower for all turkeys in period one than scores from the later two periods ($F_{1,43} = 3.15$, $P = 0.083$). Video Gait scores remained relatively constant for all weight treatments between periods two and three (Figure 4.3b).

*Footpad health and cleanliness*

The mean footpad health and cleanliness scores for all turkeys were $3.07 \pm 0.07$ (range: 0-9) and $1.52 \pm 0.03$ (range: 0-3) during the trial. For all turkeys, footpad health ($F_{2,69} = 15.58$, $P < 0.0001$) and cleanliness ($F_{2,162} = 12.01$, $P < 0.001$) scores increased over time (Figure 4.4). Across all weight treatments, footpad health scores showed a tendency to increase between periods one and two ($t_{137} = -1.81$, $P = 0.073$), and a significant increase between periods two and three ($t_{63} = -4.28$, $P < 0.0001$; Figure 4.4a). Footpad cleanliness scores increased significantly after period one ($t_{347} = -3.08$, $P = 0.0022$), and
showed a tendency to increase between periods two and three ($t_{94} = -1.88$, $P = 0.064$; Figure 4.4b).

*Number and severity of deviated toes*

The mean number and severity of deviated toes for all turkeys were 2.49 ± 0.07 (range: 0-6) and 0.92 ± 0.02 (range: 0-2) throughout the trial. Across all weight treatments, the number ($F_{2,71} = 177.10$, $P < 0.0001$) and severity ($F_{2,112} = 75.15$, $P < 0.0001$) of deviated toes increased over time (Table 4.3). The number of deviated toes increased each period (period one vs. two: $t_{46} = -11.15$, $P < 0.0001$, period two vs. three: $t_{94} = -7.60$, $P < 0.0001$; Table 4.3). The severity of toe deviations increased after period one ($t_{86} = -11.49$, $P < 0.0001$), but remained relatively constant between periods two and three (Table 4.3).

*Plumage and skin condition*

*Head and neck condition*

The mean head and neck condition scores across all turkeys were 0.57 ± 0.03 (range: 0-3) and 0.95 ± 0.05 (range: 0-5) during the trial. Across all weight treatments, both the head ($F_{2,81} = 9.87$, $P = 0.0001$) and neck condition ($F_{2,44} = 4.44$, $P = 0.018$) scores increased over the course of the trial (Figure 4.5). The head condition scores for all weight treatments increased after period one ($F_{1,66} = 17.71$, $P < 0.0001$; Figure 4.5a). However, LIGHT males had the highest mean head condition score in period two
(LIGHT × period one: \( t_{56} = 4.85, P < 0.0001 \); LIGHT × period two: \( t_{80} = 9.84, P < 0.0001 \); LIGHT × period three: \( t_{45} = 6.42, P < 0.0001 \)) whereas HEAVY and AVERAGE males showed relatively consistent or slightly higher mean head condition scores throughout the trial (HEAVY × period one: \( t_{56} = 4.89, P < 0.0001 \), HEAVY × period two: \( t_{81} = 9.55, P < 0.0001 \), HEAVY × period three: \( t_{46} = 8.44, P < 0.0001 \); AVERAGE × period one: \( t_{59} = 4.17, P = 0.0001 \), AVERAGE × period two: \( t_{77} = 7.27, P < 0.0001 \), AVERAGE × period three: \( t_{45} = 7.87, P < 0.0001 \); Figure 4.5a). Across all weight treatments, mean neck condition scores were higher after period one (\( F_{1,46} = 4.40, P = 0.042 \); Figure 4.5b). However, pens of LIGHT turkeys had the highest mean neck condition scores in period two (LIGHT × period one: \( t_{47} = 3.53, P = 0.0009 \); LIGHT × period two: \( t_{49} = 5.88, P < 0.0001 \); LIGHT × period three: \( t_{46} = 4.22, P < 0.0001 \)), whereas HEAVY and AVERAGE pens showed relatively consistent or slightly higher mean neck condition scores throughout the trial (HEAVY × period one: \( t_{48} = 3.95, P = 0.0003 \); HEAVY × period two: \( t_{47} = 5.40, P < 0.0001 \), HEAVY × period three: \( t_{47} = 4.99, P < 0.0001 \); AVERAGE × period one: \( t_{50} = 3.55, P = 0.0009 \); AVERAGE × period two: \( t_{48} = 4.25, P < 0.0001 \), AVERAGE × period three: \( t_{45} = 4.01, P = 0.0002 \); Figure 4.5b).

**Back, wings, and tail plumage**

The mean scores for the back plumage and skin condition were 0.23 ± 0.03 (mean ± SEM; range: 0-3), 1.02 ± 0.01 for wing quality (range: 0-4), and 1.21 ± 0.03 for tail condition (range: 0-3) during the trial. Across all weight treatments, the scores for back
(F_{2,82} = 9.99, P = 0.0001) and tail condition (F_{2,85} = 32.35, P < 0.0001) increased over time (Figure 4.6). Back condition scores remained constant from period one to two, but increased in period three (t_{48} = -4.37, P < 0.0001; Figure 4.6a). Tail condition scores were relatively constant for all turkeys between period one and two, but increased significantly in the last period (t_{51} = -6.80, P < 0.0001; Figure 4.6b). The condition of the wings did not differ significantly during the trial (F_{2,90} = 0.24, P = 0.79).

Snood length

At 21 weeks of age, retracted snood lengths ranged from 102.30 to 185.40 mm. The mean retracted snood length was 139.49 ± 4.54 mm for turkeys from HEAVY pens, 143.13 ± 4.38 mm for turkeys from AVERAGE pens, and 134.53 ± 4.51 mm for turkeys from LIGHT pens. However, there was no difference in retracted snood length between weight treatments (F_{2,3} = 0.63, P = 0.59). Snood length was also not correlated with the head (ρ = -0.11, P = 0.47) or neck condition (ρ = -0.18, P = 0.25) of these turkeys.

Relationship among turkey body scores

The principal components analysis using weekly weights, Live Gait, footpad health and cleanliness, the number and severity of deviated toes, and the condition of the head, neck, back, wings, and tail regions as variables, extracted five principal components (PCs), which cumulatively explained 68.82% of the total variance (Table 4.4). PC1 loaded positively with increasing weight and a higher number and severity of deviated
toes. PC2 showed that lower Live Gait scores were associated with a lower severity of toe deviations, and higher footpad cleanliness scores. PC3 loaded lower footpad health scores with higher back and tail condition scores. The fourth factor showed a positive association between head and neck condition. Finally, PC5 loaded to show that lower head condition scores were associated with higher wing condition scores (Table 4.4).

Discussion

As these turkeys matured, injurious pecking damage to the skin and plumage increased while leg health deteriorated across all weight treatments. Contrary to our prediction, a poorer gait score was not directly associated with skin and plumage damage from being a recipient of injurious pecking. Group variation in the initial body weights of these turkeys was also not predictive of their leg health or injurious pecking damage. The similar variation in body weight across all weight treatments during the trial suggests the allocation of turkeys failed to create a higher variation in body weights in the AVERAGE pens. This prevented the formation of a stable hierarchy of body weights and therefore, did not increase aggressive pecking and fighting behaviour in AVERAGE pens. The initial body weight of a turkey showed a tendency to influence body weight later in life, but was not directly predictive of a turkey’s final body weight. Furthermore, the small sample sizes of the weight treatments and high mortality in this study further impeded any conclusions from the effect of group variation in body weights on leg health and injurious pecking damage.
The increase in leg health problems and pecking damage for these turkeys over time might largely reflect the general decline in litter conditions over the course of this study. Along with high outside temperatures, the relative humidity levels within the pens were quite high during this trial, although humidity was not measured directly. The high temperature and humidity in these pens would be comparable to the conditions in closed-sided commercial barns using a power ventilation system. The hot, humid conditions might have contributed to the significant decline in gait, footpad health and cleanliness, plumage and skin quality, and the increase in the number and severity of deviated toes over the course of the trial. During the trial, higher litter moisture was observed in the pens requiring new shavings to be added more frequently. The development of footpad dermatitis in commercial tom flocks has been primarily linked to high moisture litter conditions (Mayne et al., 2007; Youssef et al., 2011; Da Costa et al., 2014). Inadequate ventilation of humid air has been shown to elevate litter moisture and ammonia levels, which can increase the prevalence of footpad dermatitis in turkey flocks (Mayne, 2005; Mayne et al., 2007; Da Costa et al., 2014). Severe cases of footpad dermatitis can be painful and limit a turkey’s activity, causing a turkey to appear more hesitant to walk (Mayne et al., 2007; Da Costa et al., 2014). Da Costa et al. (2014) reported that both poor litter conditions and heavier body weights significantly contribute to declining footpad health and gait scores in growing male turkeys. Thus, the worsening litter conditions and increasing body weights might directly explain the continuing decline in footpad health and gait scores for these turkeys from 11-21 weeks of age (Hocking and Wu, 2013; Da Costa et al., 2014).
Research in laying hens further suggests that extreme temperatures might cause elevated stress in flocks and increase rates of severe feather pecking and cannibalism (Ensminger, 1992; Jendral and Robinson, 2004). Although this relationship has not been investigated in turkeys, the high temperatures during this trial could have contributed to a proportion of the pecking damage experienced by these turkeys (Chapter 2). Alternatively, the increase in leg health problems under poorer litter conditions might have contributed to the increase in severe pecking damage to the back and tail during the trial. Although, it is still uncertain if the increase in lameness and pecking injuries in turkeys over time represents a causal relationship or temporal association.

Across all weight treatments, leg problems became more prevalent for these male turkeys with increasing age and heavier body weights. The initial weight treatments had no impact on overall leg health, but the first principal component indicated the turkeys of heavier body weights in this trial tended to have a greater number and severity of deviated toes than lighter turkeys. A survey of commercial broiler chicken farms by Santora et al. (2001) found that heavier body weights were associated with the appearance of deviated toes. In contrast, an assessment of leg abnormalities in a flock of Wrolstad White turkeys indicated that turkeys of all body weights were equally prone to exhibit leg disorders, such as deviated toes (Buffington et al., 1975). However, the Wrolstad White breed has not experienced the same high selection pressure for a large body size as modern, commercial lines of broilers and turkeys. Both male turkeys and male broiler chickens appear to be more prone to developing deviated toes than their female counterparts (Buffington et al., 1975; Santora et al., 2001). The incidence of
deviated toes in commercial broilers has been shown to increase in response to early stressors, such as inappropriate incubation temperatures, elevated temperatures, and reduced ventilation during transport from the hatchery (Oviedo-Rondón et al., 2009a,b). The positive association between body weight and toe deviations could be attributed to the combination of poor litter conditions and the growing incidence of leg conformation problems in modern turkeys that have been selected for higher body mass without proportional increases in musculoskeletal integrity (Abourachid, 1991; Buchwalder and Huber-Eicher, 2005b). The second principal component also indicated that turkeys with a lower severity of toe deviations tended to have better Live Gait scores in this trial, which suggests that severely deviated toes can hinder a turkey’s normal movement. However, research has largely ignored deviated toes as a form of lameness in turkeys. Given that deviated toes typically affect an average of 20% of turkeys in commercial flocks (Allain et al., 2013), more focus should be placed on this leg disorder as a cause of reduced welfare in modern turkeys.

All the turkeys showed worse gait scores over time, but the two scoring schemes used in this study showed very little correlation. However, these two gait scoring schemes differed considerably in application and ease of use. The Live Gait scheme developed by Kestin et al. (1992) provides detailed descriptions to allow the user to distinguish between the different scoring levels and can be applied with minimal training. A Live Gait score of zero is given to a turkey that walks normally with no defect, whereas a turkey that scores a three or higher spends the majority of its time sitting due to a severe gait abnormality (Kestin et al., 1992). In contrast, the Video Gait scheme from Quinton...
et al. (2011) was designed to select the highest performing turkeys for breeding from pedigree flocks and evaluates specific features of a turkey’s gait, including leg angulation, motion, and pitch, which requires extensive training for proper gait assessment. Video Gait scores of one to three describe a turkey still capable of fair/good to fluid motion while walking, but a score of four means that a turkey displays some hock weakness and has a twisted or bowed leg structure. Only a Video Gait score of five to six reflects a turkey with a severe gait defect that will walk only when coerced. Although these gait scoring schemes focus on different aspects of a turkey’s walking ability, the lack of correlation between the two schemes suggests that a hybrid of these scoring systems, that is both easy to use and identifies key elements of healthy leg structure, would be the most appropriate choice for on-farm gait assessment.

Group variation in initial body weights had no effect on aggressive pecking behaviour with all treatments showing similar amounts of pecking damage to the head and neck from 11 to 21 weeks of age. However, the unsuccessful allocation of turkeys to weight treatments and the use of only two replicates of each body weight treatment might have hindered our chances of finding a statistical difference between treatments. We did observe several head pecking events following mixing of the 11 week old turkeys into new pens. However, aggressive interactions are common after mixing unfamiliar turkeys and typically diminish once the dominance hierarchy is re-established (Buchwalder and Huber-Eicher, 2003, 2004, 2005a). Although head and neck condition declined across all weight treatments, injuries from aggressive pecking remained mild to moderate for the majority of turkeys during the study. These findings are in contrast to management
guidelines for laying hens, which suggest that uneven flocks with a wide variation in body size are more prone to outbreaks of destructive pecking than groups with uniform body weights (Defra, 2005). The low stocking densities in our study (0.54-0.43 m²/turkey) likely contributed to the low levels of head pecking damage as more floor space allowed the turkeys to avoid aggressive interactions with pen mates (Buchwalder and Huber-Eicher, 2004). From 17 to 18 weeks of age, head pecking was observed in one of the LIGHT pens, which is reflected in the large increase in head and neck damage to LIGHT turkeys during the second period. This large increase in head and neck pecking injuries was not seen in any other pens or treatments during this period.

Variation in snood length amongst domestic male turkeys was not correlated with the head and neck injuries obtained from aggressive interactions. It is still unknown if, similar to their wild counterparts, domestic turkeys use retracted snood length and body weight as physical indicators of another turkey’s dominance status (Buchholz, 1997). Although Badyaev (1998) previously showed that spur length strongly influences a wild turkey’s willingness to fight, this variable was not included in the analysis as commercial turkeys have been bred for reduced spurs.

Future research should focus on re-examining the relationship between lameness and injurious pecking damage to determine if a temporal or causal relationship exists between these two traits. The principal component analysis in this study suggests associations exist between measures of leg health and injurious pecking damage in growing turkeys. For instance, the third principal component showed that better footpad
health was associated with poorer back and tail condition scores. Yet, we are still uncertain of the underlying factors to explain the relationships among these indicators of leg health and injurious pecking damage. The proportion of a flock experiencing lameness and injurious pecking damage increases as turkeys mature (Ferket et al., 2009; Allain et al., 2013). However, it is uncertain if only a correlation exists between increasing pecking damage and decreasing leg health, or if one condition predisposes the other. A clearer understanding of the relationships between leg health and injurious pecking damage could aid future management strategies and improve welfare by facilitating the early detection and removal of lame or pecked turkeys.

As these male turkeys matured, they developed more pecking damage and poorer leg health. However, pen treatments with varying body weights had no effect on the leg health and pecking damage to the skin and plumage of these turkeys. Furthermore, the lower inter and intra-reliability scores for some of the weekly measures suggest that the results of this study should be interpreted somewhat cautiously. The decline in leg health for these turkeys occurred concurrently with an increase in pecking damage. Yet, the link between forms of injurious pecking damage and lameness in domestic turkeys still needs further research to clarify if these relationships are causal or temporal in nature.
Figure 4.1. Three images demonstrating the scale for scoring the severity of toe deviations for digits II-IV in turkeys. (a) Score of 0: no deviated digits. (b) Score of 1: slight toe deviation on the IV digits of both feet (toe curves less than 45° from the normal, straight extension from the tarsometatarsus joint and/or along the digit’s phalanges). (c) Score of 2: severe toe deviation on digit III of the right foot (toe curves 45° or more from the normal, straight extension from the tarsometatarsus joint and/or along the digit’s phalanges).
Figure 4.2. The mean change in body weight for turkeys in each weight treatment from 11 to 21 weeks of age. HEAVY males tended to have higher body weights than LIGHT or AVERAGE males over the three age periods. Pens of AVERAGE male turkeys also tended to have a higher mean body weight than pens of LIGHT males during the trial ($F_{2,3} = 6.37, P = 0.085$).
Period 1: 11-13 weeks of age, Period 2: 14-17 weeks of age, Period 3: 18-21 weeks of age

**Figure 4.3.** (a) The mean Live Gait scores (± SEM) for turkeys in the three weight treatments over all three periods. The Live Gait scores for all turkeys increased during the trial ($F_{2,65} = 14.72, P < 0.0001$), but showed the most significant increase after period one ($F_{1,70} = 28.92, P < 0.0001$). (b) The mean Video Gait scores (± SEM) for turkeys in each weight treatment throughout the study. Video Gait scores tended to be lower for all turkeys in period one than scores from the later two periods ($F_{1,43} = 3.15, P = 0.083$), but remained relatively constant between periods 2 and 3. Higher score denotes worse gait.
Period 1: 11-13 weeks of age, Period 2: 14-17 weeks of age, Period 3: 18-21 weeks of age

Figure 4.4. (a) The mean footpad health scores (± SEM) for turkeys of each weight treatment over all three periods. Footpad health scores increased over time across all treatments ($F_{2,69} = 15.58$, $P < 0.0001$) with a significant increase in period 3 ($t_{63} = -4.28$, $P < 0.0001$). Higher score denotes poorer footpad condition. (b) The mean footpad cleanliness scores (± SEM) for turkeys of each weight treatments over all three periods. Footpad cleanliness scores increased over time across all treatments ($F_{2,162} = 12.01$, $P < 0.001$). In particular, footpad cleanliness scores were higher after period one ($t_{347} = -3.08$, $P = 0.0022$), and showed a tendency to increase between periods two and three ($t_{94} = -1.88$, $P = 0.064$). Higher score denotes poorer footpad cleanliness.
Period 1: 11-13 weeks of age, Period 2: 14-17 weeks of age, Period 3: 18-21 weeks of age

Figure 4.5. (a) The mean head condition scores (± SEM) for turkeys in each weight treatment over all three periods. The head condition scores for all turkeys were higher after the first period ($F_{1,66} = 17.71, P < 0.0001$). LIGHT birds had the highest head condition in period two whereas HEAVY and AVERAGE groups of birds tended to show relatively consistent or slightly higher head condition scores throughout the trial. (b) The mean neck condition score (± SEM) for turkeys in each weight treatment over all three periods. Neck condition scores were higher for all turkeys after the first period ($F_{1,46} = 4.40, P = 0.042$). The pens of LIGHT birds also had the highest neck condition scores in period two, while HEAVY and AVERAGE bird groups had relatively constant or slightly higher neck condition scores throughout the trial. A higher score denotes worse skin and plumage condition.
Period 1: 11-13 weeks of age, Period 2: 14-17 weeks of age, Period 3: 18-21 weeks of age

Figure 4.6. (a) The mean back condition scores (± SEM) for turkeys in each weight treatment throughout the trial. The back condition scores remained constant for all turkeys between periods one and two, but increased considerably in period three ($t_{48} = -4.37$, $P < 0.0001$). (b) The mean tail condition scores (± SEM) for turkeys in each weight treatment throughout the trial. The tail scores for each remained relatively constant between periods 1 and 2, but increased significantly in the last period ($t_{51} = -6.80$, $P < 0.0001$). Higher score denotes worse skin and plumage condition.
Table 4.1. Footpad cleanliness scoring scheme. Cleanliness scores for a turkey reflect the most severe condition apparent on either foot.

<table>
<thead>
<tr>
<th>Score</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>The footpads, toes, and nails are fully clean and free from all dirt and/or debris</td>
</tr>
<tr>
<td>1</td>
<td>The footpads, toes, and nails have some dirt and/or debris covering &lt;25% of the total foot surface</td>
</tr>
<tr>
<td>2</td>
<td>The footpads, toes, and nails have dirt and/or debris covering 25-50% of the total foot surface</td>
</tr>
<tr>
<td>3</td>
<td>The footpads, toes, and nails have extensive dirt and/or debris covering &gt;50% of the total foot surface</td>
</tr>
</tbody>
</table>
**Table 4.2.** Scoring scheme for head condition adapted from Tauson et al. (2005)

<table>
<thead>
<tr>
<th>Score</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Skin on head in excellent condition with no apparent bruising, blood, scratches, and/or cuts</td>
</tr>
<tr>
<td>1</td>
<td>Skin on head in good condition with &lt;25% of surface area showing bruising, blood, scratches, and/or cuts</td>
</tr>
<tr>
<td>2</td>
<td>Skin on head in poor condition with 25-75% of surface area showing bruising, blood, scratches, and/or cuts</td>
</tr>
<tr>
<td>3</td>
<td>Skin on head in very poor condition with &gt;75% of surface area showing extensive bruising, blood, scratches, and/or cuts</td>
</tr>
</tbody>
</table>
Table 4.3. The mean number and severity of toe deviations for turkeys in each weight treatment across all three periods (mean ± SEM). All turkeys developed more deviated toes ($F_{2,71} = 177.10$, $P < 0.0001$) throughout the trial. The number of toe deviations increased with each period for all turkeys (period one vs. two: $t_{46} = -11.15$, $P < 0.0001$, period two vs. three: $t_{94} = -7.60$, $P < 0.0001$). All turkeys developed more severely deviated toes throughout the trial ($F_{2,112} = 75.15$, $P < 0.0001$). In particular, the severity of toe deviations increased considerably after period one ($t_{86} = -11.49$, $P < 0.0001$), but remained relatively consistent between periods two and three. Different superscript letters represent significant differences ($P < 0.05$) among periods within weight treatments. Period 1: 11-13 weeks of age, Period 2: 14-17 weeks of age, Period 3: 18-21 weeks of age.

<table>
<thead>
<tr>
<th>Weight Treatment</th>
<th>Period</th>
<th>Number of Toe Deviations Mean ± SEM</th>
<th>Severity of Toe Deviations Mean ± SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heavy</td>
<td>1</td>
<td>1.24 ± 0.19</td>
<td>0.53 ± 0.10</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>2.59 ± 0.20</td>
<td>1.03 ± 0.06</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>3.53 ± 0.14</td>
<td>1.05 ± 0.04</td>
</tr>
<tr>
<td>Average</td>
<td>1</td>
<td>1.15 ± 0.20</td>
<td>0.65 ± 0.11</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>2.43 ± 0.23</td>
<td>1.10 ± 0.07</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>3.35 ± 0.15</td>
<td>1.16 ± 0.05</td>
</tr>
<tr>
<td>Light</td>
<td>1</td>
<td>1.12 ± 0.19</td>
<td>0.49 ± 0.10</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>2.46 ± 0.22</td>
<td>0.95 ± 0.06</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>3.32 ± 0.01</td>
<td>0.95 ± 0.04</td>
</tr>
</tbody>
</table>
Table 4.4. The factor loadings\textsuperscript{a} of the weekly turkey body measures on the first five factors extracted by the principal components analysis on all 50 male turkeys from 11 to 21 weeks of age.

<table>
<thead>
<tr>
<th>Category</th>
<th>Variable</th>
<th>Factor 1</th>
<th>Factor 2</th>
<th>Factor 3</th>
<th>Factor 4</th>
<th>Factor 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leg Health</td>
<td>Weight</td>
<td>0.48</td>
<td>0.06</td>
<td>-0.02</td>
<td>-0.10</td>
<td>-0.13</td>
</tr>
<tr>
<td></td>
<td>Live Gait</td>
<td>0.23</td>
<td>-0.49</td>
<td>-0.07</td>
<td>-0.20</td>
<td>0.10</td>
</tr>
<tr>
<td></td>
<td>Footpad Health</td>
<td>0.26</td>
<td>0.39</td>
<td>-0.44</td>
<td>0.05</td>
<td>0.23</td>
</tr>
<tr>
<td></td>
<td>Footpad Cleanliness</td>
<td>0.26</td>
<td>0.44</td>
<td>-0.37</td>
<td>0.02</td>
<td>0.21</td>
</tr>
<tr>
<td></td>
<td>Number of Deviated Toes</td>
<td>0.49</td>
<td>-0.23</td>
<td>-0.03</td>
<td>-0.04</td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td>Severity of Deviated Toes</td>
<td>0.41</td>
<td>-0.41</td>
<td>-0.01</td>
<td>0.09</td>
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</tr>
<tr>
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<td>-0.16</td>
<td>0.47</td>
<td>-0.56</td>
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<tr>
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<td>Neck</td>
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<td></td>
<td>Back</td>
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<td>0.35</td>
<td>0.55</td>
<td>-0.07</td>
<td>-0.24</td>
</tr>
<tr>
<td></td>
<td>Wings</td>
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<td>-0.09</td>
</tr>
<tr>
<td>Percentage of variance explained (%)\textsuperscript{b}</td>
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<td>12.27</td>
<td>11.40</td>
<td>9.84</td>
<td>9.26</td>
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</table>

\textsuperscript{a} Loadings greater than 0.40 are presented in bold

\textsuperscript{b} Cumulative variance explained by five factors: 68.82%
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Chapter Five. Validation of HOBO Pendant® Data Loggers for Automated Step Detection in Two Age Classes of Male Turkeys: Growers and Finishers

Abstract

Activity levels can be used as a predictor of health status, physical condition, feed efficiency, and coping style in animals. Small, portable data loggers have been validated as an inexpensive and effective alternative to video or live observation for automated activity detection in several livestock species. Our study aimed to validate the use of Onset HOBO Pendant® G acceleration data loggers for automated step detection in two age classes of male turkeys: growers and finishers. The loggers were attached to one leg in an elastic harness and programmed to record each turkey’s leg accelerations every 0.1 s. For the grower turkeys, the activities of 60 males were recorded in a runway twice per week from 9-11 weeks of age. In the finisher trial, the loggers were attached to eight 14-week old male turkeys to record their stepping activities in a trial pen over 54 min. Simultaneous video observation allowed for logger suitability to be determined for reporting walking activity. The 0.1 s data points were identified as either: true positives, false positives, false negatives, or true negatives. Then the logger sensitivity, false discovery rate, specificity, precision, and accuracy were calculated for each turkey observation period. Over the 309 grower turkey observations, 4364 steps were observed in the video while the loggers detected 4865 steps. The grower logger results showed a mean sensitivity of 96.02 ± 6.82%, specificity of 99.10 ± 0.86%, and a false discovery rate of 12.41 ± 10.13% for step detection (mean ± standard deviation). For these grower
turkey loggers, the mean precision and accuracy for step detection were 87.59 ± 10.13% and 98.95 ± 0.77%. For the eight finisher turkeys, a total of 2420 steps were seen by the video and the loggers recorded 2691 data points as steps. The finisher turkey logger data showed a mean sensitivity of 89.58 ± 11.75%, mean false discovery rate of 14.73 ± 10.66%, and average specificity of 99.81 ± 0.19%. The finisher logger results had a mean precision of 85.27 ± 10.66% and a mean accuracy of 99.73 ± 0.13%. Although the loggers showed high sensitivity for detecting turkey steps under research settings, future research should try to reduce the loggers’ susceptibility to background noise, which would improve their performance for application in commercial conditions.

Introduction

An important parameter of effective poultry management is quantifying activity at both the individual and flock level to evaluate productivity and bird welfare. Lameness in turkeys is linked with lower activity levels and may be chronically painful for the affected individuals (Duncan et al., 1991; Buchwalder and Huber-Eicher, 2005b; Hocking and Wu, 2013). Lameness is a generalized term used to describe a turkey exhibiting impaired movement from any variety of environmental, nutritional, genetic, and/or infectious conditions (Dibner et al., 2007). Musculoskeletal problems that cause lameness in turkeys, include: tissue lesions (Julian, 1984), joint inflammation and infection (Riddell, 1980; Julian, 1985), footpad and hock dermatitis (Krautwald-Junghanns et al., 2011b), crooked/deviated toes (Nestor, 1971) as well as fractures and degeneration of leg bone and cartilage (Riddell, 1980; Crespo et al., 1999). Subtle leg and
foot problems are difficult to detect in large flock sizes so may go unnoticed until the affected turkeys are severely lame and incapable of normal movement. In slaughter line evaluations of turkeys, the prevalence of footpad lesions (26.6 ± 18.0% of turkeys), deviated toes (21.4 ± 18.6%), and inflammation of the hock joint (25.4 ± 17.1%) indicated that a sizable proportion of commercial turkeys exhibit poor leg health at the end of rearing (Allain et al., 2013). Lameness decreases productivity by reducing feed intake, slowing growth, and may also lead to carcass downgrades during processing as affected turkeys spend greater amounts of time sitting and may become the targets of injurious pecking from other turkeys (Dibner et al., 2007; Ferket et al., 2009). As a result, lameness may be a predisposing factor for up to half of all mortalities in the final 3-5 weeks of growth (Dibner et al., 2007; Powell, 2007; Ferket et al., 2009).

Activity levels may not only give insight into an individual turkey’s health, but also the coping style of a turkey, its resource allocation, and its likelihood to engage in injurious pecking (Jensen et al., 2005; Kjaer, 2009; de Haas et al., 2010). Research in laying hens has shown that hens selected for high feather pecking (HFP) were more active, exhibited more exploratory pecking, and vocalized more quickly than low feather pecking (LFP) or control line hens in both the home pen (Kjaer, 2009) and test arenas (Jensen et al., 2005; de Haas et al., 2010). Variation in activity levels between HFP and LFP lines of laying hens may also reflect differences in coping styles with HFP hens displaying a proactive response to novel stimuli and environmental complexity (Korte et al., 1997; van Hierden et al., 2002; Jensen et al., 2005). If the association between activity and injurious pecking also exists in turkeys, then damaging pecking behaviour could also represent a
neurochemical imbalance in hyperactive turkeys as Kjaer (2009) hypothesized to explain
the high incidence of feather pecking in modern laying hen flocks.

Previous assessments of activity levels in turkeys have primarily relied on video or live
behavioural observations, but these methods can be time consuming or unfeasible for use
with commercial sized flocks (Martin and Bateson, 2007). The application of portable
data loggers in several farm species has made activity tracking faster and easier to
implement in large groups of animals. Data logger technology has previously been
validated to track postural changes, behavioural bouts, and stepping activity in laying
hens (Quwaider et al., 2010), pigs (Ringgenberg et al., 2010), dairy cattle (Ledgerwood et
al., 2008; Martiskainen et al., 2009), horses (Burla et al., 2014), and goats (Moreau et al.,
2009). Hocking et al. (1999) used electronic pedometers to track the steps of male turkeys
at 54 weeks of age after injection with a steroidal analgesic. However, these were
preliminary observations and the accuracy of these pedometers was not subjected to
further validation. Passive infrared motion sensors have also been successfully used for
tracking whole turkey flock activity when wall-mounted to barns (Li et al., 2008).
However, there is currently no validated motion detection technology flexible enough to
easily track the movement of large groups of turkeys, and simultaneously record steps
taken by individual turkeys. The objective of our study was to validate the use of HOBO
Pendant® data loggers for automated step detection in two age classes of male turkeys:
growers (9 -11 weeks of age) and finishers (14 weeks of age). We used two different age
classes of turkeys to evaluate logger step detection as the gait and movement pattern of a
male turkey changes once the turkey starts to undergo sexual maturity. A young male
turkey typically moves using clear, quick steps with high ground clearance. In contrast, an adult male turkey will often move by strutting, which uses slow steps with minimal ground clearance. Given the high step sensitivity reported for these loggers in other species (Moreau et al., 2009; Ringgenberg et al., 2010), we predicted that HOBO loggers would be capable of detecting the stepping activity of individual turkeys with low false discovery rates and high sensitivity, specificity, precision, and accuracy.

Materials and Methods

The University of Guelph’s Animal Care Committee approved all procedures used in this study (Animal Utilization Protocol #1850) in accordance to guidelines outlined by the University of Guelph Animal Care Policy and the Canadian Council for Animal Care (CCAC, 2009).

Animals and housing

Sixty three-week old (grower) and ten 12-week old (finisher) male turkeys were used for this study. The turkeys were beak-trimmed via infrared laser at one day of age in the hatchery. All the turkeys in this study had a good overall health status, normal gaits with no detectable abnormalities, and no footpad dermatitis or other leg health problems. Turkeys were housed in pens in a close-sided barn that was power-ventilated. The sixty grower turkeys were initially housed in two pens of 30 turkeys (1.83 x 2.36 m, length x width). At six weeks of age, they were further divided into six identical 1.83 x 2.36 m pens.
pens with 10 turkeys per pen. Throughout the study, the finisher turkeys resided in a single pen (1.83 x 2.36 m). The home pens were bedded with kiln-dried pine shavings 10 cm deep. The bedding was changed bi-weekly throughout the study, but shavings were also added as needed to ensure that the pens remained dry. Water was provided ad libitum via a seven-nipple drinker line. Grower and finisher turkeys were fed a standard grower (Metabolizable energy, ME: 3023.38 kcal/kg; Crude fiber, CF: 2.90%, Crude protein, CP: 24.17%) and finisher diet (ME: 4494.26 kcal/kg, CF: 1.98%, CP: 18.66%) ad libitum from a hanging 10 kg tube feeder in each pen. Turkeys were housed under a 16Light:8Dark schedule of 20 lux incandescent lighting. The ambient temperature during the nine-week validation study for the grower turkeys ranged from 17.5-27.3°C (mean: 20.8°C). During the three-week finisher trial, the mean room temperature ranged from 16.6-20.2°C (mean: 18.2°C).

Experimental set-up

Logger details and habituation

Turkey steps were measured using a HOBO Pendant® G acceleration data logger (Onset Computer Corporation, Pocasset, MA, USA) that weighed 18 grams with dimensions of 58 x 33 x 23 mm (length x width x height). The loggers were fastened to one leg, directly above the hock, of each turkey with a Velcro®-sealed white elastic bandage harness (Figure 5.1). The logger harnesses (20 x 7 cm) were constructed from white elastic material and featured a small pocket to hold the logger (Figure 5.1). A small piece of
masking tape was also used to secure the harness to the turkey. A logger harness was firmly attached to a turkey’s leg, but with enough space to prevent injury or inhibit movement. The data loggers were programmed to record x- and y-axis acceleration readings from the turkeys every 0.1 s (measurement range: ±3 gravitational force (g); Accuracy: ±0.105 g factory calibrated). The loggers were attached and positioned on the lateral side of the leg to ensure consistent orientation of the loggers’ axes positions (Figure 5.1). The loggers were triggered to begin recording accelerations by exposure to a magnet. A memory capacity of 21.8 Kb allowed each logger to record continuously for 54 min. Each logger was attached, and recording started in less than two min, thereby preventing unnecessary disturbance to the turkey’s normal activity.

At seven weeks of age, the grower turkeys started a two-week habituation to the harnesses prior to the recording session. During the first week, an empty harness was attached to either leg of each grower turkey for approximately four h/day. The harness attachment was alternated daily between each leg. In the second habituation week, the loggers were included in the harnesses. The finisher turkeys started habituation to wearing the logger harnesses at 12 weeks of age and went through the same two-week habituation process as the grower turkeys.

*Grower turkey runway set-up, habituation, and data collection*

Steps taken by the grower turkeys were recorded in a runway (8.87 x 1.68 m). The runway was composed of black plywood walls (1.23 m high) and a black, non-slip
textured rubber floor with latched entry and exit doors at either end. The runway entry featured a 1.55 x 1.68 m start box, which was divided from the remaining runway by a latched clear Plexiglas door that was flush with the runway wall when opened. Two camcorders (Sony® HDR-XR150 120GB AVCHD Handycam Camcorder 4.1MP; Sony Electronics, San Diego, USA) with Sony® wide conversion lenses (magnification: x0.7) were mounted to the top of the runway walls to record stepping activity. The camcorders recorded 25 frames/s to ensure that the timing of each turkey’s steps could be precisely identified (Ringgenberg et al., 2010). One camcorder was positioned slightly forward of the start box door facing the end of the runway. The second camcorder was secured to the back wall at the end of the runway to capture steps taken by the grower turkeys when leaving the start box.

Grower turkeys were habituated to the runway prior to data collection from three to eight weeks of age. For the first three weeks of habituation, the grower turkeys were moved into the runway as pens of 30 turkeys for two h/day with food and water available in stainless steel dishes. Then at six weeks of age, grower turkeys were placed in the runway as groups of five turkeys for 15 min/day. At the beginning of each 15 min session, the turkeys entered at the start of the runway. Two dishes containing a mixture of the regular feed, popcorn, and vegetable scraps were provided at the end of the runway to encourage the turkeys to move along the length of the runway. During runway habituation, the start box door remained open and flush to the runway wall.
Stepping data for the grower turkeys were collected twice per week in the runway between 9-11 weeks of age for a total of six testing days. The six pens were divided into two groups for testing. Each testing day, one group was sampled during the morning (08:30-12:00 h) and the other group was sampled during the afternoon (13:00-17:00 h). The groups were switched between morning and afternoon samplings on successive testing days to ensure that a representative sample of daily activity was obtained for each turkey. Forty min before each testing session, the data loggers were attached to one leg, above the hock, of each turkey using the harness. Half of the turkeys had the logger attached to the right leg and the remaining wore the logger on the left leg. The leg of attachment was switched each day.

Each grower was tested in the runway with two other pen mates. One turkey was placed in the start box with the door closed and the other two pen mates were placed at the end of the runway to encourage the separated turkey to walk the length of the runway. The cameras were turned on to record once all three turkeys were in the runway. One experimenter entered the start box to trigger the turkey’s logger to begin recording with a magnet. The experimenter then opened the start box door and secured it to the runway wall to be clear of the turkey’s path of movement. When necessary, a grower turkey was encouraged to walk by gently tapping its back and by slowly walking behind the turkey. Once the grower reached the end of the runway, the magnet was used to stop the logger recording. After all three grower turkeys walked the runway, they were returned to their home pen and the logger harnesses were removed.
Finisher turkey trial pen and data collection

For the finisher turkeys, logger performance was evaluated in a test pen, as time limitations of this study prevented adequate training of these older turkeys to walk normally in the runway apparatus. A trial pen (5.49 x 2.36 m) situated next to the home pen was used for the finisher data collection. This pen contained an identical drinker line, feeder, and was bedded like the finisher turkeys’ home pen. Seven camcorders were positioned around the perimeter of the trial pen. Five of the cameras were fixed with wide conversion lenses to expand the sight lines.

The finisher turkeys were individually marked for easy identification with a unique colour pattern on the wings, back, and breast. These identifying colours were applied to the finisher turkeys with spray bottles and were composed of water, non-toxic gel food colouring (concentrated gel colours, Wilton Industries, Woodridge, IL, USA), and a drop of dishwashing liquid (Procter & Gamble Inc., Toronto, ON, Canada). The finisher turkeys were moved into the trial pen 40 min prior to data collection and the logger harnesses were attached. Half of the 14 week old turkeys had a logger harness attached to the right leg and the other half had a logger attached to the left leg, and this was randomized to prevent bias. At the start of data collection, one experimenter entered the test pen to trigger the turkeys’ loggers to begin recording using a magnet. After one hour, the logger harnesses were removed from the turkeys, the cameras turned off, and the finisher turkeys were returned to their home pen.
A step was defined as a turkey lifting its leg with the attached data logger off the pen floor and ended when that leg was placed back down. The video recordings from each turkey were observed continuously using the start time as the point the logger was triggered. A single trained observer recorded whether a step was underway every 0.1 s using a binary code (turkey stepping=1, turkey not stepping=0; Ringgenberg et al., 2010).

The programming and data recovery for the loggers was accomplished using the HOBOware Pro Computer software 2.x (Onset Computer Corporation, Pocasset, MA, USA; Ringgenberg et al., 2010). Due to incomplete logger data collection, two of the 10 finisher turkey recordings were omitted from the analysis. For the grower turkeys, 51 incomplete logger recordings were excluded from analysis because the loggers were not correctly triggered or the turkeys failed to walk the full length of the runway. The logger data were then transformed with a derivation of the Pan-Tompkins algorithm (Ying et al., 2007) in LabVIEW 8.0 (National Instruments, Austin, TX, USA). The algorithm processed the raw logger data using the following sequence of operations: a low bandpass-filter, differentiation, squaring operation, moving-window integrator, and a peak searching procedure (see Ying et al., 2007 for further detail). The transformation aided the analysis by disproportionally amplifying larger accelerations and combining the x- and y-axis into a resultant for clearer step detection (Figure 5.2a). Steps were identified as accelerations above a set threshold in the transformed logger data (Figure 5.2b).
There was a slight delay between the time stamps on the data loggers and video recordings. To account for the slight delay, the transformed acceleration and binary code data were then divided into two min (finisher) and 20 s (grower) blocks for comparison of stepping activity. Dividing the data into blocks ensured that steps were still considered in agreement between the video and logger data even with a small delay. The grower time blocks were much shorter than the 54 min finisher data sets as the grower turkeys took less than one min to walk the length of the runway.

Within each time block, the number of ‘stepping’ and ‘non-stepping’ 0.1 s data points were summed for the video and logger data separately (Figure 5.2c). The total number of 0.1 s steps reported from the video and logger data in each time block were then compared to categorize each step as a true positive (TP), false positive (FP), or false negative (FN) (Figure 5.2c). True positives were steps identified by both the logger and video footage. False positives were steps recorded by the logger, but not observed in the video. False negative steps were steps seen in the video data, but not detected by the logger. The total number of 0.1 s data points identified as non-stepping by both the video and logger was reported as the number of true negative (TN) points.

The sensitivity of each logger was calculated as the percentage of correctly identified logger steps in relation to the total number of steps reported from the video and was calculated as TP/(TP+FN)*100. The false discovery rate of a logger was calculated as FP/(TP+FP)*100 or the percentage of wrongly detected logger steps over the total number of steps recorded by the logger. The specificity of each logger was calculated as
the percentage of non-stepping data points correctly identified by both the video and logger over the total number of falsely identified logger steps and correctly identified non-stepping points or TN/(FP+TN)*100. A logger’s precision was defined as the logger’s ability to correctly identify steps in the video footage over the total number of steps reported by the logger and was calculated as TP/(TP+FP)*100. The accuracy of each logger was calculated as the cumulative number of correctly identified stepping and non-stepping points by the logger over the total number of data points from each observation (i.e., Accuracy = (TP+TN)/(TP+TN+FP+FN)*100).

**Results**

**Thresholds for step detection**

The optimal thresholds for the grower and finisher turkeys were chosen by comparing the logger sensitivity and false discovery rates between individuals at seven threshold levels every 0.05 g/s between 0.45-0.75 g/s. We chose the threshold level for each age class to produce a mean cumulative logger sensitivity of ≥70% (logger sensitivity-false discovery rate) across all sampled turkeys (Martiskainen et al., 2009). For the finisher turkeys, the logger results from all eight toms were compared at the seven different thresholds and the optimal threshold for finisher turkey step detection was chosen to be 0.55 g/s. Given the larger data set for the grower turkeys, four collection dates (day one AM, day two AM, day three PM, day six PM) were chosen as a representative sample (one AM & one PM date per group) to compare logger accuracy at the seven different threshold levels for all
60 grower turkeys. From this sample, the optimal threshold for step detection was chosen to be 0.70 g/s for the grower turkeys.

**Grower step detection**

There were 309 complete logger records obtained from the 60 grower turkeys over the six testing days. A total of 4364 steps and 84317 non-stepping points were observed in the video while the loggers detected a total of 4865 steps and 83816 non-stepping data points (Table 5.1). Of the recorded steps, 4185 logger steps were seen by video (TP), 680 steps were detected by only the loggers (FP), and 179 steps were observed in the video, but not recorded by the loggers (FN). A total of 83637 points were identified as TN in the grower trial (Table 5.1). During each runway walk, an average of 14.12 ± 2.49 steps were seen on video and 15.74 ± 3.77 steps recorded by the logger. For each observation, an average of 13.54 ± 2.53 steps were classified as TP, 2.20 ± 2.12 as FP, and 0.58 ± 1.05 as FN steps. The mean number of TN non-stepping points was 270.67 ± 156.84 for each runway observation. With a threshold for step detection of 0.70 g/s, the mean logger sensitivity was 96.02 ± 6.82%, the average false discovery rate was 12.41 ± 10.13%, and the mean specificity was 99.10 ± 086%. The mean logger precision for step detection was 87.59 ± 10.13% and accuracy was 98.95 ± 0.77% across the 309 complete runway recordings of the 60 grower turkeys (Table 5.1).

**Finisher step detection**
For the eight finisher turkeys, the video scored 2420 data points as steps, whereas the loggers recorded 2691 steps (Table 5.2). Out of the recorded steps, a total of 2212 were identified as TP (detected by both the loggers and video), 479 were only reported by the loggers and not the video observer (FP), and 208 steps were seen in the video, but not detected by the loggers (FN; Table 5.2). 252965 data points were identified as TN by the logger and video data. On average, each finisher turkey walked 302.50 ± 99.78 steps in the video and the logger detected 336.38 ± 161.74 steps in a 54 min observation. Each turkey was identified as non-stepping in the video for an average 31680.50 ± 290.90 data points and were recorded as non-stepping by the logger for an average 31646.63 ± 338.84 points. A mean number of TP (276.50 ± 114.13), FP (59.88 ± 58.81), FN (26.00 ± 27.09), and TN (31620.63 ± 320.34) were reported for a finisher turkey in the trial pen. At the step threshold of 0.55 g/s, the loggers had an average sensitivity of 89.58 ± 11.75%, average specificity of 99.81 ± 0.19%, and a mean false discovery rate of 14.73 ± 10.66% for the eight finisher turkeys (Table 5.2). For these finisher turkeys, the mean logger precision and accuracy was 85.27 ± 10.66% and 99.73 ± 0.13% respectively.

Discussion

The high logger sensitivities obtained for step detection from the grower and finisher turkeys were similar to reports from other species using the HOBO data loggers or similar accelerometer models (Martiskainen et al., 2009; Moreau et al., 2009; Ringgenberg et al., 2010). However, the false discovery rates for turkey step detection by the HOBO loggers in both age classes were higher than a similar experimental set-up for
sows (Ringgenberg et al., 2010). Higher logger sensitivities and lower rates of false discovery were obtained for the grower than finisher turkeys, which is likely due to the higher level of experimental control in the grower set-up, the shorter duration of walking in the runway, and the clearer and faster steps of the sexually immature males. Video observation was chosen as the true standard for step detection in this study because permanent visual recordings of the turkeys’ movements allowed the observer to revisit the footage as needed to ensure accurate reporting. Yet, we acknowledge that scoring by a single observer from video can still be problematic. This type of behavioural recording is time consuming and can still result in error from steps occurring off camera during testing. In addition, relying on a single observer to score all the data increases the risk of human error and can reduce the intra-observer reliability (Martin and Bateson, 2007).

For the finisher turkeys, the mean logger sensitivity and specificity were high (sensitivity range: 68.89-100.00%; specificity range: 99.52-99.99%), but the false discovery rates ranged widely between individuals (2.36-36.26%). There are a number of reasons for the high false discovery rates for some finisher turkeys (e.g., finisher turkeys 4 and 6). When false positives occurred in the finisher data, these turkeys were occasionally observed to body shake and peck at the loggers. This may have produced accelerations similar to steps leading to the incorrect logger recordings that have been observed in other studies (Ringgenberg et al., 2010; Rothwell et al., 2011). However, the long and gradual habituation of the turkeys to the logger harnesses meant that the majority of turkeys moved normally without disturbance while wearing the loggers. Slower turkey steps may have also contributed to the high false discovery rates by producing higher numbers of FP
in the logger recordings (Ringgenberg et al., 2010; Fortune et al., 2014). Ringgenberg et al. (2010) pointed out that a delay in accelerations between the start and end of slower steps would likely be detected as two separate stepping records by the loggers. The inclusion of stride length and gait velocity as variables for logger recordings could potentially reduce the number of FP steps from slower walking movement (Hocking et al., 1999; Fortune et al., 2014). Additionally, although the seven cameras with wide-angle lenses allowed the majority of the test pen to be filmed, some TP turkey steps could have potentially occurred off-camera resulting in higher false discovery rates.

In contrast, those finisher turkeys that showed lower false discovery rates also had below average step sensitivity in their logger recordings. For these finisher turkeys, very few FP were reported, but large numbers of steps were observed in the video, but not detected by the loggers (FN; e.g., finisher turkeys 1 and 5). One potential explanation for the large number of FN could be the threshold of 0.55 g/s may have been too high to detect the smaller acceleration peaks produced by some turkey steps. The lack of clarity in the more shuffle-like steps of a sexually mature turkey, especially when strutting, may have contributed to the higher number of FN steps reported for some finisher turkeys. These less-distinctive steps could have produced smaller vertical accelerations that were insufficient to meet the step threshold and therefore went undetected by the loggers. Additionally, the location of logger attachment and a turkey’s leg conformation may have contributed to the high number of FN steps seen in some turkeys. The loggers were attached on the lateral side of the leg above the hock and directly on top of the peroneus longus muscle. If the loggers had shifted during movement, the standardized axes
positions would have been disturbed if the loggers were not perpendicular to the ground throughout data collection (Ringgenberg et al., 2010).

The logger sensitivity, specificity, precision, and accuracy of step detection in the grower turkeys were very similar to the rates reported in the finisher trial. Therefore, similar reasoning could be applied from the finisher trial to explain the high numbers of FP and FN steps seen in some grower recordings. However, there was a smaller range of variability in the logger false discovery rates for the grower trial due to less FP steps being reported on average per runway observation for a grower turkey. The high mean accuracy and specificity values for logger step detection for both age classes suggests that these loggers provide a true measure of turkey stepping activity and are also capable of correctly recognizing when a turkey is not walking (Dohoo et al., 2009). Yet the high accuracy and specificity values may have been artificially inflated by the large number of TN points since the turkeys spent a large amount of time not stepping in both testing situations. Although a high number of FP steps were reported in some grower and finisher observations, the mean precision rates for both age classes were still high indicating these loggers consistently identified turkey steps from 9 to 14 weeks of age. However, the precision of a test can be increased by performing a large number of repeated runs and averaging the results, which may explain why the grower results showed a slightly higher precision than the finisher study (Dohoo et al., 2009).

Overall the HOBO data loggers showed a relatively high sensitivity, specificity, precision, and accuracy for step detection in male grower and finisher turkeys, but often
overestimated the step count resulting in potentially unacceptable false discovery rates. Commercial use of these data loggers for activity monitoring and early detection of lameness would be comparable to the results obtained in the finisher study where the turkeys walked in a free-run pen. At a recording frequency of 0.1 s, the HOBO loggers are only able to store 54 min of data, limiting their use under commercial settings. Furthermore, the false discovery rates varied considerably between individual turkeys, indicating that further work is needed to reduce logger susceptibility to noise before these loggers can be reliably used to track turkey activity in large free-run barns. In contrast, the heightened experimental control in the grower trial suggests these data loggers could be used as a reliable method to record the stepping activity of domestic turkeys under small-scale research settings with high sensitivity, precision, specificity, and accuracy.
Figure 5.1. Position of the HOBO Pendant® G Acceleration Data Logger on a turkey’s leg, above the hock, when attached with the white elastic harness. The x- and y-axes are superimposed to identify the directions in which acceleration readings were recorded.
Figure 5.2. Transformation of the raw logger data for comparison of sample stepping records from a representative finisher turkey between the HOBO loggers and video footage: (a) the raw x-axis (solid line) and y-axis (dotted line) acceleration data from a HOBO logger, (b) the resultant acceleration following transformation by the Pan-Tompkins algorithm with the step threshold (0.55 g/s) shown, and (c) a comparison of the timing of steps between the video binary scores (black) and the transformed logger data (grey).
Table 5.1. The total number of steps and non-stepping points detected by the video footage and data loggers from the 60 grower turkeys over each AM & PM runway session during the six testing days. The logger sensitivity, false discovery rate, specificity, precision, and accuracy of each AM/PM sampling are reported as percentages (mean ± standard deviation).

<table>
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<tr>
<th>Testing Day</th>
<th>Time of Day</th>
<th>Video</th>
<th>Logger</th>
<th>TPa</th>
<th>FPb</th>
<th>FNc</th>
<th>TNd</th>
<th>Recorded Steps</th>
<th>Sensitivity ± SD (%)</th>
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aTrue positives (TP) were steps detected by both the video and logger.
bFalse positive (FP) steps were detected by the logger, but not observed in the video footage.
cFalse negative (FN) steps were seen in the video, but not detected by the logger.
dTrue negative (TN) were data points identified as non-stepping by both the video and logger.

Sensitivity was calculated as the percentage of correctly identified logger steps over the total number of steps observed in the video or TP/(TP+FN)*100.

False discovery rate was the percentage of incorrectly identified logger steps over the total number of steps recorded by the logger or FP/(TP+FP)*100.

Specificity was the percentage of non-stepping data points correctly identified by both the video and logger over the total number of falsely identified logger steps and correctly identified non-stepping points or TN/(FP+TN)*100.

Precision was calculated as the logger’s ability to correctly identify steps in the video footage over the total number of steps reported by the logger or TP/(TP+FP)*100.

Accuracy was calculated as the cumulative number of correctly identified stepping and non-stepping data points by the logger over the total number of data points from each observation or (TP+TN)/(TP+TN+FP+FN)*100.
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**Total** | **2420** | **2691** | **2212** | **479** | **208** | **252965 ± SD** | **89.58 ± 11.75** | **14.73 ± 10.66** | **99.81 ± 0.19** | **85.27 ± 10.66** | **99.73 ± 0.13** |

**Table 5.2.** The number of steps and non-stepping points detected by the video footage and data loggers from eight finisher male turkeys in the free-run pen during each 54 min recording. The logger sensitivity, false discovery rate, specificity, precision, and accuracy from each data set are also reported (mean ± standard deviation).

<sup>a</sup>True positives (TP) were steps detected by both the video and logger.

<sup>b</sup>False positive (FP) steps were detected by the logger, but not observed in the video footage.

<sup>c</sup>False negative (FN) steps were seen in the video, but not detected by the logger.

<sup>d</sup>True negative (TN) were data points identified as non-stepping by both the video and logger.

<sup>e</sup>Sensitivity was calculated as the percentage of correctly identified logger steps over the total number of steps observed in the video or TP/(TP+FN)*100.

<sup>f</sup>False discovery rate was the percentage of incorrectly identified logger steps over the total number of steps recorded by the logger or FP/(TP+FP)*100.

<sup>g</sup>Specificity was the percentage of non-stepping data points correctly identified by both the video and logger over the total number of falsely identified logger steps and correctly identified non-stepping points or TN/(FP+TN)*100.

<sup>h</sup>Precision was calculated as the logger’s ability to correctly identify steps in the video footage over the total number of steps reported by the logger or TP/(TP+FP)*100.

<sup>i</sup>Accuracy was calculated as the cumulative number of correctly identified stepping and non-stepping data points by the logger over the total number of data points from each observation or (TP+TN)/(TP+TN+FP+FN)*100.
Chapter Six. Comparing the behavioural organization of head pecking, severe feather pecking, and gentle feather pecking in domestic turkeys

Abstract

Detection of behavioural temporal patterns (T-patterns) allows for insight into the organization of behaviours that is not apparent through qualitative analysis of the durations and frequencies of discrete behaviours. This study aimed to identify differences in the behavioural distribution and organization of two forms of injurious pecking (head pecking and severe feather pecking), and non-damaging gentle feather pecking in domestic turkeys using two analytical methods: T-pattern analysis and a conventional assessment of behavioural frequencies and durations. Video observations of pecking behaviour were obtained from focal samples of domestic male turkeys between 5-15 weeks of age. Each focal sampling observation recorded the behaviour of a single turkey 120 s before and after the turkey performed head, gentle, or severe feather pecking (241 s observation length per pecking event). Pecking type had no effect on the number of T-patterns and the frequency of T-pattern occurrences. However, both T-pattern detection and the conventional analysis showed turkeys in head pecking observations tended to be more active with shorter lying durations ($H = 7.36, df = 2, P = 0.025$), less frequent standing ($H = 5.61, df = 2, P = 0.061$), and less structured T-patterns (total T-pattern durations: $H = 5.996, df = 2, P = 0.050$, mean durations: $H = 5.34, df = 2, P = 0.068$) than turkeys engaged in gentle or severe feather pecking. The analyses also showed that turkeys that performed severe feather pecking tended to show more frequent gentle pecking than turkeys that performed head pecking ($H = 5.79, df = 2, P = 0.055$).
However, discrepancies in organization of feeding and foraging behaviour between the two analytical methods highlighted the susceptibility of both methods to behavioural variation between individuals when using small sample sizes. Future research should use T-pattern detection to evaluate age, sex, and environmental differences in the organization of the injurious pecking behaviour in domestic turkeys.

**Introduction**

Beak-related activity makes up a large proportion of the behavioural repertoire of domestic turkeys. Specifically, Hughes and Grigor (1996) reported that female turkeys at 12 weeks of age spent about 6% of their total daily activity budget pecking at the plumage and skin of their flock mates. The pecking of another turkey can be defined as being gentle, severe, or aggressive head pecking (Sherwin et al., 1999; Chapter 2). Gentle feather pecking is defined as a social and investigatory preening of another turkey, typically directed at debris on the plumage. This behaviour is performed without force and causes no damage to the pecked turkey (Savory, 1995; Hughes and Grigor, 1996). In contrast, severe feather pecking and head pecking are classified as injurious pecking as these behaviours can cause tissue damage and mortality resulting in declines in both productivity and welfare (Sherwin et al., 1999; Chapter 2). Severe feather pecking is the repeated, forceful pecking and removal of feathers by a turkey, which can result in plumage and tissue damage to the recipient (Savory, 1995). The underlying motivation of severe feather pecking in poultry is believed to represent the re-directed ground pecks of foraging behaviour in environmental conditions lacking appropriate foraging stimuli.
(Martrenchar, 1999; Sherwin et al., 1999; Dixon et al., 2008). In contrast, head pecking is considered to be an aggressive act and this pecking typically targets the head, neck, and snood of another turkey (Savory, 1995; Moinard et al., 2001; Buchwalder and Huber-Eicher, 2003).

To find practical solutions to behavioural problems, animal behaviour and welfare research is incorporating innovative statistical approaches to provide new information about the underlying structure of damaging behaviour and behavioural consequences of poor animal welfare. Temporal pattern detection has shown success in revealing temporal relationships among behaviours that cannot be detected when a continuous behavioural sequence is divided into its discrete elements by conventional qualitative analysis. Using a bottom-up approach, a pattern-detection algorithm, such as the THEME software package (Magnusson, 2000), uses the order and timing of behaviours to identify recurring temporal behavioural patterns (T-patterns) within a sequence (Asher et al., 2009; Cassarubea et al., 2015). Research by Sinclair et al. (2015) showed that turkeys with footpad dermatitis had more frequent, complex, and varied T-patterns on dry vs. wet litter and greater T-pattern frequency and variation when provided analgesic treatment. Temporal analysis by THEME has also been used to identify invariant behavioural patterns consisting of relatively few behaviours that are predictive of abnormal behaviours in both starlings and mice (Bonasera et al., 2008; Brilot et al., 2009; Feenders and Bateson, 2012). When applied along with descriptive analyses of behaviour, multivariate T-pattern detection can provide new insight into the organization of
damaging behaviour for a better understanding of why outbreaks occur and how to prevent their reoccurrence.

The objective of this study was to identify differences in the behavioural distribution and organization of head pecking, severe feather pecking, and gentle feather pecking in domestic male turkeys using two analytical methods: T-pattern analysis and a conventional assessment of behavioural frequencies and durations. Based on the existing literature on injurious pecking in turkeys, we hypothesized that the performance of injurious pecking, such as severe feather pecking and head pecking, would show more structured, yet less variable and frequent behavioural patterns over time than bouts of gentle pecking.

Materials and Methods

The use of all animals in this study was approved by the University of Guelph Animal Care Committee and adheres to the guidelines of the University of Guelph Animal Care Policy and the Canadian Council on Animal Care (CCAC, 2009).

Animals and experimental design

We evaluated the pecking behaviour of 127 focal observations of beak-treated commercial male turkeys from 5 to 15 weeks of age. The observations in this study were collected as part of a larger observational project completed from April to July 2010.
(Duggan et al., 2014). The video recordings were taken in eight commercial barns (four closed-sided and four curtain-sided; 9-20 observations per barn) at four ages: 5-6 (20 observations), 7-9 (23), 11-12 (40), and 13-15 (44) weeks of age. Video recordings were taken from 1000 to 1500 h and filmed an approximately 41 m² viewpoint of each barn. Each barn contained approximately 5000-7500 male turkeys and all barns were located at a single commercial facility (Duggan et al., 2014).

**Behavioural scoring**

Individual turkeys were identified for focal observations if the turkey performed gentle feather pecking, severe feather pecking, or head pecking behaviour during the video recordings. For each pecking observation, the sequence of behaviours of the focal turkey was scored continuously in Noldus Observer XT 11 (Noldus Information Technology, Wageningen, NL) for 120 s before and after the pinpointed pecking event occurred, including any other occurrences of pecking behaviour (241 s observation length). An observation could include more than one type of pecking behaviour; however, the observation was classified based on the pecking type that occurred at the 121 s time point in the observation. There were a total of 127 observations of pecking behaviour consisting of 74 gentle feather pecking, 27 severe feather pecking, and 26 head pecking observations.

The behaviour of the turkeys was scored using an ethogram of 17 behaviours, which included eleven exclusive states (feeding, drinking, walking, standing, lying down,
foraging, preening, dust bathing, displaying, other, and out-of-view) and six behavioural events (scratch flock mate, severe feather peck flock mate, gentle feather peck flock mate, head peck flock mate, receive peck, and peck object) that occurred concomitantly with the behavioural states (Table 6.1). The ethogram also included the states ‘other’ to score any behaviour not described in the ethogram and ‘out-of-view’ for when a focal turkey moved out of the recording area or was blocked from view by another turkey (Table 6.1). Severe feather pecking of a flock mate was defined as a focal turkey directing its beak towards the plumage or skin of another turkey and visibly pulling on the plumage or skin of the recipient turkey. Gentle feather pecking of a flock mate occurred when a focal turkey directed its beak towards another turkey’s feathers while opening and closing its beak on the feathers without any pulling motion. An aggressive head peck was defined as a focal turkey directing its beak in a swift motion towards the head and/or neck of another turkey with or without pulling on the skin of the recipient turkey (Table 6.1).

Data processing

Conventional behavioural assessment

Using Observer XT, the total time, frequency, and mean duration was calculated for each behavioural state in each of the observation files. The total frequencies of the behavioural events were also determined for each observation.
T-pattern detection

The raw Observer observation files were transferred into THEME version 5 (Noldus Information Technology, Wageningen, NL) for detection of the hidden temporal structures (T-patterns) within the pecking behavioural sequences (Magnusson, 2000; Cassarubea et al., 2015). To be analyzed by THEME, the observation files were first converted into text files using Noldus Pattern Vision DEPxp 3.1.1.1 (PatternVision Ltd, Reykjavik, ISL). THEME labeled each occurrence of a behavioural event and the start and end of each behavioural state as time-stamped behavioural event types within the observation (Cassarubea et al., 2015). A T-pattern was defined as a recurring combination of two or more behavioural event types that were linked by a non-random critical period of time (See Magnusson, 2000 for further detail). For our study, an identified T-pattern occurred at least three times within an observation with a non-random significance of $P < 0.005$ (Magnusson, 2000; Merlet et al., 2005). THEME computed the number of detected T-patterns within each observation (i.e., pattern variety) and the total frequency of all T-pattern occurrences (i.e., pattern frequency), the average total duration of the T-patterns, and the mean duration of occurrences of the detected T-patterns (i.e., pattern structure) in each file for later comparison between the three pecking types (Hocking et al., 2007; Sinclair et al., 2015). Two observations (one head & one gentle pecking observation) could not be converted in Pattern Vision and were excluded from analysis in THEME.

Statistical analysis
All statistical procedures were performed in SAS (SAS 9.2, 2007) and SPSS (IBM SPSS Statistics Version 24). For the conventional analysis, the dependent variables for the behavioural states were the total time spent performing a particular behaviour (total duration), the frequency (number of occurrences) of each behaviour, and the mean duration of each occurrence of a behaviour. The dependent variables for the behavioural events from the conventional assessment were the frequency (i.e., number) of occurrences of each behavioural event. The dependent variables from THEME analysis were the number and the total frequency of all T-pattern occurrences, the average total duration of the T-patterns, and the mean duration (s/occurrence) of T-pattern occurrences in each file. The behavioural data from both the conventional and THEME analyses showed non-normal, right-skewed distributions with equal variances and unbalanced sample sizes among the three pecking types. As a result, the dependent data from the conventional and THEME analyses were analyzed separately in SAS using Kruskal-Wallis H tests with the type of pecking observation (gentle, severe, or head pecking) as the fixed effect. When a significant type effect was detected, a post-hoc Dunn’s test using rank sums with a Bonferroni correction for multiple tests was performed in SPSS for pair-wise comparisons between pecking types. Significant effects were detected at \( P < 0.05 \) and the tendency of an effect was interpreted when the \( P \)-value was \( < 0.10 \).

Results
For the conventional assessment, other and out-of-view were excluded from analysis to limit the study’s focus to the defined behaviours (Table 6.2). Some behaviours were not observed (i.e., dust bathing) or occurred infrequently (no observations ≥75% of files; i.e., drinking, displaying, scratch flock mate, receive peck, and peck object) so were omitted from further conventional analysis (Table 6.2). Observations of feeding and foraging were summed into a single category for both the conventional (Table 6.2) and THEME analysis because there were very few observations (22 in total) of feeding behaviour.

The mean values (± SEM) for the mean duration, total duration, and frequency of the different behavioural states are shown for the three types of pecking observations in Table 6.3. Turkeys spent more total time lying when exhibiting severe feather pecking than when engaged in head pecking (Z = -2.67, P = 0.023; Table 6.3). In the observations of head pecking, turkeys had significantly greater total durations of time feeding and foraging than turkeys engaged in gentle or severe feather pecking (H = 6.08, df = 2, P = 0.048; Table 6.3). Post-hoc comparison of the pecking types showed a trend for turkeys exhibiting head pecking to spend more time in total feeding and foraging than turkeys displaying severe feather pecking (Z = 2.36, P = 0.055). Turkeys engaged in head pecking also showed a higher frequency of feeding and foraging than turkeys engaged in severe feather pecking (Z = 2.97, P = 0.01; Table 6.3). Additionally, observations of head pecking tended to have more bouts of standing than turkeys showing gentle or severe feather pecking (H = 5.61, df = 2, P = 0.061; Table 6.3). The frequency of head or severe feather pecking did not significantly differ between the three types of pecking observations (head pecking: H = 3.13, df = 2, P = 0.21, severe feather pecking: H = 1.04,
df = 2, \( P = 0.60 \)). However, observations of gentle (1.73 ± 0.01 gentle pecks; mean ± SEM) and severe feather pecking (2.00 ± 0.32) tended to have more occurrences of gentle pecking than the head pecking observations, which had few bouts of gentle pecking (1.00 ± 0.00; \( H = 5.79, df = 2, P = 0.055 \)).

Three hundred and twenty-nine non-random T-patterns were detected in 15 head pecking, 39 gentle pecking, and 11 severe feather pecking observations. No significant T-patterns were detected in 10 head pecking, 35 gentle pecking, and 15 severe feather pecking observations. The mean number, frequency, total and mean durations of significant T-patterns for the three types of pecking are presented in Table 6.4. There was no difference amongst the three pecking types in the number of unique temporal patterns (\( H = 0.50, df = 2, P = 0.78 \)) and the frequencies with which these patterns occurred (\( H = 0.23, df = 2, P = 0.89 \); Table 6.4). However, both the total duration of T-patterns (\( H = 5.996, df = 2, P = 0.050 \)) and the mean duration of T-pattern occurrences (\( H = 5.34, df = 2, P = 0.068 \)) showed a tendency to be shorter within head pecking observations than gentle or severe feather pecking observations (Table 6.4). Of the 70 non-random T-patterns detected in the head pecking observations, over 55% were a combination of standing and walking (25.71%), standing and feeding/foraging (14.29%), standing and drinking (7.14%), and patterns of standing, walking, and head pecking (8.57%; Table 6.5). The most common of the 211 detected T-patterns in the gentle feather pecking observations were sequences of feeding/foraging and standing (37.91%), feeding/foraging and other behaviour (8.53%), standing (8.06%), and lying (6.64%; Table 6.5). For the severe feather pecking observations, the largest proportions of the 48 significant T-patterns were composed of
feeding/foraging and standing (29.17%), lying (18.75%), drinking and standing (10.42%), and sequences of scratching, standing, and gentle feather pecking behaviour (14.58%; Table 6.5).

Discussion

Injurious pecking poses a serious problem to the welfare of modern turkeys, but the causation and development of this damaging behaviour is still poorly understood. The motivational basis of the different pecking types has been primarily adopted from laying hen research, which suggests that severe feather pecking in poultry represents redirected foraging behaviour due to a lack of suitable environmental stimuli (Martrenchar, 1999; Sherwin et al., 1999; Dixon et al., 2008). Gentle feather pecking in turkeys is considered the investigatory preening of debris on the plumage of flock mates (Savory, 1995). In contrast, head pecking in turkeys is considered an act of aggression (Savory, 1995; Moinard et al., 2001; Buchwalder and Huber-Eicher, 2003). To gain a better understanding of damaging pecking behaviour in turkeys, we designed this experiment to study the patterns in the behavioural sequences of gentle feather pecking and two forms of injurious pecking, head pecking and severe feather pecking. We hypothesized that the three pecking types would have a different organizational structure with observations of severe feather pecking and head pecking being more structured, but with less variable and frequent behavioural patterns over time than gentle feather pecking observations. The results from the T-pattern analysis showed pecking type had no effect on the variety or frequency of unique temporal patterns in the behavioural sequences of these male
turkeys. However, the two analytical approaches, conventional qualitative assessment and THEME analysis, both identified similar differences in the structure of lying, standing, and gentle pecking behaviour amongst the different pecking types. The conventional analysis showed that when turkeys were engaged in head pecking, they appeared to be more active, spending less time lying with more frequent bouts of standing behaviour, compared to when turkeys engaged in other types of pecking. In contrast, when turkeys exhibited severe feather pecking, this type of pecking was associated with less active behaviour with longer lying durations and less frequent standing. Similarly, THEME identified standing as a component of the four most common T-patterns seen in observations of turkeys displaying head pecking. THEME also showed that sequences of lying behaviour made up 18.75% and 6.64% of T-patterns detected in the observations of severe and gentle feather pecking. Furthermore, the T-patterns in the head pecking observations tended to have both shorter total and mean pattern durations than the T-patterns for turkeys showing gentle or severe feather pecking. This suggests that behavioural organization of head pecking is less structured than the behaviour of gentle or severe feather pecking. Our results are consistent with previous research showing turkey flocks can become more active and perform head pecking following environmental or social disturbances in order to settle the flock and re-establish the dominance hierarchy (Cunningham et al., 1992; Buchwalder and Huber-Eicher, 2003 2004). The positive association between activity and head pecking behaviour in turkeys suggests that strategies to prevent social and environmental disturbances could reduce outbreaks of head pecking in commercial flocks.
A tendency for turkeys performing gentle or severe feather pecking to show more gentle pecking behaviour was also seen in the results from both the conventional and T-pattern analysis. In the observations of severe feather pecking, almost 15% of all significant T-patterns included gentle feather pecking. The link between gentle and severe feather pecking in these observations supports the idea of a shared origin for these two pecking behaviours (Hughes and Grigor, 1996; Sherwin et al., 1999). Severe feather pecking and gentle feather pecking are both directed towards the wings, back, and tail of another turkey (Savory, 1995). Severe feather pecking is also thought to develop from investigatory gentle feather pecking that becomes more forceful pecking and results in feather removal with additional plumage and/or tissue damage (Savory, 1995; Chapter 2). More research is needed in turkeys to determine what factors cause gentle feather pecking to become forceful and result in the performance of severe feather pecking.

Although there were many consistencies, THEME and the conventional analyses produced conflicting results for the structure of feeding and foraging behaviour amongst the three pecking types. The conventional assessment showed turkeys performing head pecking had longer total durations and more frequent occurrences of feeding and foraging than turkeys exhibiting gentle or severe feather pecking. In contrast, THEME showed feeding and foraging behaviour was a component of 37.91% and 29.17% of T-patterns detected in the gentle and severe feather pecking observations whereas only 14.29% of the most common T-patterns in head pecking observations included feeding and foraging. Severe feather pecking is believed to represent highly motivated ground foraging that has been re-directed due to the absence of suitable environmental stimuli (Martrenchar, 1999;
Sherwin et al., 1999). Therefore, we would predict feeding and foraging to be more common in behavioural sequences of severe feather pecking than head pecking. Unlike T-pattern detection, conventional assessment of behavioural durations and frequencies focuses on single behaviours instead of patterns of behaviours, which might explain the opposite feeding/foraging findings from these analytical methods (Hocking et al., 2007). The conflicting results also likely reflects the sensitivity of conventional analysis to behavioural variation between individual pecking records that was amplified by the low sample sizes for both head and severe feather pecking observations in this study. However, the grouping of feeding and foraging behaviour together in this study might have ultimately incorrectly linked two discrete behaviours, which might show distinct behavioural patterns and associations with pecking behaviour in turkeys.

Another potential limitation for the interpretation of this study’s findings is the large individual variability in number of detected T-patterns with 65 of the 125 pecking observations in this study showing no significant T-patterns. Martaresche et al. (2000) theorizes that this variation represents individual adaptation strategies in the performance of a particular behaviour. Variation in the number of T-patterns between animals might also identify those individuals experiencing stress, illness, or more likely to express abnormal behaviour as those exhibiting a greater number of invariant behavioural sequences (T-patterns) in their behaviour (Brilot et al., 2009; Sinclair et al., 2015). However, given the combination of a large variation in detected T-patterns and the small sample sizes for two of the pecking types in this study, the results from the THEME analysis of head pecking and severe feather pecking must be considered exploratory.
In summary, multivariate T-pattern detection, alongside the conventional qualitative behavioural assessment, provided a complimentary examination of the organization of pecking behaviour in these domestic male turkeys. Conventional and T-pattern analysis identified similar distinguishing features in active behaviours and gentle pecking amongst turkeys engaged in head, gentle, or severe feather pecking. Yet these analyses gave conflicting results on the structure of feeding and foraging behaviour amongst the three pecking types. Future research should continue to employ analytical methods, such as T-pattern detection, for a complete representation of age, sex, and environmental differences in the organization of injurious pecking behaviour in domestic turkeys.
Table 6.1. An ethogram containing the 17 behavioural states and events initially scored from focal samplings of male turkeys between 5-15 weeks of age. All of the listed behaviours were included in the THEME analysis.

<table>
<thead>
<tr>
<th>Behaviour</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feed</td>
<td>The turkey has its head and/or beak in the pan feeder.</td>
</tr>
<tr>
<td>Drink</td>
<td>The turkey has its head and/or beak in the bell drinker.</td>
</tr>
<tr>
<td>Walk</td>
<td>The turkey takes steps, placing one foot in front of the other.</td>
</tr>
<tr>
<td>Stand</td>
<td>The turkey is immobile while standing on its feet.</td>
</tr>
<tr>
<td>Lying</td>
<td>The turkey is resting on its breast on the ground.</td>
</tr>
<tr>
<td>Forage</td>
<td>The turkey pecks at litter with beak and/or scratches at litter with feet.</td>
</tr>
<tr>
<td>Preen</td>
<td>The turkey directs its beak at its own feathers, usually accompanied with ptero-erection.</td>
</tr>
<tr>
<td>Dust bathe</td>
<td>The turkey is in the lie down position while flicking litter up into its feathers using its wings.</td>
</tr>
<tr>
<td>Display</td>
<td>While standing and/or walking, the turkey erects feathers on its back, raises its tail feathers, and drops its wings forwards.</td>
</tr>
<tr>
<td>Scratch Flock Mate</td>
<td>The turkey directs its claws at another turkey and makes a swiping motion from front to back.</td>
</tr>
<tr>
<td>Peck Flock Mate</td>
<td>The turkey directs its beak towards another turkey’s feathers/skin while visibly pulling on the feathers and/or skin with its beak.</td>
</tr>
<tr>
<td>Peck Flock Mate</td>
<td>The turkey directs its beak towards another turkey’s feathers while opening and closing its beak on the feathers without any pulling motion.</td>
</tr>
<tr>
<td>Gentle</td>
<td></td>
</tr>
<tr>
<td>Receive Peck</td>
<td>The turkey is the recipient of a peck from another turkey’s beak.</td>
</tr>
<tr>
<td>Peck Environment</td>
<td>The turkey directs its beak at objects within the barn including play pit balls, feeders, drinkers, walls, and beams.</td>
</tr>
<tr>
<td>Head Peck</td>
<td>The turkey directs its beak in a swift motion towards the head/neck of another turkey with or without pulling on the skin of the recipient turkey.</td>
</tr>
<tr>
<td>Other</td>
<td>Any other behaviour not described above.</td>
</tr>
<tr>
<td>Out of View</td>
<td>The turkey moves out of the recording area or is blocked by another turkey from the cameras view.</td>
</tr>
</tbody>
</table>
Table 6.2. An ethogram of the behavioural states and events from the 241 s observations of the pecking behaviour of focal male turkeys between 5-15 weeks of age that were included in the conventional analysis of behavioural durations and frequencies.

<table>
<thead>
<tr>
<th>Behaviour</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feed &amp; Forage</td>
<td>The turkey has its head and/or beak in pan feeder or the turkey pecks at litter with beak and/or scratches at litter with feet.</td>
</tr>
<tr>
<td>Walk</td>
<td>The turkey takes steps, placing one foot in front of the other.</td>
</tr>
<tr>
<td>Stand</td>
<td>The turkey is immobile while standing on its feet.</td>
</tr>
<tr>
<td>Lying</td>
<td>The turkey is resting on its breast on the ground.</td>
</tr>
<tr>
<td>Preen</td>
<td>The turkey directs its beak at its own feathers, usually accompanied with ptero-erection.</td>
</tr>
<tr>
<td>Peck Flock</td>
<td>The turkey directs its beak towards another turkey’s feathers/skin while visibly pulling on the feathers and/or skin with its beak.</td>
</tr>
<tr>
<td>Mate Severe</td>
<td>The turkey directs its beak towards another turkey’s feathers while opening and closing its beak on the feathers without any pulling motion.</td>
</tr>
<tr>
<td>Peck Flock</td>
<td></td>
</tr>
<tr>
<td>Mate Gentle</td>
<td></td>
</tr>
<tr>
<td>Head Peck</td>
<td>The turkey directs its beak in a swift motion towards the head/neck of another turkey with or without pulling on the skin of the recipient turkey.</td>
</tr>
</tbody>
</table>
Table 6.3. The mean total duration (s), mean duration (s) and frequency (n) (± SEM) of different behavioural states recorded during focal samplings of male turkeys between 5 -15 weeks of age in commercial barns. The behaviour of a focal turkey was observed 120 s before and 120 s after a focal male turkey engaged in gentle, severe, or head pecking.

<table>
<thead>
<tr>
<th>Behaviour</th>
<th>Pecking Type</th>
<th>Total duration (s)</th>
<th>Mean Duration (s)</th>
<th>Frequency (n)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standing</td>
<td>Gentle</td>
<td>47.09 ± 0.69</td>
<td>16.36 ± 0.27</td>
<td>3.07 ± 0.03^a</td>
</tr>
<tr>
<td></td>
<td>Severe</td>
<td>41.41 ± 1.64</td>
<td>18.50 ± 0.66</td>
<td>2.52 ± 0.08^c</td>
</tr>
<tr>
<td></td>
<td>Head</td>
<td>58.09 ± 2.71</td>
<td>14.53 ± 0.52</td>
<td>3.80 ± 0.10^c</td>
</tr>
<tr>
<td>Lying</td>
<td>Gentle</td>
<td>123.51 ± 0.80^ab</td>
<td>48.44 ± 0.39</td>
<td>3.10 ± 0.02</td>
</tr>
<tr>
<td></td>
<td>Severe</td>
<td>138.76 ± 2.40^a</td>
<td>44.16 ± 1.03</td>
<td>3.68 ± 0.07</td>
</tr>
<tr>
<td></td>
<td>Head</td>
<td>96.67 ± 2.39^b</td>
<td>37.67 ± 1.00</td>
<td>3.00 ± 0.08</td>
</tr>
<tr>
<td>Walking</td>
<td>Gentle</td>
<td>29.37 ± 0.53</td>
<td>12.40 ± 0.21</td>
<td>2.40 ± 0.03</td>
</tr>
<tr>
<td></td>
<td>Severe</td>
<td>30.52 ± 1.72</td>
<td>15.83 ± 0.68</td>
<td>2.18 ± 0.11</td>
</tr>
<tr>
<td></td>
<td>Head</td>
<td>27.40 ± 2.63</td>
<td>11.02 ± 0.41</td>
<td>2.20 ± 0.10</td>
</tr>
<tr>
<td>Feeding &amp; Foraging</td>
<td>Gentle</td>
<td>53.42 ± 1.08^abcd</td>
<td>30.07 ± 0.74</td>
<td>2.51 ± 0.05^b</td>
</tr>
<tr>
<td></td>
<td>Severe</td>
<td>32.78 ± 3.19^bcd</td>
<td>17.39 ± 0.85</td>
<td>1.71 ± 0.14^b</td>
</tr>
<tr>
<td></td>
<td>Head</td>
<td>72.89 ± 5.40^ac</td>
<td>32.66 ± 2.34</td>
<td>3.09 ± 0.17^a</td>
</tr>
<tr>
<td>Preening</td>
<td>Gentle</td>
<td>36.99 ± 0.61</td>
<td>21.17 ± 0.31</td>
<td>1.73 ± 0.02</td>
</tr>
<tr>
<td></td>
<td>Severe</td>
<td>38.71 ± 2.44</td>
<td>25.47 ± 1.60</td>
<td>1.64 ± 0.07</td>
</tr>
<tr>
<td></td>
<td>Head</td>
<td>47.84 ± 2.76</td>
<td>28.36 ± 1.30</td>
<td>2.08 ± 0.07</td>
</tr>
</tbody>
</table>

Within a column, for each behaviour, values with different superscripts differ, a±b, P < 0.05; c±d±e, P < 0.10
**Table 6.4.** The mean values (± SEM) for the total number of different non-random behavioural T-patterns\(^1\), total number of pattern occurrences, and the total and mean durations of the T-patterns from THEME analysis of focal observations 120 s before and 120 s after male turkeys exhibited either gentle, head or severe feather pecking.

<table>
<thead>
<tr>
<th>THEME Variables</th>
<th>Pecking Type</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Gentle</td>
<td>Severe</td>
<td>Head</td>
<td></td>
</tr>
<tr>
<td>Number of Different Patterns (n)</td>
<td>5.46 ± 0.23</td>
<td>4.36 ± 0.46</td>
<td>4.67 ± 0.31</td>
<td></td>
</tr>
<tr>
<td>Pattern Occurrences (n)</td>
<td>23.18 ± 1.13</td>
<td>21.27 ± 2.94</td>
<td>16.20 ± 1.19</td>
<td></td>
</tr>
<tr>
<td>Total Duration of Patterns (s)</td>
<td>27.72 ± 0.55(^d)</td>
<td>27.05 ± 3.07(^d)</td>
<td>12.19 ± 0.59(^c)</td>
<td></td>
</tr>
<tr>
<td>Mean Duration of a Pattern Occurrence (s)</td>
<td>7.21 ± 0.15(^d)</td>
<td>7.76 ± 1.02(^d)</td>
<td>3.70 ± 0.17(^c)</td>
<td></td>
</tr>
</tbody>
</table>

\(^1\)A temporal sequence of two or more behavioural event types occurring more often than expected by chance.

Within a row, values with different superscripts differ, a±b, \(P < 0.05\); c±d±e, \(P < 0.10\)
Table 6.5. The four most frequent types of different non-random behavioural T-patterns\(^1\) for each of the three different types of pecking records including the total number of pattern occurrences of each type of T-pattern and the percentage each T-pattern type amongst all detected T-patterns. T-patterns were detected in THEME analysis of focal observations 120 s before and 120 s after male turkeys exhibited either gentle, head or severe feather pecking.

<table>
<thead>
<tr>
<th>Pecking Type</th>
<th>Type of T-Patterns</th>
<th>Pattern Occurrences (n)</th>
<th>Percentage of Detected T-Patterns</th>
</tr>
</thead>
<tbody>
<tr>
<td>Severe</td>
<td>Feed &amp; Forage/Stand/(Feed &amp; Forage)</td>
<td>14</td>
<td>29.17%</td>
</tr>
<tr>
<td></td>
<td>Lying</td>
<td>9</td>
<td>18.75%</td>
</tr>
<tr>
<td></td>
<td>Scratch Flock Mate/Stand/Peck Flock Mate Gentle/(Scratch Flock Mate)</td>
<td>7</td>
<td>14.58%</td>
</tr>
<tr>
<td></td>
<td>Drink/Stand</td>
<td>5</td>
<td>10.42%</td>
</tr>
<tr>
<td>Gentle</td>
<td>Feed &amp; Forage/Stand/(Feed &amp; Forage/(Stand))</td>
<td>80</td>
<td>37.91%</td>
</tr>
<tr>
<td></td>
<td>Other/Feed &amp; Forage/(Other/(Feed &amp; Forage))</td>
<td>18</td>
<td>8.53%</td>
</tr>
<tr>
<td></td>
<td>Stand</td>
<td>17</td>
<td>8.06%</td>
</tr>
<tr>
<td></td>
<td>Lying</td>
<td>14</td>
<td>6.64%</td>
</tr>
<tr>
<td>Head</td>
<td>Stand/Walk</td>
<td>18</td>
<td>25.71%</td>
</tr>
<tr>
<td></td>
<td>Feed &amp; Forage/Stand</td>
<td>10</td>
<td>14.29%</td>
</tr>
<tr>
<td></td>
<td>Stand</td>
<td>10</td>
<td>14.29%</td>
</tr>
<tr>
<td></td>
<td>Stand/Walk/Head Peck</td>
<td>6</td>
<td>8.57%</td>
</tr>
</tbody>
</table>

\(^1\) A temporal sequence of two or more behavioural event types occurring more often than expected by chance.
Chapter Seven. An Analysis of Beak Shape Variation in Two Ages of Domestic Turkeys

Using Landmark-Based Geometric Morphometrics

Abstract

Diversity in beak shape has been traditionally quantified using linear measurements of length and width. However, these univariate measures do not provide geometric information on beak shape independent of size. Landmark-based geometric morphometrics have overcome this limitation by employing landmarks to examine beak shape variability that remains unchanged after scaling. The objective of this study was to assess phenotypic beak shape variation in domestic turkeys and determine the effects of age, sex, and beak size on beak shape variation using landmark-based geometric morphometrics. Dorsal and right lateral images were taken of the heads of 2442 turkeys with intact beaks at 6 and 18.5 weeks of age. Landmarks were digitized in TPSDig in three separate analyses of the dorsal upper mandible, lateral upper mandible, and lateral lower mandible shape of each turkey at both ages. The coordinate data were then subjected to a principal components analysis (PCA), multivariate regression, and a canonical variates analysis (CVA) with a Procrustes ANOVA in MorphoJ. For the dorsal images, three principal components (PCs) showed a main axis of beak shape variation from long, narrow, and pointed to short, wide, and blunt upper mandibles at both 6 weeks (95.36% of shape variation) and 18.5 weeks of age (92.21%). Three PCs showed a main axis of shape variation from long, wide lateral upper mandibles with long, curved tips to short, narrow beaks with short, pointed beak tips at both 6 (94.91%) and 18.5 weeks of age (94.33%). Three PCs also explained 97.80% (6 weeks) and 97.11% (18.5 weeks) of the lateral lower mandible shape variation.
ranging from wide/round to narrow/thin lower mandibles with superior/inferior beak tip shifts. Beak size accounted for varying proportions of the beak shape variation (0.96-54.76%; $P < 0.0001$) in the three analyses of each age group suggesting some morphological beak structures are more constrained by beak size than others. For all the analyses, the CVA showed sexual dimorphism in beak shape ($P < 0.0001$) with female upper mandibles appearing wider and blunter dorsally with long, curved beak tips in the lateral images. Whereas male turkey upper mandibles had a narrow, pointed dorsal appearance and short, pointed beak tips laterally. At 6 weeks of age, female turkeys had wide, round lateral lower mandibles whereas male turkeys had a narrow and thin lower beak shape; however, these sexually dimorphic beak shape phenotypes were reversed for the 18.5 week old turkeys. Future applications of beak shape variability could have a genetic and welfare value in domestic turkeys by incorporating beak shape variation to select for specific beak shape phenotypes as an alternative to beak treatment.

Introduction

A significant proportion of mortalities and culls in domestic turkeys show signs of injurious pecking, which suggests that this damaging behaviour contributes to decreased productivity and economic losses in commercial production. Injurious pecking also represents a serious welfare concern for domestic turkeys (Hocking, 1993; Sherwin et al., 1999; Duggan et al., 2014). The existing research into the development and causation of injurious pecking in turkeys suggests a complex relationship among multiple factors, but there is little literature on environmental and genetic approaches to reduce this damaging behaviour in modern flocks (Sherwin et al., 1999; Chapter 2). Current management practices to reduce damage from injurious pecking include a
combination of environmental tactics, such as lower light intensities (Lewis et al., 1998a; Moinard et al., 2001), reduced stocking densities (Gill and Leighton, 1984; Leighton et al., 1985; Buchwalder and Huber-Eicher, 2003, 2004), and the provision of enrichment (Sherwin et al., 1999; Martrenchar et al., 2001) - along with physical alterations, such as beak treatment and snood removal (Freeman, 1987; Krautwald-Junghanns et al., 2011a).

Infrared laser treatment is currently the most common form of beak trimming used in domestic turkeys and it is typically performed at the hatchery on day-old turkeys (Krautwald-Junghanns et al., 2011a). Compared to the more traditional hot blade method, infrared treatment prevents open wounds, reduces operator error, and reduces behavioural changes immediately after beak treatment as infrared treatment allows the beak tip to wear away gradually over several days (Dennis et al., 2009). Infrared beak treatment is standard practice to reduce injurious pecking damage in commercial turkey flocks. However, even with improvements of the less invasive infrared techniques, an average of 13% of all turkeys in beak treated flocks still show pecking injuries (Krautwald-Junghanns et al., 2011a). Public perception of beak treatment as a painful procedure, performed without analgesia and resulting in loss of beak tip sensation, has led to legislative efforts in several European Union countries towards banning beak treatment (Grigor et al., 1995; Fiks-van Nieker and de Jong, 2007). With beak treatment potentially being phased out of commercial practice, there is concern within the industry that environmental approaches alone will not prevent pecking damage from increasing in modern turkey flocks. One potential alternative solution is to examine the phenotypic variation in beak shape to explore the possibility of genetic selection to produce morphological results similar to beak treatment.
Traditional analyses of beak shape in poultry have used linear measurements of length, depth, and width to describe variation in beak morphology (Foster et al., 2007). However, these measurements are limited because they convey no geometric data on beak shape and the little information provided of beak shape is not independent of beak size (Rohlf and Marcus, 1993; Zelditch et al., 2004; Foster et al., 2007). Several studies of laying hens and broiler chickens have used measurements of the dorsal and lateral beak profile to describe differences in beak morphology following beak trimming, but this research was limited to discussion of the variation in beak size rather than true shape differences (Kuo et al., 1991; Craig et al., 1992; Fahey et al., 2007; Gentle and McKeegan, 2007; Marchant-Forde et al., 2008; Marchant-Forde and Cheng, 2010; Carruthers et al., 2012; McKeegan and Philbey, 2012). Landmark-based geometric morphometrics has been successfully applied to study morphological differences in beak shape between several closely related bird species resulting from adaptive radiation to different feeding strategies (Foster et al., 2007; Kulemeyer et al., 2009; Sievwright and Higuchi, 2011; Bright et al., 2016; Shao et al., 2016). This type of geometric morphometrics visualizes subtle features in the shape variation of a morphological structure as the displacement of biologically homologous landmarks (Bookstein, 1991; Zelditch et al., 2004). Compared to traditional measurements, geometric morphometrics allows for the separation of size and shape variation. Geometric morphometrics also benefits from heightened statistical power and fewer *a priori* assumptions regarding what measurements should be taken (Marcus et al., 1996; Zelditch et al., 2004).

The objective of this study was to evaluate the phenotypic variation in turkey beak shape using landmark-based geometric morphometrics, and to determine if age, sex, and beak size had an effect on the beak shape variation in domestic turkeys. To get a comprehensive understanding of turkey beak morphology, we examined the dorsal and lateral shape variation of the upper and
lower mandibles of domestic turkeys in three analyses at two ages. Determining the amount of phenotypic variation in beak shape within domestic turkeys in this study will then allow for an investigation of the genetic basis of beak shape variation. If beak shape variation shows a high response to selection, the possibility exists for future breeding to select for domestic turkeys with a reduced capacity to cause pecking damage as an alternative to beak treatment.

Materials and Methods

The experimental protocol in this study was approved by the University of Guelph’s Animal Care Committee (Animal Utilization Protocol #3171) in accordance with the guidelines outlined by the University of Guelph Animal Care Policy and the Canadian Council for Animal Care (CCAC, 2009).

Animals and housing

Beak morphology data were collected on male and female male-line Hybrid convertor turkeys (n = 2442) with known pedigree information. These turkeys came from two groups hatched two weeks apart in May - June 2014. At one day of age, turkeys were de-snooded then individually marked with numbered and bar-coded yellow plastic, tab end wing bands (National Band & Tag Company, Newport, KY, USA). The female and male turkeys from each hatch were housed together in a single power-ventilated, close-sided free-run barn and then separated into single sex flocks at 7 weeks of age in individual barns. The turkeys were housed under standard
commercial conditions and fed a standard diet of *ad libitum* feed and chlorinated water from shared feeders and drinkers (Hybrid Turkeys, 2013).

**Data Collection**

Each turkey was photographed at two ages: 6 and 18.5 weeks of age. The age class of 18.5 weeks was the average age of turkeys photographed for the second analysis of beak shape between 17-20 weeks of age. Photographs were taken as TIFF image files using a Canon Powershot G16 camera (Canon Canada Inc., Mississauga, ON, Canada) on a black wooden L-shaped platform composed on two black boards (each 20 x 20 cm, length x width) with the horizontal board secured to an adjustable camera tripod (Polaroid Corp., Minnetonka, MN, USA). Both platform boards included a 5 cm ruler for later scaling. A 5 cm plastic strip was also included on the horizontal board to ensure consistent positioning of the turkeys’ heads in the photographs. For each data collection, two photographs were taken from the dorsal and right lateral view of a turkey’s head. Dorsal photographs were taken with the camera at the top edge of the vertical platform board and captured a complete image of a turkey’s head from the beak tip to the base of the skull (Figure 7.1a). The right lateral images photographed the right side of a turkey’s head from the beak tip to the base of skull (Figure 7.1b,c). Right lateral images were taken with the camera placed on the edge of the horizontal board closest to the experimenter. For the dorsal and lateral images, the turkey’s head was positioned along the plastic strip on the horizontal platform board. To photograph a turkey, a technician lifted the turkey underneath the breast and gently held the turkey’s head on the plastic strip of the horizontal platform board while another technician photographed the turkey’s head from both angles.
Geometric Morphometrics

Placement of coordinates

Three analyses of beak shape were performed on the dorsal and right lateral images from each turkey at each age. Two analyses of the right lateral image provided a cross section of the beak shape of the upper and lower mandibles separately. A specific set of landmark and semilandmark coordinates (LM) were placed on the beak images in TPSDig version 2.17 (Rohlf, 2004) in the dorsal, upper mandible, and lower mandible analyses (Figure 7.1). For the dorsal analysis, three landmarks and 10 semilandmarks were placed along the dorsal outline of the upper mandible (Figure 7.1a). The right lateral analysis of the upper mandible used three landmarks and 10 semilandmarks on the outer margins of the upper mandible (Figure 7.1b). Shape analysis of the right lateral view of the lower mandible was also accomplished with three landmarks and 10 semilandmarks outlining the lower beak (Figure 7.1c; Foster et al., 2007; Sievwright and Higuchi, 2011). Landmarks are point locations that are biologically homologous between specimens (e.g., the tip in the upper mandible). In contrast, semilandmarks are points defined by extrinsic criteria and are commonly used to provide more shape information when traditional landmarks are unavailable (Zelditch et al., 2004; Gunz and Mitteroecker, 2013). In this study, semilandmarks were used to capture a complete outline of the beak shape in areas of the beak with no homologous points (Foster et al., 2007; Gunz and Mitteroecker, 2013).
Before the coordinates were applied, the scaling factor for measurement was set in TPSDig using the ruler that was included in the background of each image. The images were rotated (if necessary) to reduce extraneous variation in the placement of the coordinates. Dorsal images were rotated until a straight line could be drawn from LM 1 and a central line between landmarks 2 and 3 (Figure 7.1a). The lateral upper and lower mandible images were rotated to ensure the inferior edge of the lower mandible was straight before proceeding with the placement of coordinates (Figure 7.1b,c). Photographs were excluded from morphometric analysis if the images were blurry, the beak was damaged, or for the lateral lower mandible analysis, if the lower mandible was obscured underneath the upper mandible. Three technicians were individually responsible for one of the three types of analyses in TPSDig to minimize differences in coordinate placement between images.

The semilandmarks were positioned using a standardized grid and placed where the grid lines intersected the outer margins of the mandible being analyzed (Foster et al., 2007; Shao et al., 2016). For the dorsal images, a straight line was first drawn between LM 2 and 3; then the distance was calculated from this line to LM 1. The upper mandible was then divided in five equal portions along this distance and the semilandmarks positioned along the parallel lines of the grid where it intersected the dorsal outline of the upper mandible (Figure 7.1a). For the lateral upper and lower mandible images, the distance between LM 3 and the beak tip of the upper or lower mandible (LM 1) was used to divide the beak into five equal sections. The semilandmarks were then placed equidistantly at these grid lines along the right lateral outline of the upper or lower mandible (Figure 7.1b,c; Foster et al., 2007; Shao et al., 2016).
**MorphoJ shape analysis**

Multivariate statistical shape analyses of the turkey beak images were completed using TPSRelw w32 (Rohlf, 2004) and MorphoJ version 1.06d (Klingenberg, 2011). Separate MorphoJ analyses were performed for the two age groups and for the dorsal, lateral upper, and lateral lower mandible landmark configurations. After removing the outliers shown by Mahalanobis distance (i.e., the multidimensional measurement of standard deviation as the distance between an individual shape measurement and the consensus shape), morphometric beak data was available for 2429 dorsal, 2099 lateral upper mandible, and 2081 lateral lower mandible images for the six-week old turkeys (Klingenberg and Monteiro, 2005). For the 18.5-week old turkeys, morphometric analysis included 1501 dorsal, 1689 lateral upper mandible, and 1800 lateral images of the lower mandible. For the lower mandible images, LM 3 was excluded from final MorphoJ analysis as this landmark showed large variation in its placement due to differences in nostril positioning between turkeys with open or closed beaks, which prevented a clear analysis of the shape variation in the lower mandible.

The raw coordinates from each turkey image were first aligned through translation, scaling, and rotation using a generalized least squares Procrustes superimposition algorithm adjusting for sliding semilandmarks in TPSRelw. The aligned shape coordinates were then analyzed in MorphoJ (Bookstein, 1991; Shao et al., 2016). The Procrustes superimposition created a consensus beak shape for the all turkeys within each dataset by identifying the origin point, or centroid, among all the landmarks and semilandmarks in each image, which reduced the dimensionality of the coordinate data from $2k$ to $2k - 4$ ($k =$ total number of landmarks and
semilandmarks; Dryden and Mardia, 1998). The algorithm then calculated the centroid size for each image as the square root of the sum of squared distances between the centroid and each landmark/semilandmark (Rohlf and Slice, 1990; Bookstein, 1991; Dryden and Mardia, 1998). In this study, centroid size served as a measure of each turkey’s beak size independent of its shape (Kendall, 1997; Dryden and Mardia, 1998; Zelditch et al., 2004). Therefore, shape was defined as the geometric characteristics of the landmark configuration excluding its orientation, size, and position (Dryden and Mardia, 1998; Klingenberg, 2016).

In MorphoJ, a principal components analysis (PCA) was performed using the covariance matrix of the Procrustes shape coordinates to identify patterns of beak shape variation within each dataset (Zelditch et al., 2004). A canonical variate analysis (CVA) identified morphological shape patterns to distinguish the sexes within a dataset (Campbell and Atchley, 1981; Zelditch et al., 2004). For the principal components and canonical variate analyses, eigenvalues of each component/variate were considered significant for interpretation if they explained $\geq 5.00\%$ of the total beak shape variation within each dataset. A multivariate regression was used to examine the effect of beak size, using centroid size, on beak shape variation for all the turkeys in a dataset and also when the data was partitioned by sex (Klingenberg, 2016). The multivariate regression included a permutation test of complete independence between the two variables using 10000 randomization rounds. Procrustes Anova then tested the significance of the beak shape differences between male and female turkeys in each dataset (Klingenberg et al., 2002).

**Results**
Dorsal upper mandible images

The dorsal images of upper mandible included morphometric data from 1186 female and 1243 male turkeys at six weeks of age. The PCA of the dorsal Procrustes shape coordinates for the six-week old turkeys concentrated 95.36% of the explained total variance within the first three principal components (PCs). PC1 explained 74.56% of the shape variation in the dorsal shape profile of the upper mandible ranging between long/narrow beaks with pointed tips to short/wide beaks with blunt tips (Figure 7.2). PC2 explained 13.93% of the shape variation that showed a shift between a slightly rounder or thinner dorsal outline of the upper mandible and the widening/narrowing of the distance between the nostrils (LM 2 and 3; Figure 7.2a). In contrast, PC3 accounted for 6.87% of the shape variance that was associated with superior/inferior shifts of the dorsal beak outline (LM 1, 4-13) with an opposite shift in the nostrils (LM 2 and 3; Figure 7.2b).

Multivariate regression of centroid size showed beak size explained 43.50% of the dorsal shape variation in the upper mandible ($P < 0.0001$), which increased slightly when pooled by sex (45.09%, $P < 0.0001$). Along the axis of centroid size, centroid size explained the variation from long and narrow beaks with pointed tips to short and wide beaks with blunt beak tips for the dorsal upper mandible shape of both male and female turkeys. The CVA produced a single variate that explained 100% of the dorsal beak shape variation between male and female turkeys at 6 weeks of age. This variate showed female turkeys had a slightly wider dorsal upper beak outline shown as an outward shift of the semilandmarks (LM 4-13) and a more blunt beak tip (LM 1) than pointed beaks of male turkeys at this age ($F_{22,53394} = 9.14$, $P < 0.0001$; Figure 7.3).
The dorsal upper mandibles images of 773 female and 728 male turkeys at 18.5 weeks of age were analyzed in MorphoJ. Three principal components were extracted from the PCA that explained 92.21% of the total shape variation in the dorsal upper mandible for turkeys at this age. PC1 explained the majority of the shape variation within this group (64.98%) ranging from upper mandibles with a long and slender dorsal beak shape with pointed tips to short and wide beaks with blunt tips (Figure 7.4). PC2 referred to 21.61% of explained variation showing the superior/inferior shift of the dorsal beak outline (LM 4-13) with an opposite shift in the positioning of the nostrils (LM 2 and 3; Figure 7.4a). PC3 (5.62%) explained the widening/narrowing of the dorsal upper mandible outline (LM 4-13) associated with the narrowing/widening of the area between the nostrils (LM 2 and 3; Figure 7.4b).

Beak size accounted for 34.54% of the total dorsal shape variation in the upper mandibles for the 18.5-week old turkeys and 41.91% when the data was partitioned by sex (P < 0.0001). The larger centroid size of male turkeys (mean centroid size: 3.53 ± 0.01 mm; mean ± standard error of the mean) explained the longer and narrower shape of dorsal upper mandibles with more pointed tips (Figure 7.5). In contrast, female turkeys at 18.5 weeks of age had smaller centroid sizes (2.98 ± 0.01 mm), which explained the shorter and wider shapes of the upper mandibles with blunter beak tips (Figure 7.5). The shape of the upper mandibles also significantly differed between the sexes in the dorsal images of the 18.5-week old turkeys (F_{22,37136} = 99.19, P < 0.0001). The CVA of the dorsal upper mandible images produced one variate that explained 100% of the shape variation between the sexes at this age (Figure 7.6). The dorsal shapes of the upper mandible for
females were wider (LM 4-13) with blunter tips (LM 1; Figure 7.6). In contrast, male turkeys had narrower dorsal upper mandibles (LM 4-13) with more pointed beak tips (LM 1; Figure 7.6).

**Lateral upper mandible images**

For the six-week old turkeys, three principal components were captured from the PCA that cumulatively explained 94.91% of the total variation in right lateral shape of the upper mandible. PC1 accounted for 73.12% of the total shape variation and described the range in the lateral upper mandible shape from long, wide beaks with long, curved tips to short, narrow beaks with short, pointed beak tips (Figure 7.7). The PC1 shape changes were shown through rostral/cranial shifts in the beak tip (LM 1) and rostral/cranial shifts of the opposite beak margins (LM 4, 6, 8, 10, and 12 vs. LM 5, 7, 9, 11, and 13; Figure 7.7). Both the second (15.01%) and third principal components (6.78%) showed the narrowing/widening of the upper mandible accompanied by the superior and rostral/inferior and cranial shift of the beak tip (Figure 7.7).

Beak size accounted for 13.31% of the total lateral shape variation in the upper mandible for the six-week old turkeys ($P < 0.0001$). Partitioning the data by sex marginally increased the amount of lateral upper mandible shape variation explained by beak size ($r = 16.28\%, P < 0.0001$). Along the axis of centroid size, the lateral upper mandible shape of both male and female turkeys varied from wide beaks with more curved tips to narrow beaks with pointed tips. The CVA produced one variate that explained 100% of the variance in lateral upper mandible shape between the 1089 female and 1010 male turkeys in this group (Figure 7.8). Figure 7.8 shows female turkeys at this age had longer, more curved upper mandible tips (LM 1) whereas the
For the 18.5-week old turkeys, the lateral images of upper mandible included morphometric data from 932 female and 757 male turkeys. Three principal components were extracted from the PCA, which cumulatively explained 94.33% of the total variation in the right lateral shape of the upper mandible. PC1 explained the majority of the shape variation within this group (72.44%) ranging from long, wide upper mandibles with long, curved tips to short and narrow beaks with short, pointed beak tips (Figure 7.9). Figure 7.9 illustrates the PC1 shape changes shown through cranial and superior/rostral and inferior shifts in the beak tip (LM 1) and cranial/rostral shifts of the opposite beak margins (LM 4, 6, 8, 10, and 12 vs. LM 5, 7, 9, 11, and 13). The variation in the second (14.28%) and third principal components (7.61%) described the slight widening/narrowing of the lateral upper mandible shape along with the superior/inferior shifting of LM 1 showing the range from short beaks with pointed beak tips to long beaks with curved tips (Figure 7.9).

For the 18.5-week old turkeys, beak size only accounted for 0.97% of the total lateral shape variation in the upper mandible, which increased slightly to 1.03% when pooled by sex ($P < 0.0001$). Male turkeys had larger centroid sizes, which explained a more superiorly positioned, pointed upper mandible tip (mean centroid size: $8.92 \pm 0.03$ mm; Figure 7.10). Whereas female turkeys at 18.5 weeks of age had smaller centroid sizes (mean centroid size: $7.76 \pm 0.03$ mm), which explained upper mandibles with more inferiorly positioned, curved beak tips (Figure 7.10). The CVA yielded one variate that explained 100% of the shape variation in the upper mandibles of these males had shorter and more pointed beak tips ($F_{22,46134} = 15.25, P < 0.0001$).
mandible between male and female turkeys at 18.5 weeks of age. This canonical variate showed that female turkeys at 18.5 weeks of age had longer, more curved upper mandible tips whereas males had shorter, more pointed beak tips (Figure 7.11; $F_{22,37114} = 99.28$, $P < 0.0001$).

**Lateral lower mandible images**

The PCA of the right lateral lower mandible images produced three principal components that explained 97.80% of the shape variation in the six-week old turkeys. The first principal component accounted for 83.53% of the shape variation, which showed the range from wide/round to narrow/thin lower mandibles (LM 4-13) with an associated superior/inferior shift in the beak tip (LM 1; Figure 7.12). In contrast, PC2 (7.97%) and PC3 (6.29%) described the widening/narrowing of the lateral shape of the lower mandible (LM 4-13) and the superior/inferior shift of the beak tip (LM 1; Figure 7.12).

Using centroid size, beak size accounted for 34.20% of the total lateral shape variation in the lower mandible for all six-week old turkeys and 54.76% when partitioned by sex into groups of 1068 female and 1013 male turkeys ($P < 0.0001$). Along the axis of centroid size, the lateral lower mandible shape of both sexes varied slightly from narrow/wide. One canonical variate explained 100% of the variation between the lateral lower mandible beak shape of female and male turkeys at six weeks of age. The lower mandibles of female turkeys were rounder and wider with more inferiorly positioned beak tips than the more narrow, thin beaks with superior positioned beak tips of male turkeys at this age ($F_{20,41580} = 10.97$, $P < 0.0001$; Figure 7.13).
The lateral images of lower mandible included morphometric data from 962 female and 838 male turkeys between 18.5 weeks of age. Three principal components from the PCA cumulatively explained 97.11% of the right lateral shape variation in the lower mandible at this age. PC1 (83.14%) explained a majority of the shape variation ranging from wide and round to narrow and thin lower mandibles (LM 4-13) with superior/inferior shifts in the position of the beak tip (LM 1; Figure 7.14). Similarly, the second (8.33%) and third principal components (5.65%) described smaller changes between a wide and round to narrow and thin lateral shape of the lower mandible (LM 4-13) with inferior/superior shifts of the beak tip (LM 1; Figure 7.14).

At 18.5 weeks of age, beak size accounted for 15.95% of the lateral lower mandible shape variation, which was reduced to 6.29% when grouped by sex (P < 0.0001). Male turkeys had larger centroid sizes (mean centroid size: 9.03 ± 0.03 mm) that explained the wider shape of the lateral lower mandibles (LM 4-13) with more superiorly shifted beak tips (LM 1). In contrast, female turkeys at this age had smaller centroid sizes (7.44 ± 0.03 mm), which explained more narrow lateral lower mandibles (LM 4-13) with more inferiorly positioned beak tips (LM 1; Figure 7.15). CVA of the lateral lower mandible images produced one canonical variate that explained all the shape variation (100%) between male and female turkeys at 18.5 weeks of age (Figure 7.16). Female turkeys had more narrow and thin lower mandibles (LM 4-13) with an inferiorly positioned tips (LM1) than the more wide and round beaks with superiorly positioned beak tips of male turkeys at 18.5 weeks of age (F_{20,35960} = 245.89, P < 0.0001; Figure 7.16).

Discussion
Analysis with landmark-based geometric morphometrics showed a wide range of phenotypic shape variation in the beaks of domestic turkeys. For all three beak analyses, the main axes of beak shape variation were relatively consistent across ages. The dorsal outline of upper mandible showed a main axis of shape variation from long, narrow, and pointed to short, wide, and blunt beaks at both 6 and 18.5 weeks of age. Similarly, the range explained the majority of shape variation in lateral images of the lower mandible at both ages was from wide and round to narrow and thin lower mandibles with superior/inferior shifts in the lower beak tips. The lateral upper mandible showed a main axis of shape variation from long, wide upper beaks with long, curved tips to short, narrow beaks with short, pointed tips at both 6 and 18.5 weeks of age. The main shape axis for these turkeys parallels the main patterns of shape variation (long, narrow, and pointed vs. short, wide, and blunt) that have been reported in the lateral upper mandible profiles of other bird species (Foster et al., 2007; Kulemeyer et al., 2009; Sievwright and Higuchi, 2011; Bright et al., 2016; Shao et al., 2016). These authors proposed that the variation in beak shape across species corresponds most significantly to differences in feeding strategies. For domestic turkeys, the main axis of beak shape variation in turkeys likely reflects a combination of selection for male-to-male combat and behavioural feeding differences between male and female turkeys.

Sexual dimorphism in beak morphology was apparent between male and female turkeys across both ages and all three analyses. In all three shape analyses, the large degrees of freedom for the Procrustes ANOVA analyses showed a statistical difference in beak shape between the sexes, but also appeared to represent actual biological beak shape differences between the sexes as shown through the phenotypic variation in the CVA figures. The dorsal upper mandible outlines of
female turkeys at both ages were significantly wider with blunter tips than males that had narrower beaks with pointed tips. The lateral profile of upper mandible of female turkeys at both 6 and 18.5 weeks of age showed long and curved upper mandible tips, which would appear blunt dorsally. In contrast, the lateral upper mandible shape of male turkeys had short and pointed tips at both ages. The lateral variation in the lower mandible shape for these male and female turkeys showed opposite phenotypes for the two age groups. At six weeks of age, female turkeys had wide, round lower mandibles compared to the narrow, thin lower beak shape for male turkeys. However, the lateral lower mandible shape was narrow and thin for female turkeys and wide and round for male turkeys at 18.5 weeks of age. Sexual dimorphism in beak shape and size is present in other bird species and several hypotheses have been proposed to explain beak morphological differences between the sexes, including divergent feeding strategies, thermoregulation, and sexual selection for male competition and/or female choice (Berns and Adams, 2010; Greenberg et al., 2012, 2013).

In the wild, turkeys reside primarily in same sex groups so the beak shape differences between male and female turkeys might be partially attributed to the specific feed resources that each sex tends to use (Le V. Dit Durell et al., 1993; Berns and Adams, 2010; Temeles et al., 2010). Wild male turkeys use their beaks while fighting to establish dominance or gain access to females in lek-like mating displays, which suggests that the distinct male beak shape phenotype, such as the pointed shape of the upper mandible tips of male turkeys, developed as an effective weaponry for male-to-male conflict (Watts and Stockes, 1971; Buchholz, 1997; Greenberg et al., 2013). Research on a lek-breeding species of hummingbird by Rico-Guevara and Araya-Salas (2015) showed that adult males that were more successful in defending displaying territory had more
pointed beak tips than subordinate males or females. Wild female turkeys will also select males to breed based on physical qualities of fighting ability, which might include beak size and distinct beak shape characteristics (Watts and Stockes, 1971; Price, 1984; Kimball, 1996; Buchholz, 1997). Sexual selection might also explain the larger beak sizes of males in comparison to female turkeys at 18.5 weeks of age, which also likely corresponds to the larger overall body sizes of males vs. female turkeys following sexual maturity. This distinction in beak size between the sexes was not seen between male and female turkeys at six weeks of age (Babbitt and Fredrick, 2007; Greenberg and Olsen, 2010; Greenberg et al., 2013). The larger beak size of male turkeys might also have evolved to serve a thermoregulatory role by aiding in heat dissipation during male courtship displays under warmer conditions (Buchholz, 1996; Tattersall et al., 2009; Greenberg et al., 2012). However, domestic turkeys have undergone extensive selection under commercial production for physical and reproductive characteristics. Therefore, it cannot be assumed that the same biological pressures in wild turkey populations can explain distinctions in the male and female beak shape phenotypes in domestic turkeys.

In the three analyses of beak morphology, variation in beak size predicted varying amounts of the beak shape variation for these turkeys. Beak size explained approximately 35-55% of the explained morphological variation in the lower mandibles of the 6-week old turkeys and the dorsal upper mandibles of both ages. In contrast, beak size predicted less than 15% of beak shape variation in the 18.5-week old lateral lower mandibles and the lateral upper mandibles for both ages of turkeys. Bright et al. (2016) showed size-related changes in the beak and braincase accounted for 50% of the lateral upper mandible shape variation between raptor species. For domestic turkeys, specific beak features, such as the dorsal beak shape, might be closely
controlled by size, while the shape variation of other beak elements \(i.e.,\) the lateral upper mandible beak tip might be less constrained by beak size differences. However, more research is needed to substantiate the hypothetical relationships between the size and shape variation in the different beak structures of domestic turkeys.

In summary, landmark-based geometric morphometrics showed a range of phenotypic variation in the shape of dorsal upper mandibles, lateral lower mandibles, and lateral upper mandibles for domestic turkeys at 6 and 18.5 weeks of age. The main axes of shape variation were similar for the two ages, but the beak shape phenotypes of female and male turkeys differed significantly. The role of beak size in predicting beak shape for these turkeys differed between the three analyses and the two age groups. Given the wide phenotypic variation seen in turkey beak shape within this study, the beak shape variables could potentially be used to perform a quantitative genetic analysis to determine the heritability of beak shape variation. However, the implications from this turkey beak shape analysis is partially limited from only examining male-line turkeys and the reduced sample size for the shape analysis at 18.5 weeks of age. It is unclear if selection pressure for male-line traits, such as larger body weights and fast growth, could have influenced beak shape variation in comparison to female-line turkeys. However, the reduction in the sample sizes (13.6-38.2% reduction) from 6 to 18.5 weeks of age, which is attributed to poor photo quality and losses from culling and mortalities, likely impacted the interpretation of beak shape variation for the older group of turkeys. Subsequent morphometric studies of turkey beak shape variation should analyze the lateral upper and lower mandible shape together to fully understand how the complete shape of the beak varies within domestic turkeys. Before moving forward with selective breeding for beak shape, future research should examine if distinct beak shape
phenotypes influence the feeding behaviour and efficiency of domestic turkeys. Furthermore, there is a need for research to determine the potential pecking damage capability of the different turkey beak shape phenotypes before genetic selection can be considered as a realistic alternative to beak treatment.
Figure 7.1. The landmarks (grey) and semilandmarks (white) used for the geometric morphometric analyses of (a) the dorsal images of the upper mandible (LM 1, beak tip of the upper mandible; LM 2, rostral-most point of the right nostril; LM 3, rostral-most point of the left nostril; LM 4-13, semilandmarks), (b) the right lateral images of the upper mandible (LM 1, beak tip of the upper mandible; LM 2, rostral-most corner of the right eye; LM 3, rostral-most point along the major axis of the right nostril; LM 4-13, semilandmarks), and (c) the right lateral images of the lower mandible (LM 1, beak tip of the lower mandible; LM 2, rostral-most corner of the right eye; LM 3, rostral-most point along the major axis of the right nostril; LM 4-13, semilandmarks) for the domestic turkeys photographed at 6 and 18.5 weeks of age. The semilandmarks included in the three types of analyses were positioned where the beak outline intersected a standardized grid that divided the length of the beak equidistantly.
Figure 7.2. The dorsal shape variation in the upper mandible explained by (a) PC1 and PC2, and (b) PC1 and PC3 for the 2429 male (black) and female (grey) turkeys photographed at six weeks of age. The light blue beak outlines represent the mean dorsal shape of the upper mandible for these six-week old turkeys. The dark blue outlines are visual representations of the dorsal upper mandible shape at the minimum and maximum scores along the axis of each principal component.
Figure 7.3. The frequency of male (black) and female (grey) turkeys along the axis of the first canonical variate. The first canonical variate accounted for all dorsal shape variation in the upper mandible between male and female six-week old turkeys. The light blue beak outlines represent the mean dorsal shape of the upper mandible for these six-week old turkeys. The dark blue outlines are visual representations of the dorsal upper mandible shape at the minimum and maximum scores along the axis of the first canonical variate.
Figure 7.4. The dorsal shape variation in the upper mandible explained by (a) PC1 and PC2, and (b) PC1 and PC3 for the 1501 male (black) and female (grey) turkeys photographed at 18.5 weeks of age. The light blue beak outlines represent the mean dorsal shape of the upper mandible for these 18.5-week old turkeys. The dark blue outlines are visual representations of the dorsal upper mandible shape at the minimum and maximum scores for this group along the axis of each principal component.
Figure 7.5. The multivariate regression scores of the dorsal upper mandible Procrustes shape coordinates by centroid size for male (black) and female (grey) 18.5-week old turkeys ($r = 34.54\%$, $P < 0.0001$). The light blue beak outlines represent the mean dorsal shape of the upper mandible for these 18.5-week old turkeys. The dark blue outlines are visual representations of the dorsal upper mandible shape at the minimum and maximum centroid sizes for this group.
The frequency of male (black) and female (grey) turkeys along the axis of the first canonical variate. The first canonical variate accounted for all dorsal shape variation in the upper mandible between male and female turkeys at 18.5 weeks of age. The light blue beak outlines represent the mean dorsal shape of the upper mandible for these 18.5-week old turkeys. The dark blue outlines are visual representations of the dorsal upper mandible shape at the minimum and maximum scores along the axis of the first canonical variate.
Figure 7.7. The right lateral shape variation in the upper mandible explained by (a) PC1 and PC2, and (b) PC1 and PC3 for 2099 six-week old male (black) and female (grey) turkeys. The light blue grey beak outlines represents the mean lateral shape of the upper mandible for these 6-week old turkeys. The dark blue outlines are visual representations of the lateral upper mandible shape at the minimum and maximum scores for this group along the axis of each principal component.
Figure 7.8. The frequency of male (black) and female (grey) turkeys along the axis of the first canonical variate. The first canonical variate accounted for all right lateral shape variation in the upper mandible between male and female turkeys at six weeks of age. The light blue beak outlines represent the mean right lateral shape of the upper mandible for these 6-week old turkeys. The dark blue outlines are visual representations of the lateral upper mandible shape at the minimum and maximum scores along the axis of this canonical variate.
Figure 7.9. The right lateral shape variation in the upper mandible explained by (a) PC1 and PC2, and (b) PC1 and PC3 for 1689 male (black) and female (grey) turkeys photographed at 18.5 weeks of age. The light blue beak outlines represent the mean lateral shape of the upper mandible for these 18.5-week old turkeys. The dark blue outlines are visual representations of the lateral upper mandible shape at the minimum and maximum scores for this group along the axis of each principal component.
Figure 7.10. The multivariate regression scores of the right lateral upper mandible Procrustes shape coordinates by centroid size for male (black) and female (grey) 18.5-week old turkeys ($r = 0.96\%$, $P < 0.0001$). The light blue beak outlines shows the mean lateral shape of the upper mandible for both male and female turkeys at 18.5 weeks of age. The dark blue outlines are visual representations of the right lateral upper mandible shape at the minimum and maximum centroid sizes for these 18.5-week old turkeys.
Figure 7.11. The frequency of male (black) and female (grey) turkeys along the axis of the first canonical variate. The canonical variate accounted for all right lateral shape variation in the upper mandible between the sexes for the 18.5-week old turkeys. The light blue beak outlines represent the mean right lateral shape of the upper mandible for these 18.5-week old turkeys. The dark blue outlines are visual representations of the lateral upper mandible shape at the minimum and maximum scores along the axis of this canonical variate.
Figure 7.12. The right lateral shape variation in the lower mandible explained by (a) PC1 and PC2, and (b) PC1 and PC3 for 2081 six-week old male (black) and female (grey) turkeys. The light blue beak outlines represent the mean lateral shape of the lower mandible for these six-week old turkeys. The dark blue outlines are visual representations of the lateral lower mandible shape at the minimum and maximum scores for this group of turkeys along the axis of each principal component.
Figure 7.13. The frequency of male (black) and female (grey) turkeys along the axis of the first canonical variate. The first canonical variate accounted for all right lateral shape variation in the upper mandible between male and female turkeys at six weeks of age. The light blue beak outlines represent the mean right lateral shape of the lower mandible for these six-week old turkeys. The dark blue outlines are visual representations of the lateral lower mandible shape at the minimum and maximum scores for this group of turkeys along the first canonical variate.
Figure 7.14. The right lateral shape variation in the lower mandible explained by (a) PC1 and PC2, and (b) PC1 and PC3 for 1800 male (black) and female (grey) turkeys at 18.5 weeks of age. The light blue beak outlines represent the mean lateral shape of the lower mandible for these 18.5-week old turkeys. The dark blue outlines are visual representations of the lateral lower mandible shape at the minimum and maximum scores for this group of turkeys along the axis of each principal component.
Figure 7.15. The multivariate regression scores of the right lateral lower mandible Procrustes shape coordinates by centroid size for 838 male (black) and 962 female (grey) 18.5-week old turkeys ($r = 15.95\%$, $P < 0.0001$). The light blue beak outlines show the mean right lateral shape of the lower mandible for both male and female turkeys at 18.5 weeks of age. The dark blue outlines are visual representations of the right lateral lower mandible shape at the minimum and maximum centroid sizes for these 18.5-week old turkeys.
Figure 7.16. The frequency of male (black) and female (grey) turkeys along the axis of the first canonical variate. The first canonical variate accounted for all right lateral shape variation in the lower mandible for male and female turkeys at 18.5 weeks of age. The light blue beak outlines represent the mean lateral shape of the lower mandible for these 18.5-week old turkeys. The dark blue outlines are visual representations of the lateral lower mandible shape at the minimum and maximum scores for these 18.5-week old turkeys along this canonical variate.
Chapter Eight. General Discussion

The main objective of this thesis was to examine the relationships between the performance of injurious pecking and other behavioural and physical traits in domestic turkeys. This discussion summarizes the key findings and implications of the four presented studies, addresses any limitations of the experimental designs, and provides suggestions for future research.

In Chapter Four, I presented a study to evaluate the relationships among leg health, snood length, and within-group body weight variation on injurious pecking damage in male turkeys. Due to the small sample sizes and high mortality, the findings in this study are limited and might not be representative of all domestic male turkeys. Variation in body weights within the groups of turkeys in this study was not predictive of leg health, snood length, or skin and plumage damage later in life. The small number of replicates for each body weight treatment and similar variation in body weight across all weight treatments throughout the study likely prevented any detection of a statistical difference in aggressive head pecking damage between treatments. The retracted snood lengths of these males did not differ amongst weight treatments. Furthermore, variation in snood length showed no association to head pecking injuries in these turkeys. There is still uncertainty if snood length and body weight play the same role in domestic male turkeys as their wild counterparts that use these body characteristics as physical indicators of male dominance (Buchholz, 1997). A previous study by Cecil and Bakst (1991) showed the size of a domestic turkey’s testicles is positively correlated to its testosterone production. A future study to compare testes size, injuries from aggressive head pecking, and the development of male sexual ornamentation (e.g., snood length) between male turkeys could potentially impact the breeding
criteria for domestic turkeys (Appendix I). Identifying male sexual traits corresponding to aggression levels could allow for selection to reduce head pecking injuries for improved welfare in future turkey flocks.

From 11 to 21 weeks of age, the turkeys in the first study experienced declines in leg health showing worse gait scores, poorer footpad health and cleanliness, and a greater number and severity of deviated toes. The turkeys also developed more pecking damage to the head, neck, back, and tail regions over the course of the study. The increase in pecking damage occurred simultaneously with the decline of the leg health for these turkeys, but it is uncertain if one condition predisposes the other or if a temporal correlation exists between these two traits. Future research should directly examine if the relationship between leg health and injurious pecking damage is merely temporal or causal in nature. For instance, an investigation that experimentally induces mild lameness (e.g., via wet litter conditions) in two patterns of litter treatment (i.e., wet/dry vs. dry/wet) could assess if groups of turkeys have more injurious pecking damage when lame than during periods of normal leg health (Mayne et al., 2007; Youssef et al., 2011). A comprehensive understanding of the relationship between leg health and injurious pecking damage could lead to welfare improvements by supporting the early detection and removal of lame or pecked turkeys in commercial management.

For poultry, the activity level of an individual bird not only provides insight into its leg condition, but also its overall health status, feeding efficiency, and even its likelihood to injuriously peck (Duncan et al., 1991; Buchwalder and Huber-Eicher, 2005; Jensen et al., 2005; Kjaer, 2009; de Haas et al., 2010; Hocking and Wu, 2013). Video and live behavioural
observations are commonly used to assess turkey activity levels, but logistic and time constraints make these methods impractical for measuring stepping activity in large commercial flocks (Martin and Bateson, 2007). Therefore, the objective of my study (Chapter Five) was to validate the use of Onset HOBO Pendant® G acceleration data loggers for automated step detection in two ages of turkeys and two experimental conditions: grower turkeys in a runway set-up and finisher turkeys in a free-run trial pen. For both the grower and finisher trials, the data loggers showed relatively high sensitivities, specificities, precision, and accuracy for step detection. However, the loggers frequently overestimated the step count increasing the false discovery rates for step detection. In this study, logger error and lower sensitivities for step detection could be attributed to the high acceleration threshold for step detection, shifting of the logger on the leg during stepping, and a lack of clarity during the slower, shuffle-like steps of sexually mature males. Use of the HOBO loggers for monitoring the activity of individual turkeys in large flocks would be limited by the loggers’ susceptibility to background noise and the low capacity for data storage. However, these loggers can still be reliably applied to record the stepping activity of turkeys with high accuracy and low error in small-scale research settings, such as the runway set-up for the grower trial. Environmental and social disruptions have been shown to increase flock activity levels resulting in turkeys performing head pecking to calm the flock (Cunningham et al., 1992; Buchwalder and Huber-Eicher, 2003, 2004). Future research could use this recently validated technology to report fluctuations in stepping activity, alongside changes in injurious pecking rates, within a group of turkeys following a flock disturbance.

Activity levels were also identified as a distinguishing feature in the organization of the behavioural sequences of head, severe, and gentle feather pecking in turkeys. In Chapter Six,
multivariate T-pattern detection and conventional assessments of behavioural frequencies and
durations provided a complimentary look at the organization of pecking behaviour in male
turkeys. Both conventional and T-pattern analyses showed turkeys in observations of head
pecking appeared more active than turkeys engaged in gentle or severe feather pecking. These
results are consistent with previous research showing turkey flocks can become more active and
perform head pecking following environmental or social disturbances, which suggests strategies
to prevent social and environmental disruptions could reduce outbreaks of head pecking
(Cunningham et al., 1992; Buchwalder and Huber-Eicher, 2003, 2004). The conventional and T-
pattern analyses also showed turkeys in observations of severe feather pecking tended to gentle
peck more frequently than turkeys in head pecking observations. These findings support the idea
of a shared origin between these two pecking types as severe feather pecking is believed to
develop from investigatory gentle feather pecking that becomes more forceful (Savory, 1995;
Chapter 2). Yet these two analytical methods gave conflicting results on the structure of feeding
and foraging behaviour amongst the three pecking types, which highlighted limitations of both
methods and suggests these behaviours should be evaluated separately. The small sample sizes
for the head and severe feather pecking observations were limiting factors for this study and
might have skewed the results from the conventional analysis. These pecking observations had
been adopted from a previous project, and unfortunately the original video footage was no longer
available to sequence further pecking behavioural observations for this study. Another potential
limitation in this study is the large individual variability in number of detected T-patterns
suggesting the results from this research should be taken as exploratory.
The organization of an animal’s behaviour can provide insight into its welfare status, particularly with regard to its ability to cope within its environment. Asher et al. (2009) characterized animals experiencing good welfare as possessing a complex behavioural repertoire with the ability to vary their behaviour when encountering novel stimuli within their environment. In contrast, animals with compromised welfare housed under poorer social and/or environmental conditions might show fewer behaviours overall and relatively simple, invariable behavioural reactions to novel environmental stimuli (Asher et al., 2009; Brilot et al., 2009; Sinclair et al., 2015). In order to get a comprehensive understanding of the organizational differences in turkey pecking behaviour, the behavioural structure, variation, and complexity of the different pecking sequences should continue to be evaluated using other methods of statistical behavioural analysis and modeling, such as de-trended fluctuation analysis, Markov temporal models, and lag-sequential analysis of behavioural transitions (Merlet et al., 2005; Hocking et al., 2007; Lee et al., 2011). These approaches will increase our understanding of damaging vs. investigatory pecking behaviour, which will aid in the design and application of mitigation strategies to prevent injurious pecking in commercial turkey production. For instance, Lee et al. (2011) used Markov modeling based on optical flows of bird movement following a disturbance to accurately predict later plumage damage in laying hen flocks, which was attributed to outbreaks of damaging feather pecking. This experimental protocol from Lee et al. (2011) could be adapted to turkey behavioural research to further investigate the particular flock disruptions that result in increased head pecking damage in domestic turkeys.

My previous study showed that individual differences in behavioural phenotypes between turkeys (i.e., activity levels) affect a turkey’s likelihood to engage in injurious pecking. My next
step was to investigate if physical differences in beak shape phenotypes between turkeys influenced a turkey’s damaging pecking behaviour. Using landmark-based geometric morphometrics, I showed the range of morphological variation in the shape of dorsal upper mandibles, lateral upper mandibles, and lateral lower mandibles for domestic turkeys at 6 and 18.5 weeks of age. The main axes of shape variation were similar for the two ages, but the beak shape phenotypes of female and male turkeys differed significantly. The role of beak size in predicting beak shape variation differed between each age group and the three analyses. Since turkey beak shape showed large phenotypic variation, an evaluation of the heritability of turkey beak shape variation can now be conducted. The genetic variation in beak shape could be determined using the principal components coefficients of the morphometric beak shape variables in a full-sib model for a multivariate quantitative genetic analysis (Klingenberg and Leamy, 2001). This procedure would allow for patterns of genetic variation in the beak shape landmarks to be assessed using the multivariate breeder’s equation for the short-term response to selection (Klingenberg and Leamy, 2001; Klingenberg et al., 2010; Adams, 2011).

One limitation of this morphometric study of beak shape was the decision to examine the lateral shape of the upper and lower mandibles separately. Analyzing the mandibles separately did not allow for a complete understanding of how full beak shape and beak size varies amongst individual turkeys, which would be especially invaluable when assessing the puncture capability of different beak shape phenotypes. Before moving forward with selective breeding for beak shape, there is a need for further research to determine the potential pecking damage capability of the different beak shape phenotypes. A functional assessment of the beak puncture capability of turkeys could be performed using the experimental methods from Rico-Guevara and Araya-
Salas (2015). This study evaluated the force required to puncture a thin plastic film on a digital scale using distinct hummingbird beak morphologies. Rico-Guevara and Araya-Salas (2015) showed that pointier beaks punctured with less force than blunter beak shapes. Along with an experimental assessment of beak puncture variation, breeding for specific beak shape phenotypes in turkeys should include an evaluation of potential differences in injurious pecking damage inflicted by different beak shape morphologies. A clearer understanding of the direct relationship between beak shape, feeding behaviour, and injurious pecking damage is required before beak shape characteristics should be considered for inclusion in breeding objectives for commercial domestic turkeys.

This thesis incorporated new and previously unexplored methodological approaches to examine the relationships between the performance of injurious pecking and other behavioural and physical traits in domestic turkeys. In Chapter Four, the development of injurious pecking damage was recorded alongside measures of leg health, body weight, and snood length in male turkeys. Chapter Five described the validation of HOBO Pendant® accelerometers for the measurement of turkey activity levels in small-scale research settings. Future research should employ this validated technology to evaluate the relationship between the injurious pecking behaviour and the activity levels of turkeys. In this thesis, T-pattern detection software was used to analyze behavioural sequences of head, severe, and gentle feather pecking providing insight into differences in the organization of these pecking behaviours in turkeys (Chapter Six). Finally, the use of landmark-based geometric morphometrics allowed for the determination of the morphological variation in the beak shape of male and female domestic turkeys (Chapter Seven). This geometric research provides a foundation for future behavioural and quantitative genetics
studies to evaluate the pecking damage potential and the heritability of the different beak shape phenotypes.


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Appendix I

Background

The following data were collected as a pilot study to investigate the amount of testicle size variation among sexually mature domestic male turkeys. The purpose of data collection was to determine the appropriate sample size for future research to evaluate the associations among testicle size, snood length, and injuries from aggressive head pecking in sexually mature male turkeys.

Materials and Methods

For this pilot study, both testicles were extracted from the 44 male turkeys in the Chapter Four study following euthanization. The turkeys were euthanized with a single shot into the frontal bone by a Zephyr non-penetrating captive bolt pistol as outlined in Erasmus et al. (2010). Following euthanization, the turkeys were placed dorsally on the dissection table to extract both testicles. Two trained technicians used chrome-plated steel scalpels (No. 22 blade, Fisher Scientific Company, Toronto, ON, Canada) to make two incisions cranial-caudally into the ventral abdominal body cavity of each turkey parallel to the joints between both leg femurs and pelvic girdle. Once each testicle was located, a technician removed the testicle gently by cutting off the epididymis and any attached bloods vessels.

Once removed, each testicle was weighed using a compact digital scale (readability: ± 0.1 g;
Fisher Scientific Company, Toronto, ON, Canada). The length, width, and depth of each testicle were also measured with a digital caliper (0.01 mm resolution; World Precision Instruments, Sarasota, USA). Testicle length was measured as the distance between the cranial and caudal margins of the testicle as it is positioned within the body cavity. In contrast, the width of a testicle was measured as the distance between the left and right margins of the testicle measured at the point of attachment to the epididymis as the testicle is positioned within the body cavity. Finally, the depth of a testicle was measured as the distance between the dorsal and ventral margins of the testicle along its transverse plane at the point of attachment to the epididymis as the testicle is positioned within the body cavity.
Results

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