FORCE RUNNING WHEEL FOR MEASURING INDIVIDUAL LIMB FORCES IN MICE DURING SPONTANEOUS LOCOMOTION

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INTRODUCTION

Running wheels are widely used, especially with transgenic mouse models, to study basic mechanisms of how the musculoskeletal system adapts to increased running activity. Knowledge of the individual limb forces generated during wheel running may provide important mechanistic insight into musculoskeletal and neuromuscular function. Our goal was to construct a low-resistance running wheel for measuring the normal and tangential reaction forces applied to the wheel by an individual limb of spontaneously running mice. We tested our device by measuring the hindlimb reaction forces in control and diet-induced obese mice.

METHODS

An 11.5 cm diameter stainless steel running wheel (Mini Mitter) was modified to allow placement of a strain-gage instrumented rung (Fig. 1). A strain gage (Vishay) was applied to both sides of four strain sensitive surfaces in a half bridge configuration to measure forces applied in the normal and tangential directions. Four strain channels were measured by completing a modified wheastone bridge on the running wheel, passing the bridge leads through a slip ring (Michigan Scientific), and recording the bridge measurements with a high-speed bridge measurement module from National Instruments (NI 9237). An optical encoder was secured to the end of the axel opposite the slip ring to monitor wheel angular position. Ventral and sagittal plane video data were collected at 125 Hz with a high-speed camera and a 45° angled mirror. Video was collected during the dark light cycle using an infra-red light source. Strain, wheel angle, and video data were collected using a custom-written LabVIEW program whenever strain values exceeded a pre-set strain-threshold event trigger.

RESULTS AND DISCUSSION

Strain output varied linearly in the normal and tangential directions with applied loads of up to 70 g ($r^2>0.99$ for both directions). Strain output for a given load was dependent on position for the normal but not tangential component. Foot position data from video images were used to correct for this position dependence. Crosstalk was 38% and 1.5%, for the normal and tangential components, respectively. The higher degree of crosstalk for the normal component resulted in approximately a 6% maximal error in normal force measurements based on the observed peak tangential forces being only 1/6 the normal force values (Table 1). Normal and
tangential strain output varied with wheel angular position by 101mN and 70mN, respectively, due to the effect of gravity on the instrumented rung. We applied an angle-dependent correction factor to account for these gravitational errors. The natural frequencies of the normal and tangential components were 193 Hz and 68 Hz, respectively. Additional low-magnitude strain noise was observed at 60 Hz during wheel rotation. A power spectrum analysis of the normal and tangential forces applied by running mice showed that nearly all frequency components were lower than 35Hz; therefore, we filtered all strain data with a low-pass butterworth filter at 45Hz.

Figure 2: Sample trace of the normal reaction forces during steady-speed running from a control (28.9g) and diet-induced obese (50.5g) mouse.

Over the course of a night of data collection, each animal generated over 1000 force events. Each event captured 2.5 seconds of strain data (10 kHz), encoder data (10 kHz), and image data (125 Hz). In our preliminary analysis of these records, 4 hindlimb events per animal were selected for further analysis based on the following: 1) a consistent wheel rotational velocity, 2) a steady gait pattern for two strides before and after the force event, and 3) foot placement only on the instrumented rung. Control mice applied an average peak normal force of 355mN (115 % body weight, BW), about 6-fold greater than the average peak tangential forces (Table 1). High-fat mice generated greater absolute peak forces compared to control mice (Figure 2). However, when normalized to BW, peak normal forces were significantly less in high-fat animals (Table 1).

CONCLUSIONS

Peak normal hindlimb forces generated during wheel running are greater than those observed during overground locomotion (1), suggesting that the biomechanics of wheel running may be significantly different from overground locomotion. These findings are intriguing since we have previously reported few kinematic differences between wheel and overground running (2). Measuring individual limb reaction forces during spontaneous wheel running may provide a more sensitive method of quantifying changes in gait behavior that reflect musculoskeletal pathology, as with diet-induced obesity and osteoarthritis (1).

REFERENCES


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Table 1: Effect of diet on peak normal and tangential wheel reaction forces by the hindlimb of running mice.

<table>
<thead>
<tr>
<th>Diet</th>
<th>BW (g)</th>
<th>Peak Normal Forces (mN)</th>
<th>Peak Normal Forces (% BW)</th>
<th>Peak Tangential Forces (mN)</th>
<th>Peak Tangential Forces (% BW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>29.7 ± 0.9</td>
<td>335 ± 17</td>
<td>115.2 ± 5.7</td>
<td>56.7 ± 12</td>
<td>19.6 ± 4.4</td>
</tr>
<tr>
<td>High-Fat</td>
<td>50.0 ± 0.8*</td>
<td>452 ± 3*</td>
<td>92.2 ± 1.0*</td>
<td>73.9 ± 18</td>
<td>15.1 ± 3.9</td>
</tr>
</tbody>
</table>

Body weight (BW). Values are mean ± SEM. *p<0.05 versus control value (Mann-Whitney U-test).