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Effects of Slope upon Hind Limb Kinematics in Chukar Partridge (Alectoris chukar)

Anna T. Kenney
anna.t.kenney@gmail.com

EFFECTS OF SLOPE UPON HIND LIMB KINEMATICS IN CHUKAR PARTRIDGE (*ALECTORIS CHUKAR*)

By

ANNA TREMAINE KENNEY

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Approved by:

Dr. Bret Tobalske, Associate Professor,
Division of Biological Sciences

ABSTRACT

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Faculty Mentor: Dr. Bret Tobalske

Ground dwelling birds must scale all kinds of complex terrain in order to survive in their natural environments. For instance, *Alectoris chukar* live on steep hillsides with slopes of up to 60° or 172.3% slope. We undertook the present study to improve understanding of how birds successfully traverse such complex terrain. Using a high speed camera, we analyzed the hind limb kinematics of chukars during normal locomotion on a 10° and 35° incline, decline, and level slope. We compared the data collected from the video recordings, which we had used to identify and digitize the bony landmarks, between all conditions. We discovered that the kinematics of the hind limbs of chukars differed significantly depending on the angle of slope being traversed during normal locomotion. Compared to the other conditions, during descent at 35°, the maximum and minimum knee angles and the maximum angles within the foot demonstrate significant differences. This result suggests a correlation between the steepness of the slope being traversed and the muscular activity required to acquire the specific body positions necessary to accomplish locomotion on the various, demanding slopes found in their habitats.

INTRODUCTION

In the wild, *Alectoris chukar*, birds that are in the Galliformes clade, have to scale all kinds of terrain in order to survive. Certain populations live in the extremely mountainous terrain of the Himalayas, where they must traverse steep slopes (Christensen 1970). They mostly live on hillsides with rocky slopes that can range from angles of 30˚ to 60˚. In North America, chukars live in high-elevation shrub land anywhere from 4,000 to 13,000 feet. Being ground dwelling birds that can only fly short distances, they rarely resort to flying unless threatened. Instead, they rely almost exclusively on the camouflage provided by brushes and grasses. Traversing through their complex habitat requires the chukars to dart quickly from shrub to shrub in order to survive, and efficiency in gait over a wide variety of slopes is essential for energy conservation and ultimately, survival.

Traversing on sloped surfaces places different mechanical demands on the musculoskeletal system than on level surfaces, requiring significant alterations to body positions and muscular use (Biewener and Daley 2007). A study on incline running in turkeys (*Meleagris gallopavo*) found that the amount of work done by the lateral gastrocnemius muscle is proportional to the level of incline being traversed (Roberts et al. 1997). Despite this study also only examining incline locomotion, it hints at a strong association between the amount of muscle activity needed to traverse on non-level planes and the steepness of the plane. Another study focused on muscle function within the lateral gastrocnemius, as well as other prominent hind limb muscles, in guinea fowl during bipedal walking, but only conducted experiments on a level and 16˚ incline slope. This study also found there was a direct correlation between body mass and the amount of work produced in order to perform different locomotive tasks (Biewener and Daley 2003). This information suggests that muscle function depends on the conditions present during locomotion

While many scientists have researched muscle function during level and incline bipedal locomotion in birds, there is almost no research regarding decline locomotion (Roberts et al. 1997). However, one study states that moving downhill significantly reduces velocity due the fact that the bird's movements are easily augmented due to gravity (Kivell et al. 2010). Previous studies have also pointed out that bipedal animals tend to alter the function of their legs by using their limbs as brakes when moving downhill (Lammers et al. 2006). The little evidence that there is regarding decline vs incline and level locomotion emphasizes the point that the muscles within the hind limbs of birds do indeed function differently depending on the conditions of the environment that the bird is in.

We want to study whether the overall kinematics of the hind limbs of chukars will differ significantly depending on the angle of slope being traversed. Thus, rather than only studying locomotion at low level angles or during incline locomotion, as seen in the previous studies mentioned above, we will observe the kinematics during both incline and decline locomotion at up to 35˚. The result of this study can be used to help us gain a better understanding about how birds function during bipedal locomotion in a wide variety of conditions.

Given the information from previous studies that have involved similar experiments and state that angles within the hind limb joints are affected by slope, we predict that the kinematics of the hind limbs of chukars will differ significantly depending on the angle of slope being traversed during normal locomotion (Higham and Nelson 2008). In particular, we predict locomotion on a steep decline slope will differ from the other level or incline slopes. An alternative hypothesis is that there will be a correlation between the steepness of the slope being traversed and body positions necessary to perform locomotion on the various slopes. We believe that the chukars will realign their body postures in order to adapt and overcome the difficulties of walking on a steep slope within our experiment, as they do in their natural habitats.

METHODS

We analyzed the hind limb kinematics during locomotion on a 10° and 35° incline, decline, and level slope using footage recorded with a high speed camera. A study found that the hind limbs of birds still produce a sizeable force while the bird is engaged in wing assisted incline running (Bundle and Dial 2003). Due to this, we also recorded footage of wing assisted incline running at 70° in order to analyze kinematics during locomotion on extreme slopes.

Our first experiment involved four adult, male chukars. We built an adjustable ramp that we used as the substrate for our experiments. Ramp training for the chukars consisted of five sessions of decreasing length that consisted of the chukars individually walking across a level plane, as well as up and down an incline and decline ramped sloped at 10° and 35°. Each chukar was placed on one end of a level, incline, and decline ramp sloped at the previously listed angles and then encouraged to traverse in a normal walk to the other side. Because the birds regulated their gait characteristics, such as step length and swing time, the velocity of each bird was not controlled.

For recording sessions, we anesthetized the birds using an Isoflurane inhalant and then plucked and trimmed the feathers around six joints of the left hind limb: the hip, knee, ankle, foot, and the toe (made up of the distal, intermediate, and proximal phalanges on the 3rd digit or middle toe). We painted these bony landmarks with a black base, using a non-toxic "Sharpie" brand pen, and a white dot in the middle of the joint, using non-toxic, water-based acrylic paint, in order to easily digitize the points during later kinematics analysis. We also painted a point on the chest to use as a reference point that remains relatively stable during a normal stride. We then recorded three versions of each experiment during each condition, in order to control for variations, onto the Photron Fastcam Viewer (PFV) software using a photon SA-3 camera with a shutter speed of 1/5000 second. The entire experiment took place over the course of 10 weeks, including ramp training and actual recording sessions.

We then used the footage from the experiments to analyze the kinematics of the hind limb muscles during the various conditions described above. We digitized the identified bony landmarks during a full stride, tracked the points through space and time, and then converted these to angles through a custom script in MatLab, DLTdv5, and Igor Pro (Hedrick, T. L. 2008). The flexion-extension angles that we examined were the hip angle: the femur relative to the midline of the body, the knee angle: the femur relative to the tibiotarsus, the ankle angle: the tibiotarsus relative to the tarsometatarsus, the whole toe angle (foot): the tarsometatarsus relative to the first phalange of the 3rd digit, or middle toe, and the within toe angle: the distal phalange relative to proximal phalange. We just digitized one trial in accordance with the norms in this field due to the time intensive process of digitization.

RESULTS

Regarding ascension, we found that there were noticeable differences in the angles of the hip depending on whether the chukar was ascending at 35° or 10°. Compared to the ascending 35° graph, the angle of the hip stays relatively constant when the chukar is walking up a 10° slope, as seen in the differences in the range of angle fluctuations in the hip, displayed by the red line in graphs (Figs. 1 and 2). The graphs show a seemingly uneven amount of time spent between swing and stance phase, with the majority being spent in swing phase (Fig.1).

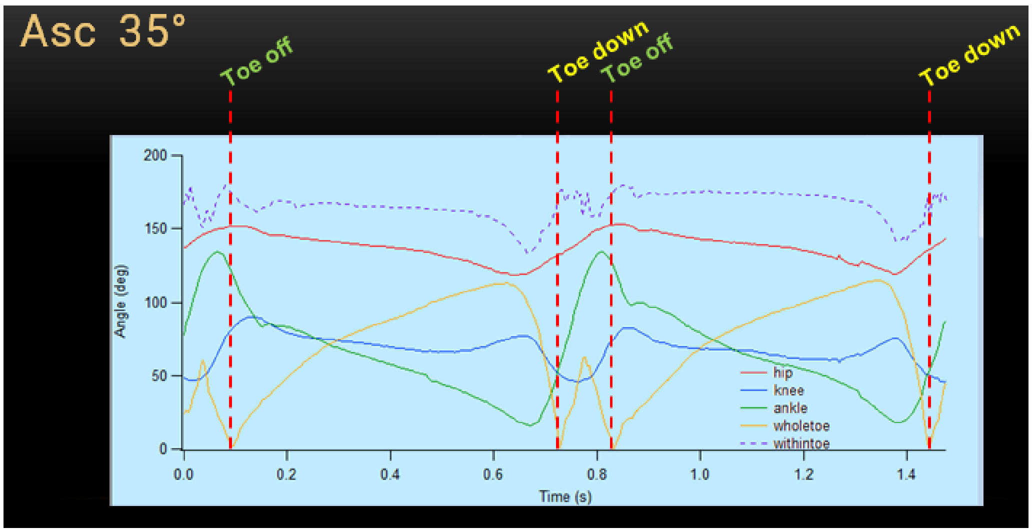

Fig. 1. Angles of all six joints over a full stride during ascending at 35°
Bottom right key: Red = hip, blue = knee, green = ankle, orange = whole toe (foot), dashed purple = within toe

To orient you to this graph, between toe off and toe down is swing phase, when the leg is not touching the ground, and between toe down and toe off is stance phase, when the hallux is in contact with the ground,

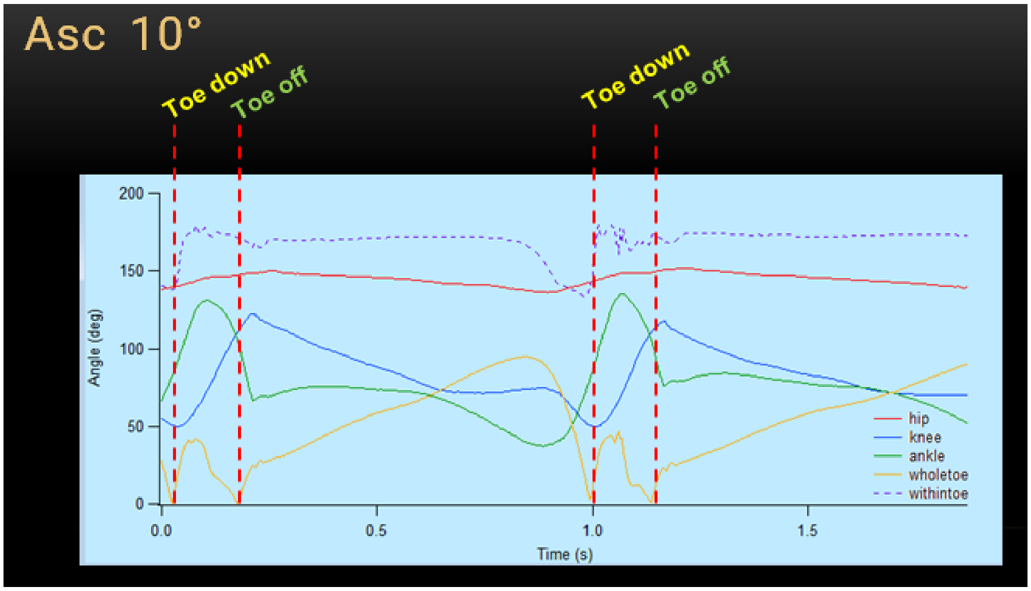

Fig. 2. Angles of all six joints over a full stride during ascending at 10°

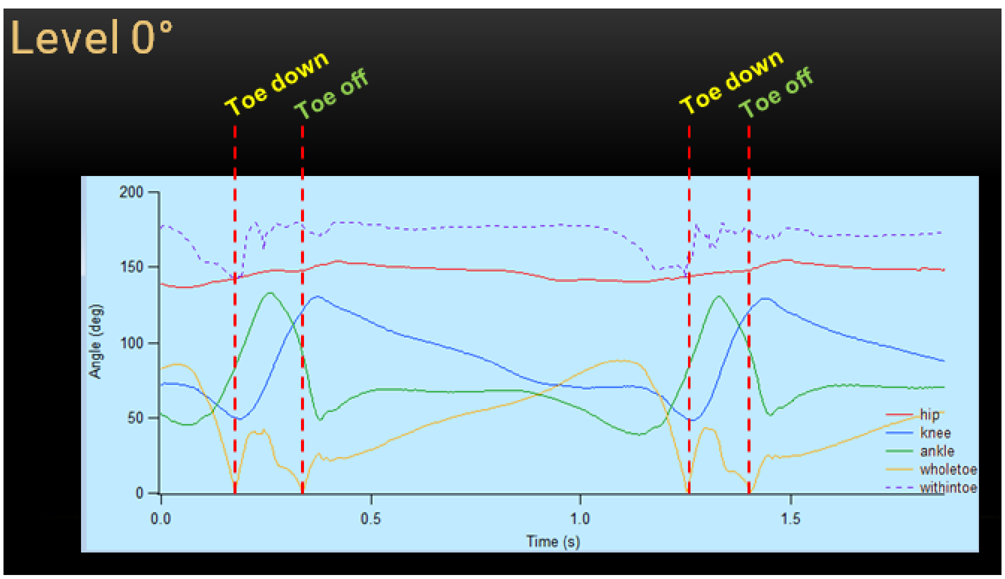

Fig. 3. Angles of all six joints over a full stride during ascending at 0°

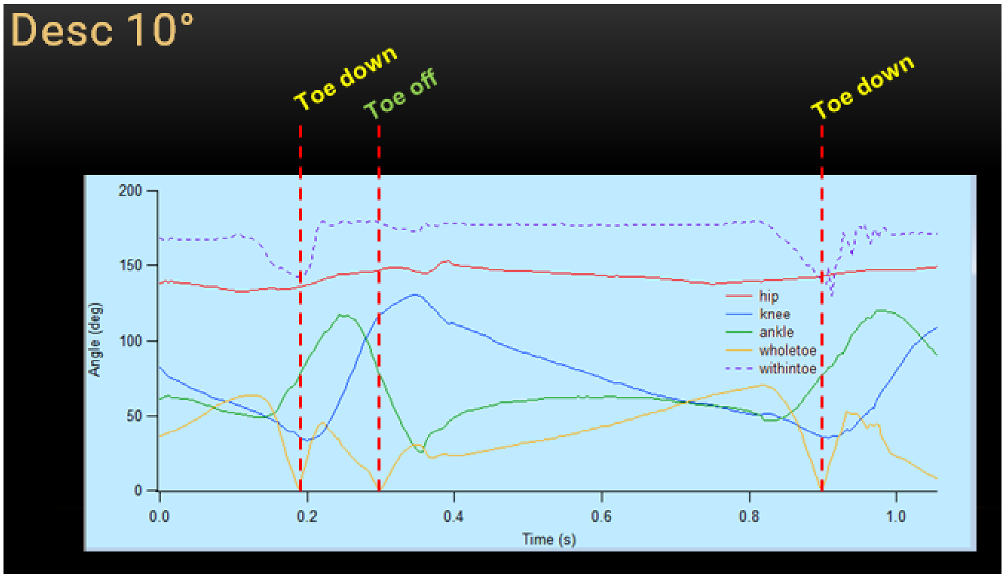

Fig. 4. Angles of all six joints over a full stride during descending at 10°

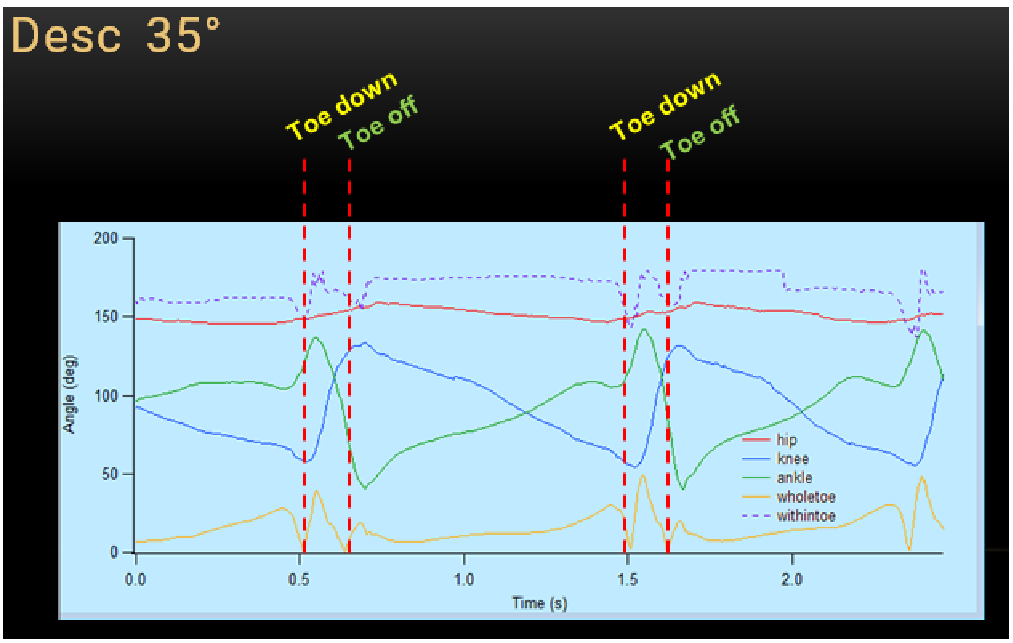

Fig. 5. Angles of all six joints over a full stride during descending at 35°

After performing a one-way ANOVA test, we discovered that there were statistically significant differences seen in the maximum knee angle, minimum knee angle, and maximum foot angle over all conditions, as shown by the highlighted P values (Table 1), (R Core Team 2013). Within the graphs below, you can see clear differences in the hind limb joint angles depending on the conditions. Most notably, however, are the differences between the angles produced during descending at 35° compared with the rest of conditions. Maximum angles during stance phase are much smaller than in the all other conditions, and the maximum height of the toe angles are smaller in both stance and swing phase (Fig. 5).

One-way ANOVA for each joint over all conditions						
Joint Max	Asc 35	Asc 10	Level	Desc 10	Desc 35	P Value
Hip	153.5 ± 17.5	152.83 ± 10.6	158.8 ± 7.29	156.6 ± 6.64	162.2 ± 9.16	0.736
Knee	106.8 ± 20.2	125.2 ± 6.9	129.7 ± 7.35	132.7 ± 5.13	137.0 ± 6.34	0.01
Tibiotarsus	139.4 ± 8.68	133.4 ± 6.78	129.4 ± 6.41	125.8 ± 5.98	135.7 ± 9.99	0.167
Foot	94.7 ± 29.2	93.52 ± 4.05	89.2 ± 1.82	71.6 ± 4.6	52.8 ± 13.9	0.0045
Toe	179.2 ± .998	178.7 ± 1.25	178.9 ± .99	179.2 ± 0.573	179.1 ± 0.783	0.916
Joint Min	Asc 35	Asc 10	Level	Desc 10	Desc 35	P Value
Hip	122.9 ± 27.9	130.1 ± 15.7	138.0 ± 7.87	138.8 ± 6.69	145.6 ± 8.1	0.323
Knee	49.6 ± 5.35	46.6 ± 5.22	41.1 ± 7.54	41.4 ± 5.59	51.9 ± 3.3	0.0524
Tibiotarsus	23.8 ± 8.77	33.85 ± 9.78	35.7 ± 3.49	33.6 ± 11.6	31.7 ± 6.99	0.36
Foot	.889 ± .55	0.667 ± 0.37	0.329 ± 0.199	0.393 ± 0.327	0.352 ± 0.217	0.167
Toe	135.4 ± 9.13	132.8 ± 11.3	135.9 ± 5.77	121.5 ± 11.4	138.6 ± 11.5	0.194

Table 1. Compiliation of all mean angles and standard deviations across all conditions

While all of the P Values from our One-way ANOVA Test test reveal which joints have significant differences over all conditions, these results are also clearly evident when looking at the box plots (Table 1), (R Core Team 2013). The Max Foot Angle box plot shows a significant difference between the maximum foot angle during descending locomotion at 35° and the rest of the maximum foot angles during the other conditions (Fig. 6). The Maximum Knee Angle box plot also confirms a significant difference from the rest of the conditions during descending at 35°, illistrating how there is an evident pattern of increasing knee angles from ascending to descending (Fig. 7). Lastly, the Minimum Knee Angle Box plot reveals that the minimum knee angle is also approaching significance during descending locomotion at 35°, which was also revealed from our One-way ANOVA Test (Fig. 8), (Table 1). However, it is also important to note that the maximum and minimum hip angles do not change in a significant manner over all conditions (Figs. 1-5).

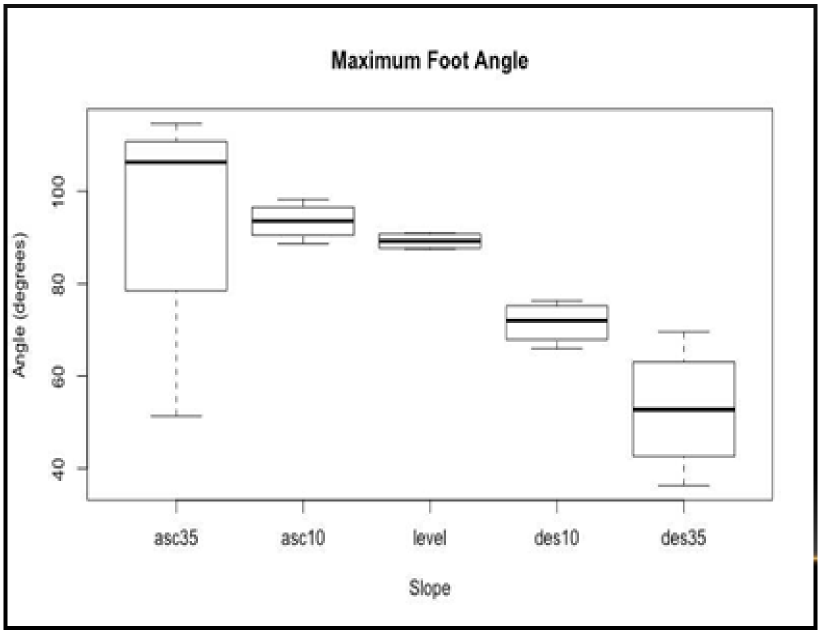

Fig. 6. Box plot of the maximum angle within the foot over all conditions.

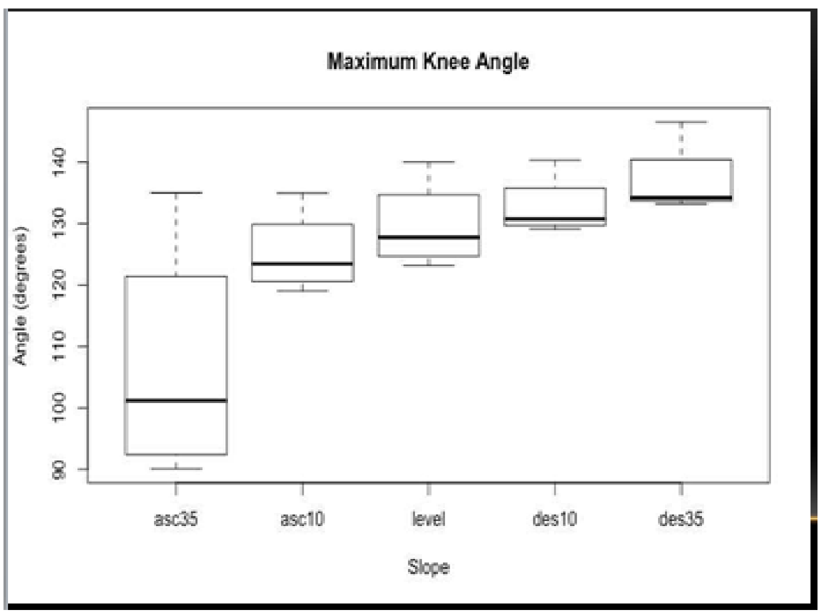

Fig. 7. Box plots of the maximum angles of the knee over all conditions

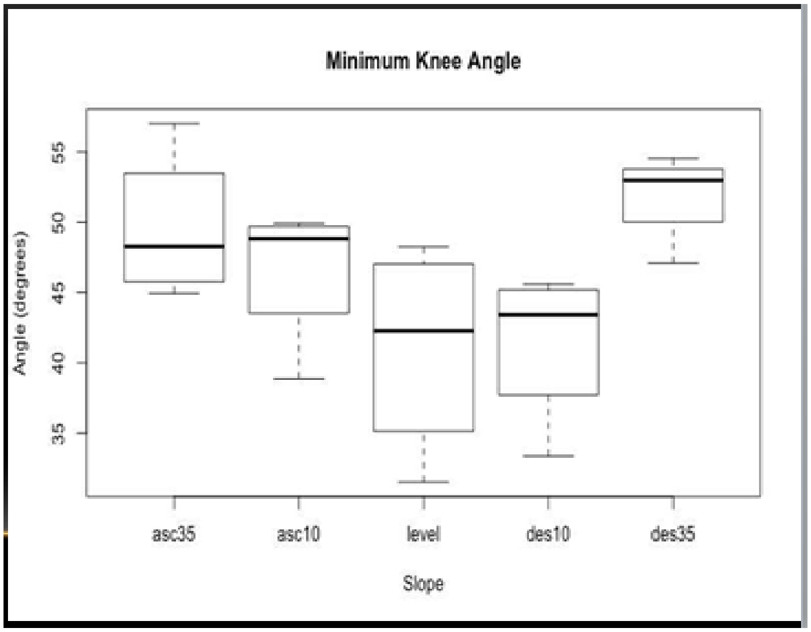

Fig. 8. Box plots of the minimum angles of the knee over all conditions

The kinematics of the foot varied among slope angles. For instance, when a chukar is ascending at 35°, as the chukar picks up its foot from the substrate, during the transition from stance phase to swing phase, there is a "rolling over" motion within the joints of the foot (Fig. 9A). This leads to a a curling of the toes that prodcues the large angles that we see in the whole toe angle results. However, when the chukar is descending at 35°, we see more of a peeling off motion that results in a relatively flat position during swing phase and the small angles shown in the whole toe angle category (Fig. 9B).

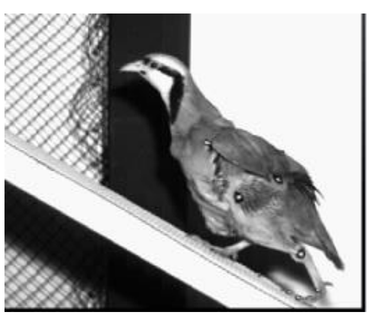

Fig. 9A.

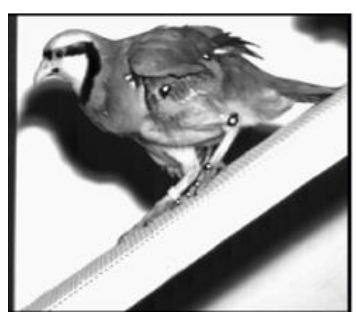

Fig. 9B.

The images show only the angles between the knee and tibiotarsus during ascending 35° and descending 35° in order to demonstrate the joints that showed the most significant differences across all conditions.

DISCUSSION

As predicted at the beginning of our experiment, we found that the kinematics of the hind limbs of chukars differ significantly depending on the angle of slope being traversed during normal locomotion. Compared to the other conditions, during decline locomotion at 35˚, the maximum and minimum knee angles and the maximum angles within the foot demonstrate notable dissimilarities, as revealed using a one-way ANOVA test (Table 1), (R Core Team 2013). While we tried to include a wider variety of conditions, when we attempted to analyze the kinematics during locomotion on the more extreme 70° slope, the recorded footage of the wing assisted incline running proved to be unusable due to the wings disrupting the image of the bony landmarks, preventing the digitization process (Bundle and Dial 2003). This precluded usable data from the 70° slope experiments.

The evidence from our experiment was not consistent with our alternative hypothesis that stated the chukars would realign their body postures depending on the steepness of the slope being traversed. We had the assumption that the chukars would adapted to the difficulties of walking up or down a steep slope by adjusting the way they use their hind limbs, and this posture change would be evident in the angles within the hind limbs. However, contrary to our predictions, we did not see any dramatic changes in the angles within all of the hind limb joints. For example, there were no significant changes in the maximum and minimum hip angles relative to the body over all conditions. This suggests that our original hypothesis is correct when compared to our alternative hypothesis regarding postural realignment.

Our results provide novel insights into the range of kinematics possible during the normal locomotion of chukars. Of course, since our experiment only included artificial slopes in a laboratory environment, which are unquestionably less complex than real-world conditions found in mountainous terrain, it would be worthwhile to extend our study to a field settings where locomotor performance could vary over a larger range of conditions that might include all of the possible circumstances that chukars could encounter in the wild. This would provide greater insight into the ecologically-relevant modulation of hind limb kinematics.

This thesis represents a preliminary study that demonstrates the need for more research to be done in order to understand how birds and other bipedal organisms move in their natural environments. This research indicates that chukars can serve as a useful example of a bipedal, ground-dwelling organism for comparative studies on terrestrial locomotion, such as Gatesy and Biewener's study on bipedal locomotion or a more recent study that focuses on locomotion deficiencies in broiler chickens (Nääs, Irenilza de Alencar et al. 2010), (Gatesy and Biewener 1991).

Since chukars and chickens (*Gallus gallus domesticus*) are both Galliformes, despite being slightly smaller, they act very similarly. Although chukars are wild, they tend to lead a sedentary lifestyle (Benjamini, L.P. 1980). Not surprisingly, domesticated chickens also spend the vast majority of their time lying down (Weeks, C.A. et al. 2000). This obvious similarity in daily activity levels is one of many reasons why these two species can be compared when discussing muscular activity. Our next step would be to do an interspecies study that looks at the differences, if any, between chukars, chickens, and even the juveniles of both species. If we find that they do in fact use their muscles in a similar manner, we may be able to apply this knowledge in order to create a safer, more humane environment and significantly reduce the number of injuries that occur during livestock production.

Previous research on boiler chicken locomotion has confirmed that broiler chickens not only have locomotive constraints that cause physical injury and counterproductive weight loss during production, but that these deficiencies increase with age and weight (Nääs, Irenilza de Alencar et al. 2010). In layer hens, the most likely cause of injury is directly correlated to housing issues and management styles, which include exercise availability and easily navigable living spaces. As more attention is brought to these kinds of issues, solutions are being requested in order to reduce injuries. However, once implemented into the living spaces, many of the "solutions" do not eliminate injury due to a lack of knowledge about what chickens need in order to move around easily. For instance, while ramps are being introduced to help layer hens navigate non-caged rearing systems, they still commonly suffer keel bone damage and other injuries (Harlander-Matauschek et al. 2015).

Research performed on turkeys (*Meleagris gallopavo*) in flight, which are significantly bigger than both chukars and chickens, also found that turkeys have different pectoralis mechanics, and thus use their muscles in different ways than chukars or chickens in order to compensate for their large body mass (Tobalske and Dial 2000). This study suggests that size is crucial in the study of locomotion. However, there may be some more comparisons to be made between birds and humans. In another similar study, high-speed light films were taken of human locomotion to compare the kinematic patterns between birds and humans (Gatesy and Biewener 1991). This research found consistent patterns of stride frequency, stride length, step length, duty factor and limb excursion that were observed in all species, with most of the variation among species being due to differences in body size.

Future work would include experimenting further with muscle functions in a variety of species. This type of research would be very useful when assessing how animals of different species use their muscles to accomplish the same locomotive tasks. With this information, not only could we improve the habitats and livelihood of domestic livestock, but we can better understand what makes each species unique when it comes to their physiology and survival tactics. For instance, knowledge of the types of muscular performance necessary to live in certain environments is crucial when analyzing why some animals can only thrive in very particular locations.

We would like to expand this experiment to include working with adult chickens in order to form a better understanding of how the muscles of these similar species work during identical conditions. We have already begun a series of experiments that integrate sonomicrometry crystals and EMG readings into this experiment in order to gather more data about how the muscles of chukars work during these conditions. This second experiment involved anaesthetizing chukars and then surgically implanting small sonomicrometry crystals into the chukars' left lateral gastrocnemius muscle. We then repeated the same steps from the first experiment, but this time, we recorded the sonomicrometry data from the implanted crystals using a Triton 120.2 sonomicrometry technology box to measure the strain of the lateral gastrocnemius during muscle contractions.

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