The Effect of a Braking Device in Reducing the Ground Impact Forces Inherent in Plyometric Training

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Abstract


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As a consequence of performing plyometric-type exercises, such as depth jumps, impact forces placed on the musculoskeletal system during landing can lead to a potential for injury. A reduction of impact forces upon landing could therefore contribute to reduce the risk of injury. Twenty subjects performed a series of loaded jumps for maximal height, with and without a brake mechanism designed to reduce impact force during landing. The braked jumps were performed on the Plyometric Power System (PPS) with its braking mechanism set at 75% of body weight during the downward phase. The non-braked condition involved jumps with no braking. Vertical ground reaction force data, sampled for 5.5 s at 550 Hz from a Kistler forceplate, were collected for each jump condition. The following parameters were then calculated: peak vertical force, time to peak force, passive impact impulse and maximum concentric force. The brake served to significantly (p < 0.01) reduce peak impact force by 155% and passive impact force by 200%. No significant differences were found for peak concentric force production. The braking mechanism of the PPS significantly reduced ground impact forces without impeding concentric force production. The reduction in eccentric loading, using the braking mechanism, may reduce the incidence of injury associated with landings from high intensity plyometric exercises.

Key words
Impact forces, passive impact impulse, plyometric

Introduction

Plyometric training involves the union between strength and speed using muscular contractions that are characterized by explosive Stretch Shorten Cycle (SSC) movements (7,20). This type of training involving dynamic SSC movements has become a popular training modality for many athletes as it enables the development of high force production over a short period of time (1,2,7). This is achieved by utilising exercises such as depth jumps, exaggerated hops, bounds and box drills. This type of training regime offers several advantages over the more traditional forms of resistance training such as weight lifting. Plyometric movements are more expensively performed enabling the athlete to rapidly develop force (13) and mimic the actual athletic performance by the use of dynamic SSC movements (2,4,23,28).

Despite the advantages of plyometric training, over other recognised training modalities, a problem arises with this type of training with regard to repetitive impact loading or excessively high eccentric impact forces. As a consequence of performing plyometric type exercises, such as depth jumps, impact forces placed on the musculoskeletal system during landings can lead to a potential for injury (9,19,24).

Recently a system was developed to address the limitations associated with traditional plyometric training. These limitations include: 1) high eccentric loads and impact forces; 2) a limited range of exercises that can be plyometrically performed; and 3) a failure of plyometric training to be performed at a load that maximises muscular power. The Plyometric Power System (PPS) (PlyoPower Technologies, Lismore, Australia) was developed to enable plyometric exercises to be performed in a manner that addresses the limitations of this form of training. This system is also suggested to provide for closed kinetic chain rehabilitation through the control of load and impact force.

Typically, the performance of plyometric exercises requires the musculature and joint mechanisms involved in the landing process to dampen the impact forces placed on the body. However, it has been reported that the neuromuscular system has a limited reaction time response, between 50 to 75 ms, to forces applied to the body (8,19). When a force is applied to the musculature prior to the response of the neuromuscular system the muscles involved are unable to absorb the shock of landing. This rapid initial sharp peak in the ground impact force has possible implications for injuries to the lower limbs related to landings (18,22). The injuries associated with the lower limbs as a result of impact landings appear to be related to cartilage degeneration (21), fatigue fractures, shin splints (3) and achilles tendon problems (14).

The initial impact forces that occur within this 50 ms time frame of landing are referred to as passive impact forces (6,22). It is these passive impact forces that have been...
speculated to result in injuries to the musculature and skeletal systems (22). The impact forces that the body sustains from landing appear to be influenced by the inter-relationship between several mechanical parameters. The height of the jump (9,25) and the loading applied to the body (10,11,24) can be directly related to the velocity at impact (8,16,18,29). Subsequently it is the momentum attained prior to ground contact that influences the impact loads upon landing (16). Landing technique (10,24,27) has also been shown to effect the impact forces. It has been documented that stiff legged landings produce higher impact forces than landings which attempt to dampen the movement with hip and knee flexion (8,16,31).

Further, there are a limited number of exercises that can be plyometrically performed with most exercises essentially limited to the lower body. It is evident in the literature that plyometric exercises seem to concentrate on the lower body (1,2,4,7,20). While in comparison there is a lack of exercises reported concerning upper body plyometric training (7,20). The only information on upper body plyometric training stated in the literature was the mention of medicine ball routines and the possibility of using light weights (7,20).

Finally, there is an inability of most plyometric exercises to be performed at a load that maximises the power output. Currently, plyometric training is essentially limited to the acceleration and deceleration of body weight as in activities such as depth jumping and bounding (7,30). This is despite the findings of many researchers that power output is maximised at a load of approximately 30% of maximum (15,17,28).

The purpose of this study was to investigate the effect of a specifically designed braking mechanism on the ground impact forces associated with high intensity plyometric training. Additionally, the effect of this mechanism on concentric force production was also assessed. In each case the jumps involved two footed landings from maximal countermovement jump heights involving a braked and non-braked condition.

Materials and Methods

Subjects

Seven male and thirteen female subjects volunteered to participate in this study. All subjects were recruited from the university population and were currently involved in a range of sports and activities (basketball, netball, football, athletics, aerobics) that required explosive-reactive leg movements. The mean subject characteristics for age, height and mass are summarised in Table 1.

The study was approved by the Human Ethics Committee of the University of New England, Northern Rivers. Prior to the commencement of the study all subjects were verbally informed about the experimental procedures before signing an informed consent document.

<table>
<thead>
<tr>
<th>Subjects</th>
<th>Age (yrs)</th>
<th>Height (cm)</th>
<th>Mass (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male (n = 7)</td>
<td>19.71 ± 2.06</td>
<td>179.00 ± 7.35</td>
<td>69.33 ± 11.18</td>
</tr>
<tr>
<td>Female (n = 13)</td>
<td>21.77 ± 5.57</td>
<td>166.85 ± 8.40</td>
<td>61.45 ± 7.72</td>
</tr>
<tr>
<td>Total (n = 20)</td>
<td>21.05 ± 4.68</td>
<td>171.10 ± 9.85</td>
<td>64.21 ± 9.59</td>
</tr>
</tbody>
</table>

Equipment

The PPS enables subjects to perform plyometric exercises with a loaded bar that is housed in a heavy metal frame that limits movement to a purely vertical plane, as detailed in Fig. 1. The machine limits bar movement to the vertical plane and the downward movement of the bar can be controlled within an accuracy of 0.02 m. The movement of the bar is achieved by the use of linear bearings attached to either end of the bar. This allows the bar to slide about two hardened axel steel shafts with a minimum of friction. The machine is connected to a rotary encoder which produces pulses indicating the displacement of the bar. One pulse was produced for each 0.00106 m of bar movement. Each pulse was recorded by a counter timer board installed in a 386 DX IBM compatible computer which was capable of measuring pulse frequencies up to 1 MHz. This information was recorded by computer and software calculated the work done (mass x gravity x height) and mean power output (work/time) (30). The system was calibrated prior to use by measuring the total number of pulses produced as the bar was moved through its full vertical range (2.8 m). The system also incorporates an unidirectional electromagnetic braking system which when engaged will immediately act to brake the bar movement. The PPS system allows for movement to occur which: 1) ensures the safety of the subjects at all times by the use of the brake and metal stops; 2) controls the movement of the bar; 3) controls the limb position such that the bottom range or joint angle can be set to restrict movement beyond this point; and 4) accurately records the displacement of the bar.

Testing schedule

Prior to testing a standard warm-up involving a 5 minute cycle at 60 rpm at a workload of 60 watts was performed on a Monark stationary bicycle. On completion of the cycle subjects were instructed to perform a 3 minute standard stretching routine for the lower body. Prior to data collection subjects familiarised themselves with the testing equipment by performing a series of submaximal jumps with and without the braking mechanism engaged.

Fig. 1 The Plyometric Power System.
In each test subjects performed four successive jumps while being instructed and encouraged to jump for maximal height. Using a repeated measures design the sequence of presentation of both jump conditions was randomised to control for order effects among subjects. The first group initially performed the jumps with the brake mechanism engaged, followed by jumps without using the braking device. The second group were tested in the reverse order to that of the first group. Between all repeat jumps a 3 to 5 minute recovery period was imposed to negate any physiological effects of fatigue (12).

Experimental tasks

Braked jumps

The braked jump condition, which reduced the landing velocity of the eccentric phase of the movement, was performed on the PPS and will be termed a 'braked jump'. The PPS enables standard weight training exercises to be performed in a plyometric manner (30) and has the capacity to control eccentric loading through an electronic braking mechanism. The braked jumps were performed on the PPS using the unidirectional electronic brake set to a braking force equivalent to 75% of the individual's body weight, including the 10 kg (98.1 N) bar weight.

The PPS incorporates a friction based braking system that is electronically controlled by a computer. Once the subject attained their maximal jump height and commenced in a downward direction braking was applied and maintained throughout the descent of the jump. The displacement of the bar was measured by the rotary encoder of the PPS which sends this data to the computer so that the brake can be switched on the instant maximum height is achieved. The brake is unidirectional and does not operate during the concentric phase. The braking level is completely variable between the range of 0 to 1200 N. Since the heaviest subject tested was only 86 kg (843.7 N) the maximum braking force required was 75% of the combined body weight and 10 kg bar (98.1 N). Therefore, the braking level that was needed for this individual was (843.7 + 98.1) x 75/100 = 706.4 N, which is well within the upper limit of the brake. A 75% braking force was selected from pilot data as it represented a level that appeared to reduce the downward momentum of the subject prior to landing without negating the Stretch Shorten Cycle nature of the jump.

All jumps performed on the PPS used a 10 kg bar secured to the shoulders by a harness fastened to the upper torso. All subjects performed the jumps with a minimum knee angle of 110 degrees which was visually monitored (5,6). Beyond this depth the knee angle was restricted as the safety mechanisms on the PPS were positioned to restrict excessive knee flexion.

Non-braked jumps

The jump condition involved jump squats performed while holding a 10 kg barbell across the shoulders. These jumps are termed 'non-braked jumps' as they were not performed with a braking device. The non-braked jumps were administered without the PPS and its braking mechanism to simulate plyometric training as performed in most traditional plyometric training routines. The non-braked jumps were standardised by ensuring that the same knee flexion of 110 degrees was adhered to while jumping. The depth was visually monitored (5,6) and any subject that flexed the thigh beyond this level was retested.

Data collection procedures

Force measurement

Vertical ground reaction forces were collected using a Kistler forceplate (type 9287) that was mounted flush with the floor. During the braked jump condition the PPS was secured over the forceplate so that each subject landed centrally on the forceplate. Prior to the collection of all data the forceplate was reset to zero. The force data output was recorded via a charge amplifier to a 14 bit analog to digital converter board in an IBM AT compatible computer. All data was recorded at a rate of 550 Hz, over a 5.5 s period, and stored to disk for later analysis. The forceplate was calibrated immediately before and after the testing session.

For both the braked and non-braked jump conditions the peak vertical ground reaction forces were normalised to the subjects body weight. The force data for each of the two conditions were used to calculate the following impact parameters (Fig. 2): peak impact force, passive impact impulse and peak concentric force production. The passive impact impulse was defined as the area under the vertical ground reaction force curve during the first 50 ms of the impact phase (22). All data was averaged for the second and third jumps performed in the four jump series.

Statistical analysis

The data for the braked and non-braked jumps were statistically compared using a multivariate analysis of variance (MANOVA) (sex x 2 conditions) with repeated measures on one factor (condition). There was no significant (p<0.01) difference between the results for the male and female subjects. Subsequently the data were pooled together into braked and non-braked groups. A two-tailed paired t-test was then used to identify differences between the braked and non-braked jump conditions. The alpha level was set at 0.01 for all comparisons.

Fig. 2 A representative vertical ground reaction force curve. The following parameters are shown: passive impact impulse**, flight time, the concentric phase and the eccentric phase of the jump.

**Passive impact impulse was calculated as the area (sum of force x time) under the vertical force curve during the first 50 ms of the impact phase.
Results

A comparison between the braked and non-braked jump conditions are summarised in Table 2. The mean peak vertical ground impact force for the braked vertical jump (1.19 BW) was significantly (p < 0.01) less than the impact experienced by the non-braked vertical jump condition (3.04 BW).

Table 2 Comparison between 'Braked' and 'Non-Braked' jump conditions.

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<thead>
<tr>
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<th>'Braked' Jumps</th>
<th>'Non-Braked' Jumps</th>
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<tbody>
<tr>
<td>Peak impact force (BW)</td>
<td>1.19 ± 0.26*</td>
<td>3.04 ± 0.49*</td>
</tr>
<tr>
<td>Passive impact impulse (BW)</td>
<td>0.30 ± 0.21*</td>
<td>0.90 ± 0.86*</td>
</tr>
<tr>
<td>Concentric Force (BW)</td>
<td>2.32 ± 0.20*</td>
<td>2.19 ± 0.34*</td>
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</table>

*Statistically significant difference between 'Braked' and 'Non-Braked' jump conditions, p < 0.01.

The passive impact impulse was significantly (p < 0.01) lower in the braked jump condition (0.3 BWs) than in the non-braked jump condition (0.9 BWs). There was no significant (p < 0.01) difference between the peak concentric force production for the braked jump (2.32 ± 0.03 BW) and the non-braked jump (2.19 ± 0.34 BW).

Discussion

The purpose of this study was to investigate the effects of a braking mechanism on the ground impact forces associated with high intensity plyometric training. The peak impact forces obtained for the braked and non-braked jump conditions represents a 155% reduction in impact force for the braked jump condition. The corresponding impact forces for the two jump conditions are presented for a representative subject in Fig. 3. The peak impact force of the non-braked jump condition of 3.04 BW are similar to those reported in the literature for jumps (9, 16, 27, 29). However, the peak impact force obtained for the braked jumps of 1.19 BW was much lower than those reported for landings (8, 9). The lower ground impact forces resulting from the use of the braking mechanism has the potential for reducing the incidence of injury.

By successfully reducing the peak impact force and passive impact impulse at landings the occurrence of injury to soft tissue and skeletal mechanisms can be addressed. The braking mechanism may therefore have implications for rehabilitation and athletic training. The arduous process of rehabilitation often requires a gradual transition from static, dynamic and then specific muscular actions. However, the rehabilitation process may be expediated by the performance of loaded SSC actions whereby the load can be specified and velocity at impact modified. This would benefit the rehabilitation process by directly focusing movements at the specific nature of the injury and intended sports performance.

Concentric force production

The results of concentric force production would suggest that there was no adverse effect on the concentric performance of the braked jump stemming from the application of the brake. As a consequence of performing dynamic SSC exercises the musculature utilises the elastic strain energy and the neuromuscular patterns within the system which serve to facilitate performance (23). The reduction of the eccentric load with the braking mechanism could alter the elastic transfer between the prestretch and shortening phase thus changing the intended training response. However, the results of this study demonstrate that the application of the brake results in no adverse effects on concentric force production.

Any landing strategy that will allow the performance of plyometric type exercises, such as depth jumps, with increasing heights and loads while reducing the velocity of impact has the potential to modify the training effect. The PPS has applications to athletic training whereby the braking device
can allow the safe performance of heavily loaded plyometric exercises, such as jump squats, with loads in excess to that which are possible without a braking mechanism.

The braking capacity of the PPS has implications to the performance of exercises such that the SSC movement can be negated in full, in part or not at all. As such the braking mechanism has the capacity to influence the performance of plyometric exercises in both athletic training and the rehabilitation environment. With no braking applied an athlete can perform a variety of exercises of a plyometric nature to develop explosive muscular power. When the braking force is applied in a progressive manner, to the athlete or during rehabilitation, one can selectively develop explosive concentric forces using heavy weights to perform exercises, such as jump squats, while limiting impact forces upon landing. Alternatively, during the rehabilitative process, or, athletic training, one can graduate the adaptation to high eccentric forces inherent in plyometric exercises by reducing the amount of braking.

Conclusions

The use of the electronic braking device on the PPS has been shown to be effective in reducing vertical ground impact force (155 %) and the passive impact impulse at landings (200 %). The results may indicate that by successfully reducing these impact parameters the likelihood of sustaining an injury from excessive impact forces has been decreased. Furthermore, the braking mechanism did not interfere with the dynamic concentric nature of the jumping action. The use of the braking device not only has the potential to reduce injury it can also be used in dynamic rehabilitation of athletes where dynamic closed kinetic chain movements, such as jump squats, can be performed without large impact forces. Further research work is required to assess the efficiency of such a device in rehabilitation.

References


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