INTRODUCTION

In 1965, the Brambell Committee in the United Kingdom issued a report advocating that farm animals be ensured Five Freedoms: to turn around, lie down, stand up, stretch, and groom, without restriction of movement (Brambell, 1965). Two US states have recently enacted legislation that echoes this language. For example, California’s Prevention of Farm Animal Cruelty Act (2008; effective 2015) stipulates that confined farm animals must not be prevented for most of the day from standing up, lying down, fully extending their limbs, and turning around without touching the side of an enclosure or another animal. For egg-laying hens, “extending limbs” is defined as spreading both wings without touching the sides of an enclosure or other hens. Michigan has a similarly worded statute, but which also requires that each hen have “access to at least 1.0 square feet of usable space” (929 cm²; Animal Industry Act, 1988, amended 2009). Neither law explicitly mandates or outlaws the use of particular hen housing systems.

These laws pose challenges in terms of translating the performance-based requirement for freedom of movement into an engineering-based standard applicable to all hen housing systems. Engineering standards for minimum floor area for both cage and noncage systems are already in use in many countries and regions, including the European Union (EU; CEC, 1999) and the United States (United Egg Producers (UEP), 2010; Table 1). The EU standards were based upon scientific research, practical experience, and discussion occurring during comments on proposed regulations (Appleby, 2003). The UEP (2010) standards for conventional cages were based on a literature review focused mainly on mortality, feather quality, stress, and egg production data (Bell et al., 2004), whereas those for noncage systems were also based on practical experience because there were less available published data.

Although there has been significant research on the effects of stocking density in different hen housing systems on health, production, and availability of resources, there has been less on how hens use space while performing particular behaviors. Most research has involved evaluating how providing different amounts of

Determination of space use by laying hens using kinematic analysis

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ABSTRACT Two states in the United States now have legislation requiring that laying hens be provided with sufficient space to perform particular behaviors. To provide a framework for translating these performance standards into a space requirement, kinematic analysis was used to measure the amount of space needed for White Leghorn hens to stand, turn around 180°, lie down, and wing flap. Hyline W-36 hens (n = 9) were marked on the tops of their heads and the tips of both wings and 3 toes with black livestock marker. Each hen was then placed in a floor pen (91.4 × 91.4 cm) and filmed using 2 high-speed cameras. The resulting images were processed using a software program that generated 3-dimensional space use for each behavior. Because none of the hens lay down in the test pen, the 2-dimensional space required for lying was determined by superimposing a grid over videos of the hens lying down in their home cages. On average, hens required a mean area of 563 (± 8) cm² to stand, 1,316 (± 23) cm² to turn around, 318 (± 6) cm² to lie down, and 1,693 (± 136) cm² to wing flap. The mean heights used were 34.8 (± 1.3) cm for standing, 38.6 (± 2.3) cm for turning, and 49.5 (± 1.8) cm for wing flapping. However, space requirements for hens housed in multiple-hen groups in cage or noncage systems cannot be based simply on information about the space required for local movement by a single hen. It must also incorporate consideration of the tendency of hens in a flock to synchronize their behaviors. In addition, it must include not just local movement space but also the space that hens may need to use for longer-distance movements to access resources such as food, water, perches, and nest boxes.

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Research Note
space affects the expression of various behaviors (Savory et al., 2006), particularly in the context of flock social interactions (reviewed by Weeks and Nicol, 2006). An approach more directly relevant to the aforementioned state regulations involves measuring the amount of space used during the performance of different behaviors. Dawkins and Hardie (1989) measured video images to determine the space required for hens to stand, ground scratch, turn, wing stretch, wing flap, feather ruffle, and preen. They used Ross Brown hens, which are larger than the white birds that make up the majority of US egg production.

The development of kinematic technology provides the opportunity for more accurate determination of the space used by animals to perform behaviors than manual measurement from video recordings and has the additional advantage that space use can be evaluated in 3 dimensions. Kinematic analysis is most often used to assess gait patterns of animals (e.g., Nielsen et al., 2003), but also been employed to assess the amount of space that dairy cows use when lying down in order to make recommendations about improving stall design (Ceballos et al., 2004). The goal of the current study was to use kinematic analysis to evaluate the space required for Hy-Line W-36 hens, the strain most commonly used in US egg production, to stand up, lie down, fully extend both wings (wing flap), and turn around freely. This information was then used to derive a formula for calculation of space required per hen that can be used to determine a minimum space requirement, taking into consideration different interpretations of regulatory language related to freedom of movement.

### MATERIALS AND METHODS

Nine mature (approximately 1.5 yr of age) well-feathered Hy-Line W-36 hens from the Hopkins Avian Research Facility flock at the University of California, Davis, were used. They were housed individually in cages (45.7 × 45.7 cm) before the start of the study. One hen was euthanized for flock management reasons before the recording of lying behavior; all other hens were returned to the flock after being filmed. Housing and experimental procedures were approved by the Institutional Animal Care and Use Committee of the University of California, Davis.

Each hen was marked with black livestock marker on the top of her head, tip of her tail, tips of 3 of her toes, and tips of both of her wings and placed in a test pen constructed of polyvinyl chloride (PVC) pipe and chicken wire (91.4 × 91.4 cm) for up to 1 h while being video recorded. A round PVC perch (2.54 cm diameter, 91.4 cm long) was placed in the pen approximately 12.7 cm from the floor to stimulate the hen to jump up and down and thus to wing flap.

A control object of known measurement was placed in the pen and the space calibrated by filming and digitizing the object. Two high-speed cameras (Fastcam PCI, Photron, San Diego, CA) were placed at the front of the testing pen. Hens were recorded 1) standing in a relaxed posture, 2) turning 180°, and 3) wing flapping. The 2-dimensional files from these cameras were combined to create one 3-dimensional (3-D) event file using Vicon Motus 9.2 software (Vicon, Los Angeles, CA). Standing and turning were filmed at 60 Hz, and wing flapping was filmed at 500 Hz. The average floor space in 3-D used by the hens was calculated for each behavior using the maximum length and width of the hens, as determined by the software. Each hen was filmed until she had performed all of the behaviors once. Because none of the hens lay down during the test period, space required for lying was determined by recording lying hens from above in their home cages, superimposing a premeasured grid over the video recording, and deter-
mining the hen’s length from head to tail and her width at the widest cross-section. Hens were also weighed using a digital scale (Ohaus, Pinebrook, NJ). Mean values and their SE were calculated for each behavior and for BW for the 9 hens used in the study.

**RESULTS AND DISCUSSION**

The means and SE for the space measurements obtained from the kinematic recording and video measurements are presented in Table 2. The data are similar to those reported by Dawkins and Hardie (1989) for larger-bodied Ross Brown hens weighing between 1.9 and 2.6 kg (mean = 2.2), compared with the 1.3 to 1.9 kg (mean = 1.6 ± 0.7) weights of the W-36 hens in the current study. This indicates that space for movement is only minimally influenced by BW, at least within this range of weights.

However, the results of the current study do differ in some respects from those of Dawkins and Hardie (1989). The mean value for standing for the W-36 hens (563 ± 8 cm²) was larger than that for the Ross Browns (475.3 cm²), and the range of values was also wider (W-36: 391–716.8 cm²; Ross: 428–592 cm²). This was probably because the hen’s head position during standing can be either erect or extended, which plays an important role in determining the floor area when kinematic analysis is used, because the area is measured using the “drop” from the beak tip and tail. The mean area for turning (1,316 ± 23 cm²) was similar to that for Ross Browns (1,271.8 cm²), although the range was wider (W-36: 925.8–2,191 cm²; Ross: 475.3–1,518 cm²). Hens can make turns that vary in the area covered. In our study we defined a turn as a 180° movement, whereas Dawkins and Hardie (1989) did not provide a turning definition. For wing flapping, the W-36 mean value (1,693 cm²) was somewhat less than that for Ross Browns (1,876.3 cm²), and the range was also slightly narrower (W-36: 1,085.6–2,446.6 cm²; Ross: 1,085–2,606 cm²). The maximum value we recorded for wingspan (61.7 cm) was smaller than Hyline’s reference value (71.9 cm) for the W-36 wingspan (Neil O’Sullivan, Hyline, Des Moines, IA, personal communication). However, examination of the videotapes showed that hens do not fully extend their wings when flapping to the extent that a person would extend a hen’s wings when taking a wingtip-to-wingtip measurement. Although Dawkins and Hardie (1989) did not provide a measure of wingspan for the Ross Browns they used, the current data demonstrate that using body measurements such as wingspan to calculate space may not provide an accurate measurement of the actual space required to perform particular behaviors.

Table 2 also shows values for the behavior that on average used the most space, wing flapping, with an additional 2.54 cm added to the mean length and width. This value was arbitrarily chosen to provide additional space for hens to wing flapping without touching the enclosure or other hens. With this addition, enclosures that provide less than 1,913 cm² total floor area (the mean area needed for wing flapping), do not have a length or depth of at least 53.1 cm (mean wingspan plus 2.54 cm), or both, would not meet the requirements even for a singly housed hen.

In addition, enclosures that do not have a height of at least 49.5 cm over the minimum floor area might prevent wing flapping. Nicol (1987) and Albentosa and Cooper (2004) evaluated behavior in cages of different heights. In the former study, which was carried out in conventional cages, wing flapping/raising was very rare and was observed only in the tallest cage (55 cm), whereas in the latter study, which used small (10-hen) furnished cages, full wing flapping was not observed even in the tallest cage (45 cm). This could be either because cages physically restrict wing flapping, or because they restrict long-distance movement and wing flapping is usually observed mainly when hens are running or flying. Wing flapping is often referred to as “comfort” (stretching) behavior, and hens also show other comfort-type behaviors that involve wing raising (slight elevation of both wings) and wing stretching (one wing stretched downward). Because these behaviors require less space than wing flapping, they were not measured in this study. Although wing flapping is often associated with running or flying it is also seen when hens are stationary, making its function unclear.
(Duncan, 1981). Regardless, a recent study of US commercial hen facilities indicates that the majority of A-frame cages are not only insufficient in height for hens to wing flap, but to stand (Kiess et al., 2012), based on the current data.

Extrapolating these data to derive a minimum space recommendation for group-housed hens requires information about how many hens need to be able to perform the stipulated behavior(s) simultaneously. Although there are several studies evaluating behavioral synchrony in hens kept in pairs in cages (Mench et al., 1986; Webster and Hurnik, 1994) or in small groups in pens (Collins et al., 2010), the data are insufficient to determine how motivated hens are to perform behaviors simultaneously in different commercial housing systems under different conditions of group size and resource provision. Using the Dawkins and Hardie (1989) data, Broom and Fraser (2007) provided an estimation of the per-hen space that would be needed in 5-hen conventional cages under several scenarios, with the least space required for 4 hens crowded together and one wing flapping (544 cm²), and the most space for 2 hens standing, 2 turning, and 1 wing flapping (917 cm²).

Because hens in all housing systems spend a significant proportion of their time standing or lying down (e.g., Keeling, 1994; Webster and Hurnik, 1994; Channing et al., 2001; Savory et al., 2006), one reasonable interpretation of the US regulatory language might be that space needs to be provided for one hen to wing flap while the remaining hens are standing or lying. Using the maximum value for wing flapping (plus 2.5 cm; 1 in) and the average value for standing (which required more space than lying), the per-hen floor space (in cm²) required is estimated for different group sizes (n) as follows: 2,711 + [(n − 1) × 563.2]/n. Using this equation, Figure 1 shows the amount of space needed per hen for different group sizes in both centimeters and inches. As can be seen from this figure, less space per hen is required as group size increases, although the overall size of the enclosure obviously also increases. The floor space required per hen essentially levels off at approximately 599 cm² (93 in²) when the group size reaches 60, although very large groups (1,000 or more) require slightly less space per hen [approximately 564 cm² (87 in²)]. The Michigan (Animal Industry Act, 1988, amended 2009) engineering standard of “at least 1 square feet of usable space” (0.093 m²) would therefore provide sufficient space under this scenario in a 5-hen enclosure that measures at least 0.47 m² (5 ft²), but not enough space if more than one hen must be allowed to wing flap simultaneously.

These results agree with theoretical predictions about relationships between group size and freedom of movement within enclosures. Appleby (2004) modeled free movement in furnished cages and showed that larger enclosures provided more free movement space even if each hen was only provided with slightly more space than her body size. Free space opens up in larger enclosures because hens do not use all of the space available to them but instead cluster (Keeling and Duncan, 1989; Collins et al., 2010). This free space permits local freedom of movement for behaviors such as feeding, scratching, stretching, preening, and sitting (Appleby, 2004).

A variety of factors, some static and some dynamic, affect how much space hens need and how that space is used (Keeling, 1995). These factors include genetics, group size, environmental variables (e.g., ambient temperature), hen age, social effects (e.g., Keeling, 1994; Lindberg and Nicol, 1996), and resource provision and distribution. The floor space allocation calculated here for a 60-hen group (599 cm² or 93 in²) is virtually identical to the minimum EU usable floor space requirement for furnished cages (600 cm²; Table 1); 60 hens is a common group size in newer versions of such cages. It is also very similar to the minimum floor space value
per-hen space in noncage systems could potentially obstruct the longer-distance movements necessary for hens to reach resources such as feed, water, nests, and perches, stressing the importance of basing space standards on multiple welfare criteria.

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REFERENCES


