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Gait Adaptation of a Dung Beetle Rolling a Ball up a Slope

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1 Introduction

Insects like ants and stick insects are found to adapt their motor pattern when they walk on inclined planes [1, 2]. Interestingly, dung beetles can not only adapt their motor pattern to walk but also roll a dung ball throughout an uneven terrain as well as on an inclined plane. A previous study describes the gait pattern of the ball rolling behavior on flat terrain [3], but little is known how the dung beetles adapt their movement to roll a ball up a slope. Thus, in this work, we perform a visual investigation of dung beetles' ball rolling behavior on 0 and 20-degree slopes and perform statistical analysis on the gait patterns to identify how dung beetles adapt their movement to roll a ball up a slope.

2 Methods

2.1 Data Collection

Videos of the dung beetle *Scarabaeus (Kheper) lamarcki* rolling a 3 cm diameter and 30 gm dung ball on 0 and 20-degree slopes on a rough surface (preventing slipping of the tarsus in contact) were recorded (Figure 1). Then we extracted gait patterns from the videos by using the gait extraction method from our previous work [3]. Each gait pattern was extracted from different trial of the ball rolling behavior. We analysed 21 gait patterns (2 s for each gait pattern) from five individual beetles in the 0-degree slope condition and five gait patterns (4 s for each gait pattern) from one beetle in the 20-degree slope condition.

2.2 Data Analysis

The gait patterns were then used to find a stance percentage of each leg (L1, L2, L3, R1, R2, R3, see Figure 1) in both 0 and 20-degree slope conditions. The stance percentage is calculated by dividing the time that the leg is in contact with the ground or dung ball by the total recording time. The stance percentage of cycle time is calculated from the stance phase in the gait that can be identified as a full stepping cycle. In addition, the stepping frequency of each leg in both conditions is also calculated. The stepping frequency is calculated by dividing the amount of time that the leg steps (1 period of swing phase is count as 1 step) by the total recording time. The stance percentage, stance percentage of cycle time, and stepping frequency can be calculated by the following equations:

$$Stance\%(l) = \frac{Total\ stance\ time}{Total\ time} \tag{1}$$

$$Stance\%\ cycle\ time(l) = \frac{stance\ time}{Total\ cycle\ time} \tag{2}$$

$$Stepping\ frequency(l) = \frac{Total\ step\ count}{Total\ time} \tag{3}$$

where l represents each leg of the dung beetle (L1, L2, L3, R1, R2, R3, see Figure 1).

3 Results & Discussion

In Figure 2(a) and 2(b), we show the representative rolling gait patterns of the 0 degree and 20 degree slope conditions. The stance percentage of each leg in both conditions is shown in Figure 2(c). We found that in the front legs (L1, R1) and hind legs (L3, R3), the legs have a higher stance percentage in the 20-degree than 0-degree slope condition. A higher stance percentage indicates a higher duration that the leg is in contact with the ground or ball. The result can imply that while the dung beetle rolls a ball up the slope, its front legs tend to stay on the ground and the hind legs tend to contact the ball more often than when it rolls a ball on the horizontal surface. Moreover, we can clearly see that the stepping frequency of each leg on the 20-degree slope is lower than on the horizontal surface (Figure 2(d)). Therefore, when rolling the ball up the slope, the dung beetle steps or swings less frequently compared with rolling the ball on

Figure 1: Snapshots of the dung beetle rolling a dung ball up the 20-degree slope with rough surface.

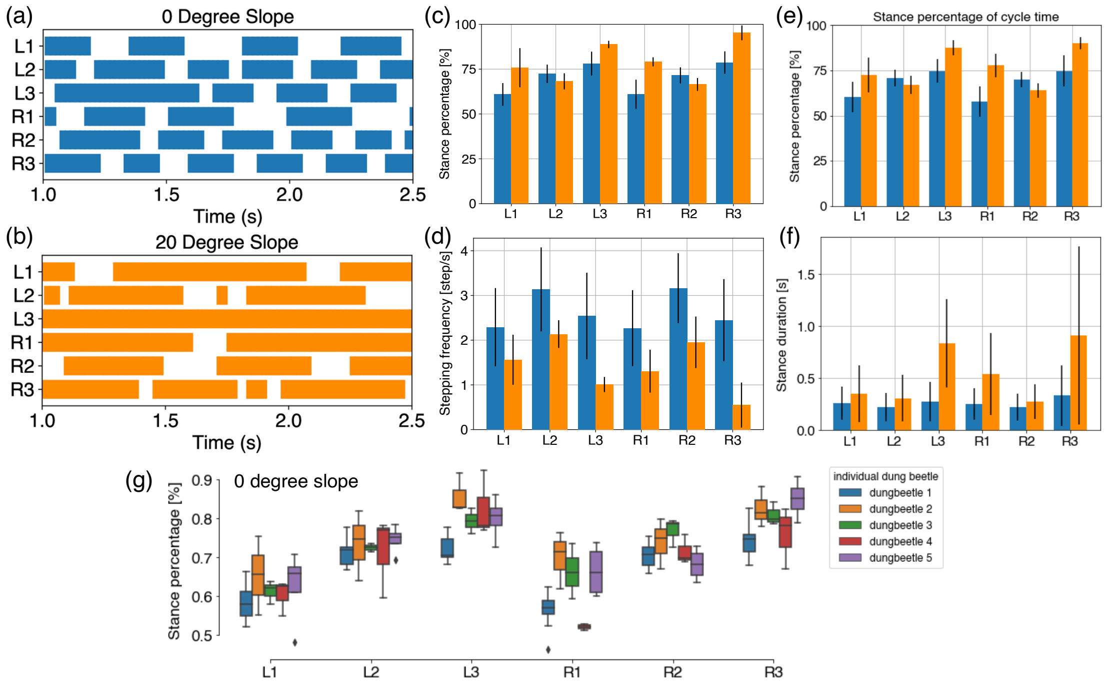

Figure 2: **(a)** Rolling gait pattern of the 0-degree slope condition. **(b)** Rolling gait pattern of the 20-degree slope condition. **(c)** Stance percentage, **(d)** Stepping frequency, **(e)** Stance percentage of cycle time, and **(f)** Stance duration of each leg (L1, L2, L3, R1, R2, R3) in the 0-degree (blue) and 20-degree (orange) slope conditions. **(g)** Stance percentage distributions of each leg across individual dung beetles in the 0-degree slope condition. Each gait pattern (**(a)**, **(b)**) represents one trial. The white color in the gait pattern (**(a)**, **(b)**) indicates the swing phase of the leg and the blue and orange colors indicate the stance phase of the leg. The error bars in the bar charts represent standard deviation across different trials.

the 0-degree slope, to ensure its stability. These results show the gait adaptation of the dung beetle when rolling a ball in different conditions (i.e., level ground and slope). Stick insects can also change the gait pattern and ants can adapt the stepping frequency when walking on an incline slope [1, 2]. On the slopped terrain, the dung beetle also bears the weight of the dung ball while rolling it. To successfully and stably hold the ball, the dung beetle needs to provide more force and support to counter the ball weight and better balance the ball by increasing the stance duration of the front and hind legs. Thus, the adaptation might increase the stability for rolling the ball up the slope. In addition, figure 2(e), 2(f), and 2(g) shows additional data related to the experiment.

4 Conclusion

In summary, we show that the slope of the terrain affects the gait pattern of the dung beetle's ball rolling behavior. The dung beetle's front legs and hind legs tend to stay in contact with the ground and dung ball more often in the 20-degree slope than in the 0-degree slope condition. There are also many interesting questions which can be answered by further analysis of the gait pattern, for example, why the stance percentage of the middle legs is slightly lower in the 20-degree slope condition compared with the 0-degree slope condition.

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