Assessment of Sprinting Abilities Using a Resistant Self-driven Treadmill

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In the present study, an ergometer (SErg) was developed to determine the force-velocity-power relationship in sprint running and to examine its applicability for assessing sprinting ability on the ground. The SErg consisted of a low friction belt, a rotary encoder, a force transducer attached to the runner’s waist, and an electrical brake on the belt. The subjects (nine healthy and active men, including two sprinters: age, 22.6±2.1yrs; body height, 175.3 ±4.1cm; body weight, 74.1±9.3 kg) sprinted with maximal effort at five loads that were generated by the braking force. The mean velocity (V) and force (F) were calculated where the mean belt velocity in six steps was maximal. In addition to the treadmill running, the subjects performed a 60m maximal sprint on the ground. From the F-V relationship, the value of the intercept on the V axis was regarded as estimated maximal velocity (eVmax). The maximal power (ePmax) was also calculated from V-P regression. The test-retest reliability of the eVmax and ePmax was high (ICC>0.79). The eVmax (8.25+/-.089m/s) and ePmax (856.5+/-.135.0W) were highly correlated to the maximal velocity (8.91+/-.075m/s, r=0.91) and acceleration (3.55+/-.024m/s², r=0.91), respectively, in the 60 m sprint on the ground. The present results indicate that the SErg can be applicable to determine the F-V-P relationship during sprint running and to estimate maximum velocity and acceleration in maximal ground sprinting.

Keywords: Self driven treadmill, Force-Velocity, Running Speed, Running Acceleration

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and force applied to the belt. However, how the force-velocity relationship obtained from the ergometer can be related to the sprint running ability on the ground was not examined. On the other hand, Chelly and Denis (2001) found that mechanical power determined by a self-driven treadmill was related to maximal velocity and initial acceleration during running on the ground. However, since power was calculated by averaged mechanical power from start to maximal speed on the treadmill with a single belt load, neither the force-velocity relationship nor peak power during the treadmill run was clarified. Therefore, it is not clear how the propelling force changes with running speed on the treadmill.

In sum, it is not clear how the force-velocity-power relationship measured by a treadmill with adjustable load correlates with sprint running ability. In the present study, we developed a resisted self-driven treadmill (Sprint Ergometer, SErg) in which the load applied to the belt can be controlled by an electrical magnetic brake. Firstly, the force-velocity-power relationship during sprint running was determined using the treadmill. Then we examined how the maximal velocity and power estimated from the force-velocity-power relationship correlate with sprint running ability on the ground. The final goal of the study was to examine whether our novel method can assess sprint running ability.

2. Methods

2.1. Subjects

Nine healthy and active males (age, 22.6±2.1yrs; body height,175.3±4.1cm; body weight,74.1±9.3 kg; mean ±SD), including two sprinters, voluntarily participated in the present study which was approved by the Waseda University Ethical Committee for Human Experiments. The subjects were fully informed about the procedures and the purpose of the study and written informed consent was obtained from all participants.

2.2. Sprint Ergometer (SErg)

The SErg consists of a treadmill belt, electrical magnetic brake, and force transducer to measure a subject’s pulling force. The treadmill belt is moved by the subject’s strides and the electrical magnetic brake provides load to the belt. A rotary encoder is connected to the front roller to measure belt displacement. The pulling force exerted by the subject was recorded by the force transducer connected horizontally to the waist with an adjustable strap approximately 1 to 1.3 m in length.

In order to confirm the load applied to the belt by the electrical magnetic brake, the force at every 1V interval from 0 to 12V was measured during slow and stable walking (approximately 1.5m/s) on the SErg. Figure 2 shows the mean values of four attempts at every brake amplitude. It also shows that the load by the brake system was proportional to the voltage of the magnetic brake only at measurements over 3V. In the present study, therefore, we only use loads over 3V.

2.3. Experimental procedure

The transducer attached to the subject’s waist was connected horizontally to a fixed steel frame. The subjects sprinted with maximum effort for about 10 seconds on the SErg at five different loads (i.e. 3, 4, 6, 9, 11 voltage) in random order with a rest period of 10 minutes between each sprint. The mean values of force (F) and velocity (V), where the mean velocity
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Figure 2  Magnetic brake load as a function of adjustable voltage volume. Mean value of four attempts of the slow and stable walk on the SErg.

of 6 continuous steps was maximal (Figure 3), was adopted to reduce any error due to inconsistency in F peak and acceleration of the belt. As the load increased, F increased and V decreased rectilinearly. Maximal velocity was estimated by extrapolating the linear regression equation between F and V (eVmax, Figure 4 upper panel). Mechanical power was calculated as the product of F and V. The estimated maximal power (ePmax) was estimated from the V-P curve (Figure 4, lower panel). To examine the reliability of the SErg method, all subjects sprinted on the SErg twice on different days. The estimated maximal velocity and maximal power are referred to as eVmax and ePmax, respectively.

Figure 3  Changes in instantaneous belt speed and pulling force while sprinting at five different loads.

Figure 4  Relationship between F and V for typical (upper panel). Maximum velocity (eVmax) was calculated by extrapolating from the F-V line. Changes in P at given V (lower panel). Maximal power (ePmax) was estimated from the P-V curve.
Table 1 Reliability of V, eVmax, P and ePmax

<table>
<thead>
<tr>
<th>V [m/s]</th>
<th>Load</th>
<th>1st</th>
<th>2nd</th>
<th>ICC</th>
<th>regression</th>
</tr>
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<tbody>
<tr>
<td>0V</td>
<td>6.52 ±0.57</td>
<td>6.73 ±0.53</td>
<td>0.864</td>
<td>y= 1.006 x -0.252</td>
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<tr>
<td>4V</td>
<td>6.43 ±0.48</td>
<td>6.47 ±0.61</td>
<td>0.873</td>
<td>y= 0.767 x +1.468</td>
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<tr>
<td>6V</td>
<td>5.80 ±0.56</td>
<td>5.86 ±0.47</td>
<td>0.940</td>
<td>y= 1.118 x -0.749</td>
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<tr>
<td>9V</td>
<td>4.51 ±0.55</td>
<td>4.66 ±0.50</td>
<td>0.935</td>
<td>y= 1.077 x -0.509</td>
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</tr>
<tr>
<td>11V</td>
<td>3.78 ±0.44</td>
<td>3.94 ±0.43</td>
<td>0.844</td>
<td>y= 0.920 x +0.151</td>
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<tr>
<td>eVmax</td>
<td>8.25 ±0.89</td>
<td>8.25 ±0.67</td>
<td>0.904</td>
<td>y= 0.698 x +2.487</td>
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</table>

<table>
<thead>
<tr>
<th>P [W]</th>
<th>Load</th>
<th>1st</th>
<th>2nd</th>
<th>ICC</th>
<th>regression</th>
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</thead>
<tbody>
<tr>
<td>0V</td>
<td>546.78 ±140.50</td>
<td>524.16 ±83.91</td>
<td>0.791</td>
<td>y= 1.498 x -238.174</td>
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<tr>
<td>4V</td>
<td>611.87 ±104.83</td>
<td>567.13 ±81.98</td>
<td>0.968</td>
<td>y= 1.070 x +5.080</td>
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<tr>
<td>6V</td>
<td>710.12 ±131.46</td>
<td>700.15 ±97.92</td>
<td>0.913</td>
<td>y= 1.271 x -179.615</td>
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<tr>
<td>9V</td>
<td>810.35 ±127.94</td>
<td>807.59 ±104.89</td>
<td>0.953</td>
<td>y= 1.178 x -141.175</td>
<td></td>
</tr>
<tr>
<td>11V</td>
<td>870.20 ±133.66</td>
<td>869.65 ±137.04</td>
<td>0.951</td>
<td>y= 0.923 x +67.937</td>
<td></td>
</tr>
<tr>
<td>ePmax</td>
<td>856.47 ±135.01</td>
<td>855.05 ±127.25</td>
<td>0.972</td>
<td>y= 0.910 x +72.070</td>
<td></td>
</tr>
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</table>

x: 1st trial  y: 2nd trial

2.4. Measurements of velocity and acceleration during sprinting on the ground

The subjects were requested to run a 60 m maximal sprint test on an athletic ground. Running velocity was measured using a laser apparatus (LA VEG Sport LDM-300C, JEN OPTIC) positioned behind the subject that allowed measurement of changes in the distance that each subject traveled forward. Running velocity and acceleration every 5 m from the start was calculated from the time differentiation of the velocity curve. The measured maximal running velocity and acceleration are referred to as gVmax and gAmax, respectively.

2.5. Statistics

The descriptive data are presented as means and SDs. Pearson’s correlation coefficient was used to analyze relationships among the measured variables obtained from the nine subjects who completed the tests. Statistical significance is indicated at p <0.05. The interclass correlation coefficient (ICC) was calculated to examine test re-test reliability. The ICC score is reasonably high and interpreted as reliable (Vincent 1995).

3. Results

Table 1 summarizes the results on the reliability of the velocity (V) and power (P) measurements. The V, P, eVmax, and ePmax indicate a significantly high ICC (0.79–0.97). The mean value of each variable did not significantly differ between the two trials. The data obtained at the first trial, which was the earlier trial after the ground running test, was applied to the following analysis.

Increasing the load of the belt, F increased and V decreased. The relationship between F and V for each subject was linear and significant (r=-0.99~0.98). The eVmax and ePmax were 8.25+/−0.89 m/s and 856.5+/−135.0 W, respectively.

Figure 5 shows changes in running speed (gV) and acceleration (gA), and their maximal values (gVmax, gAmax) during the ground running test. During maximal sprinting on the ground, gAmax was maximal in the first 5m from the start (3.55+/−0.24 m/s²). The gVmax was observed between 30 to 50m from the start (8.91+/−0.75m/s). All subjects decelerated their running speed in the interval between 50 and 60m. The eVmax was 0.66 m/s lower than gVmax (p<0.001), but it was closely correlated with gVmax (r=0.906, p<0.01, Figure 6). The ePmax was significantly related to gAmax (r=0.905, p<0.001, Figure 6) while no significant
relation was observed between eVmax and gAmax.

4. Discussion

The main finding in this study is that eVmax and ePmax calculated from the F-V-P relationship during treadmill sprinting are closely correlated with gVmax and gAmax, respectively, during maximal sprinting on the ground.

Unlike Lakomy (1986) the SErg used in this study did not have a system with which the actual horizontal component of the pulling force can be assessed. However, in the present study, the adjustable belt attached between the subject’s waist belt and force transducer was 1 to 1.3m in length. Assuming that the displacement of the centre of body mass was about 6cm (Cavagna, et al., 1964), the error on the horizontal component of pulling force due to oscillation was calculated at less than 0.1%, which should be small enough to be ignored.

In the present study, the pulling force from the force transducer at the subject’s waist strap was used for analysis instead of the belt load applied by the electric magnetic brake. This made the analysis simpler and easier. During running, however, a greater vertical force should apply to the belt during the stance phase compared to walking. Because of the greater belt friction due to the vertical force, subjects need to accelerate the belt against this friction in addition to the brake load. In fact, a greater force was actually observed during running than during brake calibration with the same load.

Therefore, the force is underestimated if we use the belt load instead of the pulling force from the force transducer at the subject’s waist strap.

The rectilinear relationship between F and V is in line with the findings of previous studies using a treadmill (Jaskolska, et al., 1999) and a cycle ergometer (Nadeau, et al., 1983). The force-velocity relationship is a rectangular hyperbola for an isolated muscle or a single joint movement (Hill 1938, Wilkie 1950, Tihanyi, et al., 1982), but it is linear when movements are more complex such as running or cycling (Sargeant, et al., 1981, Nadeau, et al., 1983, Vandewalle, et al., 1987). Jaskolska (1999) reported that the linear relationship between force and velocity in running and cycling is probably a consequence of the fact that both types of movement result from the action of several muscle groups and joints.

The observed correlation coefficient between the velocities obtained on the treadmill and ground was higher than that reported by Funato, et al., (1999)
who found a significant correlation ($r=-0.797$) between mechanical power during the self-driven treadmill running and the time taken to run 50m on the ground. This might be due to differences in the method for calculating mechanical power on the treadmill. In the study of Funato, et al., (1999), the belt load was not adjustable, depending on the friction and inertia of the belt. The force detected by the force transducer, or the power calculated from the force depended on the belt load. In the present study, because the belt load was adjustable, it was possible to obtain the force-power-velocity relationship and $eP_{\text{max}}$ during the treadmill running. This is probably one causal factor for the high correlation between the velocity variables of running on the treadmill and the ground as compared to that observed in the previous study.

The high correlation between $eP_{\text{max}}$ and $gA_{\text{max}}$ indicates that the mechanical power exerted by running is related to the propulsion force that accelerates the body while sprinting. However, $eV_{\text{max}}$ was lower than $gV_{\text{max}}$. The reason for this might be that belt friction decreases the belt velocity during the aerial phase of the running cycle, resulting in a lower velocity compared with sprinting on the ground.

Though a high correlation coefficient was observed between $eV_{\text{max}}$ and $gV_{\text{max}}$, as shown in Figure 6, the average value of $eV_{\text{max}}$ was approximately 2.5m/s faster than the fastest V in the observed SErg test. The reasons for this are unknown but might involve factors relating to running technique during top speed. Running technique at top speed would affect running speed more than that at slower running speeds. However, the speculation in this point should be clarified in further study.

In conclusion, the present results indicate that the SErg is useful for estimating the maximum velocity and acceleration in the maximal ground sprinting with estimated values calculated from F-V-P relation during SErg running.

References