Detection of jumping and landing force in laying hens using wireless wearable sensors

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ABSTRACT Increased mobility of hens in noncaged housing presents possibilities for bone breakage due to crash landings from jumps or flights between perches or housing infrastructure. Because bone breakage is a welfare and economic concern, understanding how movement from different heights affects hen landing impact is important. By tracking 3-dimensional bird movement, an automated sensor technology could facilitate understanding regarding the interaction between noncage laying hens and their housing. A method for detecting jumps and flight trajectories could help explain how jumps from different heights affect hen landing impact. In this study, a wearable sensor-based jump detection mechanism for egg-laying hens was designed and implemented. Hens were fitted with a lightweight (10 g) wireless body-mounted sensor to remotely sample accelerometer data. Postprocessed data could detect occurrence of jumps from a perch to the ground, time of jump initiation, time of landing, and force of landing. Additionally, the developed technology could estimate the approximate height of the jump. Hens jumping from heights of 41 and 61 cm were found to land with an average force of 81.0 ± 2.7 N and 106.9 ± 2.6 N, respectively, assuming zero initial velocity ($P < 0.001$). This paper establishes the technological feasibility of using body-mounted sensor technology for jump detection by hens in different noncage housing configurations.

Key words: wearable sensor network, laying hen, jump detection, keel bone breakage, poultry welfare

2014 Poultry Science 93:2724–2733
http://dx.doi.org/10.3382/ps.2014-04006

INTRODUCTION

Laying hens are motivated to roost on elevated perches at night for sleep and for resting during the daytime (Newberry et al., 2001; Schrader and Muller, 2009). The provision of perches is an important component of hen welfare because perches accommodate the natural roosting behavior of the birds (Lay et al., 2011). As the laying hen industry increases noncage egg production, understanding the effect of perch layout and height on hen mobility is paramount. Perches have been shown to improve bone strength (Fleming et al., 1994), facilitate symmetrical growth (Campo and Prieto, 2009), and allow hens a safe refuge from perceived dangers (Newberry et al., 2001). However, hens with access to perches and other elevated structures can experience keel bone breakage (Wilkins et al., 2011; Nasr et al., 2012a), which has been associated with reduced productivity and ensuing economic loss (Nasr et al., 2012a) as well as causing pain and discomfort to the hen (Nasr et al., 2012b).

In noncage housing, perches are located at different levels within multi-tiered units. The perches and tiers increase the effective space available to the hens by allowing them to use the vertical space within the unit. The increased vertical mobility of hens in this noncage housing presents a situation where hens must move among vertical levels to access resources, potentially placing them at risk of bone breakage due to crash landings or impacts with the environment. Bone breakage is a welfare concern, and therefore it is important to understand effects of hen movement among vertical levels on bone health. Understanding the landing forces on hens as they move from different perch heights can facilitate the development of housing that provides hens with perches and tiers in safe configurations that minimize the risk of bone damage.

The goals of this paper are to introduce a new sensor technology for automated tracking of hen movement in 3-dimensional space, present preliminary data demonstrating feasibility of the technology, and discuss challenges, applications, and future steps needed to improve this technology. A wearable sensor-based mecha-
nism was developed to detect whether a hen has made a jump, defined as the departure of a hen from a perch toward a lower landing surface, with no ascent due to wing flapping, although the wings may be used to slow the descent. Additionally, to understand the physical mechanism of landing, the sensor technology was used to calculate the landing force, the approximate height from which the jump was performed, the jump initiation time (i.e., the time at which a hen started a jump), and the landing time (i.e., the time at which a hen landed on the ground). Understanding the forces a hen undergoes during a jump will provide a platform for future research into how movement throughout the environment could result in physical injury.

MATERIALS AND METHODS

Sensor System

A Mica2Dot mote radio node (Crossbow Technology Inc., San Jose, CA), operating at a 900 MHz radio frequency channel, provided the hardware basis for the developed detection system. The Mica2Dot mote, which operates on a 560 mAh coin cell battery, was equipped with a low-power 3-axis ADXL335 accelerometer (Analog Devices, Norwood, MA) capable of measuring acceleration over a ±3 g range with ±0.3% nonlinearity and ±0.01%/°C temperature stability. The total weight of the sensor was approximately 10 g, and it was placed inside a casing and mounted on a hen’s back with a figure-8 nylon harness (Figure 1). This sensor was termed the mobile node. After experimenting with several other attachments, it was found that mounting the mobile node on the back of the hen using the harness resulted in the maximum amount of sensor stability while maintaining sufficient signal quality for collection of acceleration data and avoiding any tissue damage to the hen. To further stabilize the sensor movement inside the casing, fine-celled thermoset phenolic plastic foam was used. The foam was cut to proper dimensions and formed the bedding inside the casing on which the sensor was placed. Additionally, the lid of the casing was lined with soft urethane foam to provide further cushioning and support.

Data were collected at the rate of 100 Hz (10-ms sampling interval). Once activated during the data collection process, the mobile node continuously sampled acceleration data (−3 g to +3 g) in 3 axes and sent them to a laptop PC via a base station (BS) using a 900-MHz wireless link. The BS was a Mica2 mote equipped with custom hardware capable of sending data through an RS232 serial link. The antenna used on the system determined the radio range for the mobile node and the BS. Quarter wave whip antennas of solid copper wire were used for both the mobile node and the BS, which gave a range of approximately 10 to 15 m. This basic construction antenna was sufficient for the requirements of this study. However, long-range antennas may be used if a higher range is desirable.

Birds and Housing

Prior to the start of the study, all animal-based procedures were approved by the Michigan State University Institutional Animal Care and Use Committee. Twenty beak-trimmed Hy-Line W-36 hens were housed in 2 identical pens (n = 10/pen) starting at 16 wk at the Michigan State University Poultry Research and Teaching Center. Hens were fed a commercial layer diet ad libitum. Each pen (3.2 m²) was fitted with 2 nest boxes that provided 0.2 m² of nest space, a commercial tube feeder, a water line with 3 nipples, and 3 cm of wood shavings on the floor as litter, as well as 2 wooden perches providing 15 cm perch space per hen, both at a height of 46 cm from the floor. Hens were exposed to 15 h (0600–2100 h) of incandescent light daily, providing light intensities ranging from 17.4 to 30.1 lx at hen height depending on distance from the 12 light sources.
and variation in housing infrastructure that may have blocked the light in some pens. Room temperature fluctuated from 8.1 to 24.6°C depending on ambient weather conditions. At 29 wk, 6 hens (3 from each pen) were selected for the training process based on strong displays of food motivation and willingness to approach humans. At 41 wk, hens were transferred to a new room (3 × 4.5 m) where all 20 hens were housed together. This room was furnished with four 30 × 30 cm nest boxes arranged in a 2 × 2 grid mounted on the wall 33 cm off the ground, a water line containing 10 nipples, one commercial tube feeder, and a wooden perch system placed 30 cm from the wall with three 1.8-m-long perches at different heights. Perch heights were 30, 53, and 76 cm in height from the floor with perches positioned at an increasing elevation toward the nearest wall and spaced 23 cm apart. Data collection began at 54 wk.

**Data Collection Arena and Apparatus**

A 3 × 4.5 m room within the same barn in which the hens were housed was designated as the data collection (testing) room. A wooden perch apparatus with a height-adjustable perch (length: 76 cm, width: 3.8 cm) was constructed within the room (location shown in Figure 2). Perch heights of 46 and 61 cm were selected for data collection within the range of heights from which hens typically jump within a noncage system. Light intensity was 30.5 lx at hen level at the location of the perch apparatus. Prior to data collection, each hen was weighed using a digital bench scale (Acculab sv-50, Bradford, MA); BW data were needed to calculate landing forces. A pressure mapping system (HRV2-VersaTek-Map #7101D, Tekscan, South Boston, MA) with a testable matrix area of 97.5 × 44.7 cm was used to collect landing force data. The pressure mapping system was covered with a beige vinyl material for protection and provided a nonslip landing surface for the hens. Two video camcorders (Canon VIXIA HRM41, Tokyo, Japan) were used to record hen jumps, one from the side and one from the front. Video data were needed to interpret and validate the sensor data so that, in the future, the sensor technology could stand alone as a fully automated measurement device. The approximate location of the side view camcorder was 117 cm from the perch apparatus at a height of 71 cm. The camcorder recording from the front was located approximately 203 cm from the perch at a height of 145 cm. These values were approximate due to minor adjustments made by changing the camera position and zooming the lens to ensure that the entire jump and landing was captured. Data from the pressure mapping system were interpreted using the Walkway Clinical Software (Tekscan), which was run on a laptop PC.

**Hen Training Procedure**

Each habituation and training step was performed by a single handler over the period specified in Table 1. The sensor harnesses were fitted to the hens 3 wk prior (at 26 wk) to the training phase to allow for ha-
bituation (Daigle et al., 2012), and remained on the hens throughout the entire training and data collection period. Hens were habituated to the handler by holding each hen individually within her home pen for a period of 30 to 60 s, beginning with 30 s the first day and increasing at 10-s increments until 60 s was reached. After the appropriate time had elapsed, the hen was presented a dish of mealworms and peas and placed gently back on the floor. The same dish was used throughout all training and data collection.

Hens were subsequently habituated to the testing room. Hens were carried individually from their home pen to the testing room where they were held for 30 to 60 s, increasing in time each session as done previously. After the time had elapsed, the hen was presented the dish of mealworms and peas and returned to her home pen. This was repeated for all the selected hens. Once the hens were accustomed to the testing room, they were introduced to a recorded beep sound, which would later help cue the hen to jump during the data collection phase. Each hen was individually removed from her home pen and carried to the testing room where she was placed on the floor and a 1-s-long beep was played. Immediately following completion of the beep, the hen was presented with the dish of mealworms and peas. This process of playing the beep and giving the reward was repeated until the beep had been played 10 times in a single session. The hen was then returned to her home pen. Hens were next habituated to the perch apparatus. Hens were individually carried to the testing room where they were placed on the perch. While on the perch, the beep was played and the reward was presented. The process of playing the beep and presenting the reward was repeated until the beep had been played 10 times in a single session. The hen was then picked up and returned to her home pen. This was repeated until all of the selected hens had been habituated to the perch and beep.

Finally, the hens were trained to jump from the perch onto the ground in front of the perch. Hens were individually removed from their home pens and carried to the testing room where they were placed on the center of the perch. The beep was played and immediately following completion of the beep the dish of worms and peas was placed on the ground 30 to 60 cm in front of the hen. If the hen did not jump toward the dish, she was gently tipped forward until she jumped and then was immediately allowed to eat a pea or a worm and was given verbal praise. If the hen jumped before the beep, no food reward was given. The hen was then placed back on the perch and the process was repeated until the hen had made 10 food-rewarded jumps per training session. After each session, the hen was returned to her home pen. All hens except one were successful in meeting the training criterion of jumping within a few seconds after hearing the beep.

At 37 wk (8 wk into the training phase), the hens were habituated to the vinyl protective cover for the pressure mapping system. The cover was placed directly in front of the perch apparatus and hens were cued to jump in the same manner as previously used to train jumping. The vinyl cover was used in subsequent training as well as during data collection. After vinyl cover habituation was completed, training was given twice per week to maintain levels of jumping performance between testing sessions.

### Data Collection

An additional Mica2 mote was used during the data collection process. It served 2 main purposes: (i) synchronize the BS and the mobile node, and (ii) trigger the audible cue (beep) for the hen to initiate the jump/flight. The mobile node and the BS needed to be synchronized before each jump. Once synchronized, the mobile node started collecting accelerometer data at 100 Hz and sent the data to the BS, which transferred the data to the laptop PC. Additionally, the pressure mapping system (Tekscan, described above) reported the landing force of the hen, and the jump was also recorded using video cameras.

The number of jumps per hen on each data collection day varied and was dependent on her willingness to jump. When hens were willing, data collection took approximately 20 min/hen. Care was taken to avoid keel bone damage to the bird subjects. Regular keel bone palpation indicated no problems. Data collection took place during the afternoons of 4 nonconsecutive days over a 2-wk period. Data were collected on 2 d from the 46-cm perch height, and 2 d from the 61-cm perch height, and a paired t-test (PROC TTEST) was conducted in SAS 9.4 (SAS Institute Inc., Cary, NC) to identify differences in the landing forces from the 2 perch heights. Three individuals familiar to the hens

### Table 1. Hen training schedule

<table>
<thead>
<tr>
<th>Training period</th>
<th>Week</th>
<th>Training days/week</th>
</tr>
</thead>
<tbody>
<tr>
<td>Habituation to handler</td>
<td>1 and 2</td>
<td>3</td>
</tr>
<tr>
<td>Habituation to testing room</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Habituation to sound of beep</td>
<td>4 and 5</td>
<td>5</td>
</tr>
<tr>
<td>Habituation to perch</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>Training to jump</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>Habituation to vinyl cover</td>
<td>8 to 25</td>
<td>Initially 5/wk, gradually decreasing to 2/wk over the 17-wk period</td>
</tr>
<tr>
<td>Continuation of jump training</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Data collection</td>
<td></td>
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</tr>
</tbody>
</table>
RESULTS

In the absence of any drag force or buoyancy, the force acting on the hen’s body can be represented as shown in Figure 3. In the figure, (1) is when a constant acceleration (1 g) is acting on the hen when she is stationary on the perch. When the hen jumps (i), she is under free-fall and the force acting on the hen is 0 at (2). The force component increases at (3) when the hen lands on the ground (l), and an equal and opposite force acts upon the hen at (4). This is also when the magnitude of the force becomes greatest. Next, as the hen settles on the ground (5), a constant acceleration (1 g), as shown by (6), acts on the stationary hen.

were present during the data collection procedure. One ensured proper functioning of the sensor and controlled the timing of sensor data collection, the second person ran the Walkway software and the pressure mapping system data collection, and the third person handled the hen and provided her with rewards.

Detection Method

The detection procedure consisted of 3 steps: force calculation, postprocessing, and jump-detection and validation.

**Force Calculation.** The static and dynamic acceleration acting on the hen was calculated from the data collected from the accelerometer:

\[ a = \sqrt{a_x^2 + a_y^2 + a_z^2}, \]

where \( a_x, a_y, \) and \( a_z \) are the acceleration components in the \( x, y, \) and \( z \) directions, respectively. The force component was calculated using \( F = ma, \) where \( m \) was the mass of the hen in kilograms. Figure 4(a) shows the force extracted from the accelerometer data from a typical jump.

**Postprocessing.** The calculated \( F \) values (i.e., the raw force components) were postprocessed by passing them through a moving-average low-pass filter:

\[ F'_i = \frac{\sum_{k=i-2}^{i+2} F_k}{5}, \]

where \( F_k \) was the force component at the \( k\)th time instant. Next, \( F'_i \) was passed through a step function:

\[ F''_i = \begin{cases} \mu, & \text{if } |F'_i - \mu| < t \\ F'_i, & \text{if } |F'_i - \mu| \geq t \end{cases}, \]

where \( F''_i \) was the postprocessed force component, \( \mu \) was the mean acceleration of the hen at a stationary position and \( t \) was a threshold used to remove the low-

![Figure 3](image-url)  
**Figure 3.** Hen jump model. In the figure, (1) is when a constant acceleration (1 g) is acting on the hen when she is stationary on the perch. When the hen jumps (i), she is under free-fall and the force acting on the hen is 0 at (2). The force component increases at (3) when the hen lands on the ground (l), and an equal and opposite force acts upon the hen at (4). This is also when the magnitude of the force becomes greatest. Next, as the hen settles on the ground (5), a constant acceleration (1 g), as shown by (6), acts on the stationary hen.

![Figure 4](image-url)  
**Figure 4.** (a) Force (F) in Newtons for a typical jump from 46 cm height and (b) the postprocessed force component (F'') in Newtons corresponding to the same jump.
amplitude components. Figure 4(b) shows the postprocessed data corresponding to the data in Figure 4(a). As can be seen from the figure, the processed data closely match the model presented in Figure 3.

**Jump-Detection and Validation.** Jump-detection was performed using the filtered data. The maximum peak in the data (spike), which occurred at the moment of impact with the ground after the take-off, indicated a jump. A threshold-based mechanism detected that a jump had been performed if the processed force component had crossed a certain threshold value.

Landing time \((l)\) was the moment of impact of the hen with the ground as denoted in the model in Figure 3. The force acting on the hen was greatest at the moment of impact, and the corresponding time was the landing time.

Jump-initiation time \((i)\) was the time when the hen left the perch as indicated in the model. For the detection of jump-initiation time, the lowest valley within a given time window preceding \(l\) was chosen. The time window \(w\) was chosen such that \(w \gg l - i\).

Approximate jump-height \((h)\) could be estimated from the landing force of the hen using \(h \propto l - i\) and \(h \propto \max\{F\}\).

**Detection Results**

**Jump-Detection.** The jump detection procedure was performed offline after the accelerometer data had been collected. Jump-detection was perceived as a binary variable where 1 indicated that a jump had been performed, and 0 indicated no jump. Because a jump involved significant changes in acceleration of the hen, it could be differentiated from other hen activities and detected by a threshold-based mechanism. A threshold variable \(\tau\) was used

\[
J = \begin{cases} 
0, & \text{if } F'' < \tau \\
1, & \text{if } F'' \geq \tau 
\end{cases}
\]

where \(J\) was the binary variable indicating whether a jump had been performed. From the experiments, it was observed that a \(\tau = 50\) N was sufficient for \(h \geq 46\) cm.

Figure 5 shows both the raw and postprocessed force component, for different hens and multiple jump instances, calculated from the accelerometer data. During the landing, the force fluctuated between 60 and 130 N, depending on the subject hen because, unlike an inanimate object free fall, hens do not stop instantaneously once they land on the ground. During the jump, the hen extends her wings, and upon impact, she bends and contracts her leg muscles and joints to absorb the shock of landing. Additionally, the landing process does not stop instantly after the hen touches the ground. Rather, it consists of multiple short hops resulting from the moment of inertia, similar to a ball, dropped from a height, bouncing on the ground until it becomes stationary. The fluctuations in the force component are a result of such movements of the hen. For example, from the postprocessed jump data \((F')\) of hen 1, run 1, Figure 5(a) shows that there was a sudden decrease in force from 62.3 to 50.9 N at time = 281 ms. This was attributed to the hen extending her wings, providing resistance to a straight fall. Similar observations were made for other subject hens. Thus, for hen 3, run 2, Figure 5(b) shows a drop in the force from 93.2 to 63.1 N at 356 ms. The maximum impact force of 120 N occurred when the hen completely landed on the ground at 372 ms.

**Jump Initiation Time and Landing Time.** The detected jump initiation time \(i\) and landing time \(l\) obtained from the sensor data were validated by comparing them with the \(i\) and \(l\) from video data. The corresponding times are marked in Figure 5. The mismatch errors can be attributed to 2 factors. (i) The video was recorded at 30 frames per second (fps), which is a low sampling rate when compared with the millisecond resolution of the sensor data. (ii) The video data were decoded by a human, whose reaction time is in the order of tens to hundreds of milliseconds.

**Force Calculation.** The force calculated from the sensor data was compared with the data obtained from the pressure mapping system. Figure 6 shows the 2 components and the corresponding error. There was close correspondence between the calculated \(F\) from the 2 systems. However, in certain instances, the error was as high as 33%. This disparity may be attributed to movement of the accelerometer inside the casing, as well as movement of the casing on the hen’s body. The force and error rate for each hen were relatively consistent across initial and subsequent jumps, suggesting that increased experience jumping from the perch did not affect the amount of force during landing. The main physical attributes of the subject (i.e., weight, feather cover, and other features of the hen) were relatively unchanged between the different jump instances. However, the force values were not exactly equal because, although the jumping style and landing technique were similar across jumps for the same hen, the jumps were not performed in exactly the same manner over multiple instances.

**Approximate Jump Height.** Figure 7 shows that the landing force (N) measured from the hens as they jumped from the 0.61-m perch was higher than the force measured after they jumped from the 0.46-m perch \((t_{14} = -5.98, P < 0.0001)\). The difference in landing force was not sufficient to definitively classify the height from which the jump was performed \((h)\). However, when this information was used in addition to the jump duration (i.e., \(l - i\)), \(h\) could be categorized. For instance, in 90% of cases (30 out of 33 jumps), \(F\) for a given hen at 61 cm was higher than \(F\) for the same hen at 46 cm, and for 100% of cases \(l - i\) for 46 cm was less than that for
61 cm. This classification mechanism could be extended for different jump heights by collecting landing force and jump duration data for multiple jump heights and for hens belonging to different weight and size groups.

**DISCUSSION**

A wearable wireless sensor technology was developed and implemented to detect whether a jump was per-
formed by a hen. Additionally, the system was able to detect jump initiation and landing times, force of impact during landing, as well as the approximate height of the jump. When deployed in noncage housing systems, such technology could automatically detect and register jump times and the approximate height of jumps. Despite the presence of metal obstacles in such environments, reliability and robustness can still be ensured. Because the data are initially stored on the sensor itself, packet losses due to multipath or attenuation could be compensated using acknowledgment-based retransmission mechanisms. This information could aid in pinpointing events and locations that present an increased risk for hen keel bone breakage, subsequently leading to improved housing design. Future work on the sensor will include improvement of sensor stability, as well as integrating a detection mechanism into the sensor, which will perform online processing and send instantaneous notification to the user software interface when a jump is detected. Future application of such sensor-based data could be used to facilitate understanding about how much force is required for bone damage or breakage and could identify risk factors in

Figure 6. Force measured in Newtons plotted from pressure mapping system and accelerometer data and the corresponding error (%) for the same 3 hens at (a) height = 46 cm and (b) height = 61 cm.

Figure 7. Forces (N) upon landing from 2 perch heights by the same hens. Different letters (a,b) indicate significant differences, \( P < 0.0001 \).
the hen’s environment potentially associated with bone breakage.

Toscano et al. (2013) determined that when a 3.8-kg weight was dropped onto the carina of the keel of dead hens with an impact force of 95.3 kJ, there was a 43% probability of producing a severe keel fracture, and a 57.3 kJ force had a 70% probability of not producing a keel fracture. In comparison, we found that live hens jumping from 41 and 61 cm landed with an average force of 15.85 and 20.80 kJ, respectively, assuming zero initial velocity, suggesting that our hens were not at risk of keel fracture when jumping from these heights. In reality, there are several other factors acting on the hen that need to be taken into consideration when interpreting the sensor data. Primarily, when landing, a hen will usually flap her wings to reduce the force of impact with the ground. Additionally, upon impact with the ground, her leg muscles and joints will bend and contract to absorb the shock of landing. Other factors include air-drag from feather cover, variation in landing behavior across different jumps and different hens, and differences in the initial jumping trajectory and the initial velocity. These factors must be taken into consideration to accommodate hens with variation in feather cover (due to feather pecking, molting, or interactions with the environment) and are at different stages in the laying cycle. Such data will allow for a conservative approach to housing design that promotes hen safety throughout life. Therefore, further development of the sensor system will include hens of varying ages and feather cover to ensure that even though the forces associated with a jump differ, a jump is still reliably detected.

Also, for studies requiring more precise validation of sensor detection accuracy, a high resolution, high-speed recording system would be necessary to minimize human error and reaction time inaccuracies during visual validation. One solution would be the use of high-speed cameras capable of recording thousands of fps. For example, even a camera recording at 1,000 fps would increase the resolution of the analyzed image by more than 30 times. However, because this equipment is expensive, careful consideration should be given to the tradeoffs regarding cost and resulting quality. For our study, financial constraints required the use of video cameras utilizing a 30-fps recording rate, and upon review of video footage, this resolution was deemed sufficient to validate the approximate jump initiation and landing times of the hen. The sensor system was also designed in a way that precluded the need for sensor-specific calibration before deployment. As long as the training algorithm and run-time deployment use the same hardware (i.e., the same accelerometer chip) specifications, no separate calibration would be needed. Chip-to-chip (i.e., chips with same specifications) accuracy variation was found to be well within the tolerance of the presented training/learning algorithm. For the hardware used in our system, the nonlinearity range was ±0.3%, whereas the package alignment error and inter-axis alignment error were within 1 and 0.1 degrees, respectively, and the cross-axis sensitivity was also within 1%.

Movement of the sensor and the casing relative to the bird also limited the accuracy of the current system. Use of surgical glue may improve stability of the device on the bird, facilitating investigation of optimal sensor placement locations on the bird’s body. However, even if the current system has some noise, its ability to detect most jumps will be useful for hen housing research by reducing labor involved in direct behavioral observation. In the future, advances in miniaturization will enable use of multiple sensors on a single bird to investigate relative movement of different body parts during take-off, flight, and landing. When further miniaturization is coupled with advances in power supply, it will become feasible to implant sensors under the skin for long-term surveillance of bird movements.

The sensor system, when coupled with assessment of bone damage and the force required to break a keel bone at various stages of production, can aid in determining whether bone breakage in hens occurs due to jumping per se, or if damage has been sustained via other avenues such as faulty landing technique or non-jump-related environmental factors. Upon further development, this technology may also detect occurrences of upward flight by hens and provide similar information related to landing times, impact forces, and flight heights. This system has practical application in the evaluation of landing forces on individual hens differing in age, size, plumage integrity, and previous experience as hens move between vertical levels in a large commercial noncage housing system. This information will enable improvements in housing design that contribute to hen health, well-being, and productivity by understanding what is a safe height for hens to jump from as they maneuver through their environment.

**ACKNOWLEDGMENTS**

This project was supported by Agriculture and Food Research Initiative competitive grant no. 2009-65120-05752 from the USDA National Institute of Food and Agriculture.

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