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Effects of exercising with a weighted vest on the output of lower limb joints in countermovement jumping

Behdad Tahayori
Louisiana State University and Agricultural and Mechanical College, btahay2@tigers.lsu.edu

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A Thesis

Submitted to the Graduate Faculty of the
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requirements for the degree of
Master of Science

In

The Department of Kinesiology

By
Behdad Tahayori
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ABSTRACT

The effect of exercising with a weighted vest equal to 15% of body mass on vertical jump height was assessed. It was hypothesized that the defined treatment protocol could enhance jumping performance by increasing hip, knee and ankle joint power. The findings of this study showed that the defined active stretching protocol significantly increases jump height in male participants (0.3364 m compared to 0.3456 m from pre to post exercise respectively) but did not yield a significant increase in females. No significant changes in joint angle, torque, power or velocity were observed between the pre and post exercise jumping. However, the pre-take off phase of jumping was significantly decreased after the exercise. Also a significant increase in the initial velocity was observed in the post loaded jumping in men (2.507 m·s\(^{-1}\) vs. 2.588 m·s\(^{-1}\) from pre to post exercise respectively).

Analysis of jumping with the weighted vest revealed numerous significant changes in temporal aspects of jumping as well as joint output. It was observed that performing the weighted jumping for five sets of three repetitions, could increase the jump height which was originally decreased by applying the vest.

Findings of the analysis of jumping with the weighted vest and those of jumping after the removal of the vest did not support the increase of a specific parameter for a specific joint. Rather, it suggests that the application of this treatment increases the performance by optimizing the timing of various movement sequences.
Chapter 1  INTRODUCTION

Numerous pre-exercise protocols, both acute (pre-event) and chronic (training), have been introduced to acutely increase jumping performance in terms of the height of jumping. These procedures range from passive stretches to various active movements [1, 2]. In a broad sense, the protocols can be divided to specific and nonspecific methods. Nonspecific protocols exploit movements that are not directly related to the subsequent exercise whereas specific ones design the protocol based on the same activity which will be subsequently performed [3]. Stretching protocols are non-specific methods in which selected muscles are being stretched for usually 30 seconds at a point of a mild discomfort [4]. Dynamic methods consist of various types of exercises such as speed skips, push-ups, high jumps and complex training which is a combination of using heavy resistance and lighter resistance exercise consecutively within a session [5].

During the past two decade a growing body of research has scientifically examined the effect of acute pre-exercise training methods on the enhancement of the subsequent movement. The review of the literature shows that not all the protocols have the same effect on the jumping performance. These differences can partly be explained by the difference in the type of exercise being used as the acute treatment for increasing the performance. For example Nelson, Cornwell and Heise [6] reported a reduction in jump height following an acute application of static stretching. Young and Behm [7] also concluded that static stretch had an adverse effect on jump performance. Contrarily, Unick et al. [4] reported that static stretching neither increased nor decreased the vertical jump height in a group of trained women.
Active stretching programs have also been examined by different investigators. For instance, Burkett et al. showed that exercising with a loaded vest equal to 10% of body mass has a significant advantage over either no activity or stretching and submaximal exercise [8]. Gourgoulis et al. [9] reported a 2.39% increase of the jump height following a series of submaximal half squats. They also suggested more effectiveness of this method in athletes with higher strength ability. Additionally, Faigenbaum et al. [10] compared 4 exercise protocols with and without weighted vests and suggested that exercise with a vest weighted with 2% of body mass is the most effective method. Thompsen et al. [11] compared static stretching methods with dynamic methods with and without vests and concluded that dynamic methods are superior to static, but the superiority of dynamic with vest over dynamic without vest was dependent upon the type of subsequent jump; dynamic with vest had a significant superiority for long jumping.

Various mechanisms have been proposed about the effectiveness of active stretching. However, the most pronounced known mechanism is probably post activation potentiation (PAP). PAP is “The transient increase in muscle contractile performance following previous ‘conditioning’ contractile activity” [12]. PAP is manifested mostly in activities involving endurance, speed and power. Muscle activation level is history dependent, and it is believed that performing active stretching temporarily increases muscle activation through the mechanisms involved in PAP. It is hypothesized that PAP increases the sensitivity of myosin light chains to Ca^{2+} and therefore facilitates the following contraction and increases the strength of each twitch with less ATP consumption. Both experimental and applied studies have provided evidence to support
the effect of PAP [12]. For instance, it has been shown that following the performance of maximum voluntary contraction, H-reflex was significantly potentiated in lateral gastrocnemius muscle. Many studies have examined the effect of complex training on enhancing the power output of athletes [13]. It is believed that dynamic activities are superior to static protocols since they can better increase body core temperature, enhance motor unit recruitment and excitability and increase awareness of kinesthetic changes. For this reason some recent works have developed jumping exercise with weighted vests. Such methods, while being regarded as active dynamic stretches, are actually specific to the type of desired activity. However, it is not well understood how exercising with a weighted vest increases jump height. Possible mechanisms include increasing the power output or the velocity of the joints as well as changing the timing and/or coordination of the movement and thereby optimizing the movement. Therefore, it can be proposed that a pre-exercise activity with a weighted vest might temporarily affect some specific characteristics of jumping both during and shortly after the removal of the vest and thus viably affect the subsequent bout of exercise.

The aim of this study is to find supportive evidence on the possible changes in the lower limb joint mechanical outputs during weighted countermovement jump and after removing the weighted vest. We hypothesize that during jumping with a weighted vest and after the removal of the vest, joint power of hip, knee and ankle increase which manifest in the increase of jump height.
**Problem Statement**

Some recent works have integrated jumping with weighted vests. These protocols, while being dynamic, are actually specific to the type of desired activity. However, it is not well understood how a weighted vest affects the neuromechanics of this movement. Therefore, it was proposed that an active stretching treatment with weighted vest would temporarily affect specific characteristics of jumping during and shortly after the removal of the vest and thus viably affect the subsequent bout of exercise. The aim of this study is to find supportive evidence on the possible changes in jumping pattern and/or lower limb joint mechanical outputs during weighted countermovement jump exercise and after removing the weighted vest.

**Hypothesis**

It is hypothesized that a series of countermovement jumps with an exercise vest weighted 15% of body mass can significantly increase the jump height after the removal of the vest.

It is also hypothesized that after removing the vest, angular velocity of hip, knee and ankle joints will show an increase.

**Delimitations**

Participants of this study were selected from undergrad and graduate students of Louisiana State University. As such, it is possible that the findings of this study cannot be applied to other groups with different age range or physical activity level.

Two constraints were imposed on the jumping method:
1- Subjects were asked to assume akimbo position to eliminate the effect of upper limb movement variation on jump height.

2- Subjects were asked not to bend forward from the hip joint during both lowering and take off phase of jumping as this might cause obstruction of pelvis markers.

Limitations

The maximum weight of the vest was 18 kg. However in practice the maximum weight that could be applied was 15.5 kg. As such the maximum acceptable weight of the subjects could not exceed 100 kg.

Each weight bar of the vest weighed 0.34 kg. As a result 15% of body mass was rounded to the nearest possible weight.

The weight distribution to the front and back part of the vest could not be always kept equal. In some cases where the number of bars was not equal in the front and back part of the vest at most there was up to 0.34 kg difference of weight distribution on the front and back.

Definition of Terms

Body Center of Mass (BCOM) - Was defined as the point where the behavior of all segments’ mass can be represented with. In this study all body segments were included for determining the position of BCOM except for the hands (from wrists onwards).

Countermovement Jump (CMJ) - A CMJ is a type of jump in which there are two distinct phases; a lowering phase proceeded by a push off phase.
**Jump Height** – Jump height was defined as the difference in vertical position of body center of mass at toe off to the vertex of center of mass trajectory.

**Joint Angles** - joint angles were defined according to the rotational sequence of segment coordinate system to laboratory coordinate system.

**Joint Velocity** - Joint velocity was defined as the first derivative of joint angle over time.

**Start of the Movement** – The point at which vertical component of ground reaction force starts decreasing.

**Take Off** - The moment of time at which the feet clear the ground and the acceleration of BCOM equals -9.81 m/s².

**Phase Classification of the Jumping Movement**

For the ease of discussion, the following classification of the sequence of a typical countermovement jump (Initiated from upright standing position) is presented here and shall be used afterwards.

The time from start of the movement to take off is referred to as the pre-take off duration. This duration can be divided into two main phases [14]:

1- **Preparation Phase** is the downward movement of BCOM and is defined as the period between the start of the motion to lowest point of BCOM where the vertical velocity becomes zero.

2- **Propulsion Phase** is defined as the period from the lowest point of COM to take off where there ground reaction force becomes zero and the body is on the air. This phase is divided into two sub-phases:
a. Acceleration sub-phase: This period starts from the minimum point of COM position to the point at which vertical velocity reaches its maximum. In this period both velocity and acceleration are positive.

b. Deceleration phase: this phase starts from the peak of vertical velocity and ends at take off. In this period, velocity is positive but acceleration is negative.
Chapter 2  METHOD

Participants
Eighteen college students (10 male, 8 female) with the mean age of 21.71 ±1.2, body mass of 64.41±16.26 kg and height of 1.67±0.809 m participated in this study. The procedure and the risks associated with the study were verbally explained to each participant. After accepting the procedure, they read and signed the consent form approved by the institutional board of review (IRB) of Louisiana State University. Prior to the study they filled the PARQ form. Upon answering YES to any of the questions they would be excluded from the study. None of the participants had a history of musculoskeletal disorder or severe or recurrent ankle sprain.

Data Collection Procedure
One familiarization session was held for each participant prior to data collection. In this session they practiced the protocol and the method of jumping to avoid confusion and subsequent variation in the jumping pattern.
Different sizes of one shoe type (SAUCONY®) were provided in this experiment to avoid variation of shock absorption properties of the shoes. Participants selected the size with which they felt comfortable. Retroreflective markers were placed on 12 body segments as follows. Four markers on head (two on the sides and two in front), on C7, proximal ends of clavicles, both shoulder joint (Acromium process) medial and lateral elbow and wrist of both upper extremities, ASIS and PSIS of both sides, cluster markers (four on each cluster) were attached to both thighs and both shanks. Five markers were permanently placed on each shoe on the heel, toe box, lateral side of quarter, medial and
lateral border between the vamp and toe box. Fourteen calibration markers were used to determine the length of the defined segments for further calculations. Detailed placement of markers is provided in table 1.

Table 1. Definition of segments and marker placement on each segment.

<table>
<thead>
<tr>
<th>Segment</th>
<th>Markers (Tracking and Calibration)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head</td>
<td>Lateral and medial, anterolateral and anteromedial sides of skull</td>
</tr>
<tr>
<td></td>
<td>Right and left thoracic outlet (calibration)</td>
</tr>
<tr>
<td>Trunk</td>
<td>R&amp;L clavicles, R&amp;L PSIS, R&amp;L ASIS, C7</td>
</tr>
<tr>
<td>Arm</td>
<td>Shoulder, lateral and medial elbow</td>
</tr>
<tr>
<td>Forearm</td>
<td>Lateral and medial elbow, lateral and medial wrist</td>
</tr>
<tr>
<td>Pelvis</td>
<td>R&amp;L PSIS, R&amp;L ASIS</td>
</tr>
<tr>
<td></td>
<td>R&amp;L Iliac crest (calibration)</td>
</tr>
<tr>
<td>Thigh</td>
<td>Four cluster markers on the mid-thigh</td>
</tr>
<tr>
<td></td>
<td>Greater Trochanter (calibration)</td>
</tr>
<tr>
<td>Shank</td>
<td>Four cluster markers on the mid-shank</td>
</tr>
<tr>
<td></td>
<td>Medial and lateral knee joint (Calibration)</td>
</tr>
<tr>
<td>Foot</td>
<td>Permanent markers on shoes (heel, toe box, lateral side of quarter, medial and lateral border between the vamp and toe box)</td>
</tr>
<tr>
<td></td>
<td>Medial and lateral ankle joint (Calibration)</td>
</tr>
</tbody>
</table>

All markers and electrodes were secured on the skin using Co-flex bands and medical adhesive tapes to reduce the chance of motion artifact.
Testing Procedure

Two different sessions were held for each subject; a treatment session and a control session. The treatment session consisted of three phases. Phase one was jumping without load. Five trials (jumps) were recorded in this phase. Phase two was the loaded-jumping period. A commercially developed exercise vest (GoFit ®) was used to load the subjects. The load bars of the vest were adjusted to 15% of body mass of each subject. Two jump recordings were done immediately after applying the vest. Afterwards the subjects were asked to perform five sets of triple jumps with 30 second interval between each set. Following this bout of exercise, two more jump recordings were done and then the vest was removed. The third phase was initiated two minutes after removing the vest. Five separate jumps were recorded in this phase.

The control session also consisted of three phases with the difference that in the second phase of five sets of triple jumps, no vest was applied. In the third phase, five jumping trials were recorded for further analysis. A schematic chart of the testing procedure is provided in figure 1.

During the recording trials subjects were asked to stand with only the right foot on the forceplate. Having only one limb in contact with the forceplate secured correct inverse dynamic calculations.

A rope was hung down from the ceiling right in front of the subjects. Two adjustable paper markers where attached to the rope. The top one was adjusted to subjects’ eye level in full upright position and the lower one was adjusted to the eye level when bending the knee to approximately 75 degrees of flexion. During the familiarization session and also
prior to the experiment, they were asked to practice in a way to not dip down lower than
the second target. Subjects were trained to automate their jumping style and to try not to
concentrate on the target during real data collection as this could potentially alter their
jumping pattern.

After calculating the jump heights for all trials, the highest jump from each situation was
selected for statistical analysis.

**Instrumentation**

**A. Hardware**

1- **Motion capture system**

An eight camera VICON motion capture system (VICON, Oxford, UK) was used to
capture kinematic data.

2- **Forceplate**

One AMTI forceplate (Watertown, MA, USA) was used to collect the ground reaction
force.
B. Software

VICON workstation was used to simultaneously capture kinematic, kinetic and EMG data. Further processing was done in Visual3D software (C-Motion, Germantown, MA, USA). Statistical analysis was performed by SAS (Cary, NC, USA).

Environment

Data were collected in Biomechanics Lab, Room B2 at the basement of COX building.

Statistical Analysis

A repeated measure ANOVA was performed with one main factor with 5 levels and one blocking factor as subjects. Significance level was set to 0.05. Independent variables of interest were jumping conditions (pre-exercise jump, jump with vest, and post-exercise jump). Gain scores of the treatment and control sessions were compared with a paired t-test.

Dependent variables were jump height and maximum angular velocity of hip, knee and ankle joint during the push-off phase.

Data from the men and women were analyzed separately.
Chapter 3  RESULTS

Description of Countermovement Jump

In this study, participants were asked to perform the countermovement jump while having only one leg in contact with the force plate. This movement has two distinct parts: the lowering part (countermovement) and the subsequent upward movement. A sample of this movement from the start of lowering center of mass to landing on the ground is presented in figure 2.

Figure 2. Displacement, Velocity and acceleration of body center of mass in a sample countermovement jump of one subject.
Different phases of the movement with respect to the changes of body COM displacement, velocity and acceleration are shown in this graph. As can be seen in figure 2, the preparation phase contains the majority of duration of the movement from the start to take off. Propulsion phase consists of two subphases of acceleration and deceleration. Maximum velocity is attained at the end of acceleration subphase.

**Temporal Analysis of Countermovement Jump**

Timing of the defined phases of countermovement jump was determined and compared among different jumping conditions. The results are presented in table 2. In this table, the duration of each phase was normalized to the total time from start of the movement to take off. It was done by dividing the time of each phase to the total duration of the jump. The absolute duration in seconds is also reported.

Statistical analysis showed that in males the absolute duration of jump decreased significantly between the pre-treatment and post-treatment phases (0.835s Vs 0.788s). This change was not observed for females or in either control sessions. The analysis of the percentile timing showed that the preparation phase was significantly reduced in males, but not in females, or in either control session.

Compared to both pre and post treatment jumping, the timing of jumping with weighted vest increased in both males and females. However, the difference between jumping with vest and without the vest was statistically significant only between loaded and post treatment jumping in males.
Table 2. Timing of phases of the jump in different conditions of jumping. Prep: preparation phase, acc: acceleration subphase, dec: deceleration subphase, abs t: absolute time of pre-take off duration. The percentages are % of abs t. (a) indicates significant difference between post and loaded, (b) indicates significant difference between loaded and pre, (c) indicates significant difference between post and pre situations.

<table>
<thead>
<tr>
<th></th>
<th>Treatment</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>timing</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pre</td>
</tr>
<tr>
<td>Men</td>
<td>prep (%)</td>
<td>68.053</td>
</tr>
<tr>
<td></td>
<td>acc (%)</td>
<td>29.795</td>
</tr>
<tr>
<td></td>
<td>dec (%)</td>
<td>2.690</td>
</tr>
<tr>
<td></td>
<td>abs t (s)</td>
<td>0.835</td>
</tr>
<tr>
<td>Women</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>prep (%)</td>
<td>66.135</td>
</tr>
<tr>
<td></td>
<td>acc (%)</td>
<td>30.395</td>
</tr>
<tr>
<td></td>
<td>dec (%)</td>
<td>3.470</td>
</tr>
<tr>
<td></td>
<td>abs t (s)</td>
<td>0.806</td>
</tr>
</tbody>
</table>

Analysis of the Jump Height in Different Conditions

Jump height in the different phases of the two sessions was determined from the vertical displacement of center of mass. The average of each phase for both males and females is presented in table 3.

Statistical analysis showed no significant changes in jump height in the control session in either gender. However, there was a significant increase in jump height in male subjects following exercise with the loaded vest compared to pre-treatment jump height values of the treatment session.
Table 3. Average values of jump height in different conditions of the two sessions. (\(^a\)) indicates significant difference between post and loaded, (\(^b\)) indicates significant difference between loaded and pre, (\(^c\)) indicates significant difference between post and pre situations.

<table>
<thead>
<tr>
<th>Jump Height (meter)</th>
<th>Treatment</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre</td>
<td>Loaded</td>
</tr>
<tr>
<td>Men</td>
<td>0.3364</td>
<td>0.2845(^b)</td>
</tr>
<tr>
<td>Women</td>
<td>0.2099</td>
<td>0.1803(^b)</td>
</tr>
</tbody>
</table>

In both male and female subjects applying the vest caused a significant reduction of jump height relative to pre and post treatment jumps. Difference between pre and post loaded exercise was 1.89 cm (SD = 1.03) for men and 1.06 cm (SD =  for women. For the control sessions the pre to post differences were 0.41 cm (SD = 2.11) for men and 0.70 cm (SD = 1.14) for women. For men, the 1.89 cm treatment gain was significantly greater (p<0.001) than the control gain of 0.41 cm and confirmed that a significant increase in jump height occurred for men following the loaded jumps.

**Joint Angle, Moment, Power and Velocity**

Joint angle, moment, power and velocity for hip, knee and ankle were calculated for the right lower limb. The graphs of these parameters for one subject are presented in figure 1. In these graphs the absolute pre-take off duration has been used as the time in seconds. For the aim of comparison, all three conditions of the treatment session have been presented together.
Figure 1. Joint parameters in three different conditions. Pre = Pre-treatment jump, weighted = jump with the vest, post = post treatment jump.
(Figure 1 Continued)

**Hip**

**Power (W/kg)**

![Graph of Hip Power](image)

**Time (s)**

- Hip Power pre
- Hip Power weighted
- Hip Power post

**Velocity (deg/s)**

![Graph of Hip Velocity](image)

**Time (s)**

- Hip Velocity pre
- Hip velocity weighted
- Hip Velocity post
(Figure 1 Continued)

Knee

![Knee Angle Graph](image_url)

Knee angle data

Knee_angle_pre
Knee_angle_weighted
Knee_angle_post

Knee Moment Graph

![Knee Moment Graph](image_url)

Knee moment data

Hip_moment_pre
Hip_moment_weighted
Hip_mom_post
(Figure 1 Continued)

Knee

Power (W/kg)

Time (s)

Knee_power_pre  Knee_power_weighted  Knee_power_post

Knee

Velocity (deg/s)

Time (s)

Knee_velocity_pre  Knee_velocity_weighted  Knee_velocity_post
Ankle

Angle (deg)

Ankle_angle_pre  
Ankle_angle_weighted  
Ankle_angle_post

Time (s)

Ankle

Power (W/kg)

Ankle_power_pre  
Ankle_power_weighted  
Ankle_power_post

Time (s)
For statistical analysis, the peak value of each curve was detected. Summaries of these values are presented in table 4.
Table 4. Peak values of angle, moment, power and velocity for hip, knee and ankle joints for both treatment and control session with the separation of gender. (\(^a\)) indicate a significant difference between post treatment and loaded jumps. (\(^b\)) indicates a significant difference between loaded jump and pre-treatment jumps.

<table>
<thead>
<tr>
<th>Joint</th>
<th>Angle (deg)</th>
<th>Treatment</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Pre</td>
<td>Loaded</td>
</tr>
<tr>
<td>Hip</td>
<td>-82.34</td>
<td>-82.77</td>
<td>-85.70</td>
</tr>
<tr>
<td>Knee</td>
<td>99.12</td>
<td>100.38</td>
<td>101.97</td>
</tr>
<tr>
<td>Ankle</td>
<td>39.19</td>
<td>39.40</td>
<td>39.55</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Joint</th>
<th>Moment (Nm/kg)</th>
<th>Treatment</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Pre</td>
<td>Loaded</td>
</tr>
<tr>
<td>Hip</td>
<td>-1.56</td>
<td>-1.39</td>
<td>-1.65(^a)</td>
</tr>
<tr>
<td>Knee</td>
<td>1.61</td>
<td>1.46</td>
<td>1.61(^a)</td>
</tr>
<tr>
<td>Ankle</td>
<td>-1.44</td>
<td>-1.27</td>
<td>-1.42(^a)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Joint</th>
<th>Power (W/kg)</th>
<th>Treatment</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Pre</td>
<td>Loaded</td>
</tr>
<tr>
<td>Hip</td>
<td>5.35</td>
<td>4.58</td>
<td>5.33</td>
</tr>
<tr>
<td>Knee</td>
<td>8.57</td>
<td>7.35(^b)</td>
<td>8.47(^a)</td>
</tr>
<tr>
<td>Ankle</td>
<td>7.13</td>
<td>6.37(^b)</td>
<td>6.83</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Joint</th>
<th>Velocity (deg/s)</th>
<th>Treatment</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Pre</td>
<td>Loaded</td>
</tr>
<tr>
<td>Hip</td>
<td>260.35</td>
<td>240.95(^b)</td>
<td>265.87(^a)</td>
</tr>
<tr>
<td>Knee</td>
<td>695.19</td>
<td>635.98(^b)</td>
<td>705.02(^a)</td>
</tr>
<tr>
<td>Ankle</td>
<td>-692.84</td>
<td>-630.93(^b)</td>
<td>-695.95(^a)</td>
</tr>
</tbody>
</table>

None of the parameters changed in the control session where the exercise was performed without the vest. There were also no statistically significant changes in any parameter.
between the post and pre-treatment phases. However, in both males and females a few parameters showed significant changes in the weighted vest jumping compared to pre and/or post treatment phases. In males joint moments of all lower limb joints were significantly higher compared to the loaded phase. Although these values were increased compared to the pre-exercise phase, the amounts of increase did not yield a statistically significant difference. Knee and ankle joint powers showed significant decreases during weighted vest exercise in males. These values remained lower during post treatment compared to pre-treatment; however, the decrease was not statistically significant. In both males and females, all lower limb joint velocities were significantly lower in loaded phase compared to both pre and post treatment. Females showed fewer changes during the loaded exercise compared to the males.

Comparison of Initial Velocity

The initial velocity of each jump was calculated using the formula:

\[ V_i = g \times t_{\text{peak}} \]

Where g is earth gravity and \( t_{\text{peak}} \) is the time between take off to the peak of the jump. This number is an indicative of linear velocity of the total body center of mass rather than a specific joint. A summary of the results are presented in table 5.

Statistical comparison showed no significant change in the initial velocity in either the control session for both males and females, or in the treatment session of females. However, initial velocity of loaded jumping showed a statistically significant reduction compared to both pre and post treatment in both males and females. There was also a significant increase in the post treatment initial velocity compared to pre-treatment.
Table 5. Summary of the average initial velocity in each phase and session of the study. \(^{(a)}\) indicates significant difference between post and loaded, \(^{(b)}\) indicates significant difference between loaded and pre, \(^{(c)}\) indicate significant difference between post and pre.

<table>
<thead>
<tr>
<th></th>
<th>Treatment</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre</td>
<td>Loaded</td>
</tr>
<tr>
<td>Initial Velocity (m/s)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Men</td>
<td>2.5</td>
<td>2.3 (^{(b)})</td>
</tr>
<tr>
<td>Women</td>
<td>2.0</td>
<td>1.9</td>
</tr>
</tbody>
</table>

**Analysis of Jumping with Weighted Vest**

As was described in the method section, the second phase of the treatment session was jumping with the weighted vest. This phase was preceded by the pre-treatment phase. During the loaded phase two recordings were taken immediately before putting on the vest and two after performing the exercise with the vest. It was in the interest of the research to observe any acute adaptation in loaded-jumping due to the brief bout of exercise with the vest. Therefore, the first weighted jump (before the bout of exercise) was compared with the highest weighted jump after the exercise. Jump height, joint angle, moment, power and velocity of these two jumps were compared.

**Jump Height Comparison during the Loaded Phase**

The highest jump in the pre treatment jump with the vest was compared with jumping with the vest after exercise. The statistical analysis showed a significant increase in weighted jump height in males, but no significant increase was observed in females. The average jump heights are presented in table 6.
Table 6. Comparison of jump height during the second phase of treatment session. highest loaded jump prior to exercise and highest loaded jump after the exercise were compared. (*) indicates a significant change from the left side cell.

<table>
<thead>
<tr>
<th>Jump Height (meter)</th>
<th>Before</th>
<th>After</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Men</strong></td>
<td>0.2648</td>
<td>0.2845a</td>
</tr>
<tr>
<td><strong>Women</strong></td>
<td>0.1848</td>
<td>0.1891</td>
</tr>
</tbody>
</table>

Peak values of joint angle, moment, power and velocity of each selected jumping were determined for each subject. A summary of the average of these values is reported in table 7.

Table 7. Comparison of the peak values of joint angle, moment, power and velocity between loaded vest prior to exercise and loaded jumping succeeding the exercise. (*) indicates a significant change from the above cell.

<table>
<thead>
<tr>
<th></th>
<th>Angle (deg)</th>
<th>Moment (Nm/kg)</th>
<th>Power (W/kg)</th>
<th>Velocity (deg/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Men</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hip Before</td>
<td>-77.19</td>
<td>-1.29</td>
<td>4.19</td>
<td>226.61</td>
</tr>
<tr>
<td>After</td>
<td>-82.77a</td>
<td>-1.39</td>
<td>4.58a</td>
<td>240.95</td>
</tr>
<tr>
<td>Knee Before</td>
<td>95.48</td>
<td>1.48</td>
<td>7.77</td>
<td>623.23</td>
</tr>
<tr>
<td>After</td>
<td>100.38a</td>
<td>1.46</td>
<td>7.35</td>
<td>635.98</td>
</tr>
<tr>
<td>Ankle Before</td>
<td>39.29</td>
<td>-1.32</td>
<td>7.18</td>
<td>-634.7</td>
</tr>
<tr>
<td>After</td>
<td>39.4</td>
<td>-1.27a</td>
<td>6.37a</td>
<td>-630.9</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Women</strong></th>
<th>Angle (deg)</th>
<th>Moment (Nm/kg)</th>
<th>Power (W/kg)</th>
<th>Velocity (deg/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hip Before</td>
<td>-83.16</td>
<td>-1.28</td>
<td>3.56</td>
<td>232.67</td>
</tr>
<tr>
<td>After</td>
<td>-83.91</td>
<td>-1.23</td>
<td>3.71</td>
<td>234.02</td>
</tr>
<tr>
<td>Knee Before</td>
<td>91.55</td>
<td>1.07</td>
<td>4.54</td>
<td>613.51</td>
</tr>
<tr>
<td>After</td>
<td>91.12</td>
<td>1.13</td>
<td>4.77</td>
<td>614.7</td>
</tr>
<tr>
<td>Ankle Before</td>
<td>35.99</td>
<td>-1.13</td>
<td>5.1</td>
<td>-648.9</td>
</tr>
<tr>
<td>After</td>
<td>35.01</td>
<td>-1.1</td>
<td>5.2</td>
<td>-637.9</td>
</tr>
</tbody>
</table>
The analysis showed no statistically significant changes in the peak values of the graphs in females. However, in males, maximum hip and knee flexion significantly increased after the loaded exercise. Maximum hip power showed a significant increase in the loaded jump after the exercise. However, maximum ankle power and ankle moment in loaded jumping showed a statistically significant reduction following the exercise. No change was found in the angular velocities of this group after the bout of exercise.
Chapter 4  DISCUSSION

In this study the effect of exercise with a weighted vest on the jump height was studied. The aim of this study was to examine whether the effects of exercising with a loaded vest on the performance of the subsequent jumping is related to changes in joint parameters such as changes in range of motion, moment, power or velocity of the joints. This type of treatment is regarded as a “specific method” which is the utilization of the same movement as the preparation for the same type of movement. However, first it had to be proved that a brief bout of exercise with a vest weighted with 15% of body mass could significantly increase the subsequent jump height immediately after removing the vest. Previous studies have supported this method to be effective and increase the jump height after the protocol. However, some contradictory results have been published to show the ineffectiveness of the protocol. After examining these studies, it was thought that the effectiveness was under the influence of multiple factors ranging from the duration and amplitude of the exercise to the weighted of the vest and the subjects of the experiment. Therefore, it was not plausible for us to follow a protocol proved to be the most effective mainly because the effectiveness of the method is dependent upon the population being tested and cannot be generalized to other demographics. Therefore, the first step for this research was to develop a treatment protocol and examine its effectiveness in enhancing the movement in terms of increasing the jump height and after that analyze the movement to find possible causes of its effectiveness or ineffectiveness. To the best of our knowledge, no work has been done to study the changes in the jump movement with
loaded vest whilst the analysis of weighted jump gives us information about the acute adaptations due to the excess load.

For the ease of the discussion, we first present to main findings of the study and then will discuss the hypotheses of this research.

**Main Findings**

1- The comparison of pre and post loaded jumps in male subjects in the treatment session showed a significant increase in the jump height. Such a change was not observed in the control session.

2- The comparison of pre and post loaded jumps in female subjects did not show a significant increase in the jump height in either the control or the treatment session.

3- The duration of pre-take off phase is shortest in the post loaded condition in the treatment session and is longest in weighted vest jumping.

4- Analysis of peak values of joint angle, joint moment, joint power and joint velocity did not suggest any significant change between the pre and post loaded situations in either control session or treatment session.

5- Numerous significant changes in joint output measurements were observed during jumping with weighted vest compared to both pre and post loaded conditions in the treatment session in male group. Jumping with the weighted vest after the bout of exercise caused a significant decrease of knee and ankle joint moment, power and velocity compared to both pre and post loaded. For the hip joint, only joint
velocity showed a significant reduction. Joint angles did not show statistically
significant changes in either of the situations.

6- The peak values did not show the same extent of changes in female group in pre-
loaded-post comparison; changes were confined knee joint power and velocity
between pre-loaded and loaded-post situation and changes in velocity of all joints
in post exercise phase compared to loaded phase.

7- Initial velocities \( (V_i) \), an indicator of the jump height, were significantly different
from each other in all conditions of treatment session in male group. Post-Hoc
analysis showed a significant change in \( V_i \) among pre-post, pre-loaded and post-
loaded condition. Non-significant changes in \( V_i \) were observed in female subjects
and in control sessions for both genders.

8- In the weighted vest jump phase, subjects were asked to jump immediately after
applying the load and after the bout of exercise with the vest on. The aim of this
comparison was to find any possible immediate changes due to acute adaptation to
jumping with extra weight. Jump height comparison showed a statistically
significant increase in the jump height in male group only. Comparison of peak
values of hip, knee and ankle joint angle, moment, power and velocity failed to
suggest a uniform or consistent pattern of change. However one notable finding
was a statistically significant decrease of ankle joint moment and power following
the loaded exercise in male group. No significant change was observed in female
participants.
However, throughout the study and interpreting the results it should be kept in the mind that all joint analyses were performed in the right lower limb which was the dominant side in all participants. The assumption is that both limbs act identically. However, we did not perform any analysis to compare the two sides.

Second important consideration during the interpretation of data is the style of jumping which was a countermovement jump with hands on the hips. This was for eliminating extraneous factors such as the influence of upper limb strengths on the jump height. This restriction, however, is regarded as a major perturbation in jumping style. Harmen et al. [15] and Luhtanen and Komi [16] have shown that restricting arm movements during jumping, could result in 10% reduction in performance.

The morphology of the graphs of joint angle, moment, power and velocity are very consistent with those reported in the literature. However the comparison of values and positive, negative signs of the graphs must be done with caution. The reason is the definitions used to calculate these parameters. Difference in laboratory coordinate systems and joint coordinate systems could cause some changes in the values and sign of the graphs. Also the normalization method could fundamentally change the values. Nonetheless the graphs presented in this thesis could be very well matched with those presented in [17].

**Effectiveness of the Protocol and Gender Effect**

In the current study, pre and post exercise jump height were 33.64 cm and 35.52 cm respectively. This was comparable to the jump heights of other researchers. For example, in the method used by Gourgoulis et al, jump height increased from 33.67 cm to 34.48
cm [9]. Other works have reported higher values of jump height. In the study of Thompsen et al, for example the pre exercise was 41.7 cm and the post exercise height was 43.9 cm [11]. For the jump height in females, Duthie et al. have reported 13.1 cm and 13.2 cm for two of the methods that they examined [2]. However, Unick et al. reported 41.50 cm and 40.41 cm for pre and post exercise jump height from their subjects who were 16 trained women [4]. One reason of these differences of jump height between the different researchers is attributed to difference in the participants’ population. The comparison of above mentioned research suggest that trained athletes have bigger jump heights.

The present study was mainly designed to find possible mechanisms through which weighted jump exercise influenced the subsequent movement outcome. It was shown that exercising with a weighted vest with 15% of body mass could increase jump height for average of 1.89 cm for male participants. However, it failed to change the jump height for female group. Previous research, as far as we are aware, have mostly tested only one gender and/or have not separated the analysis for different genders. As such, it cannot be inferred whether the presented protocols are gender dependent or not. However, one noticeable finding in the work of Faigenbaum et al. was that a 2% weighed vest was more effective than a 6% vest in their group of 20 female high school athletes. Thus it is possible that in our research that 15% was too heavy for the females, however, the current design scope and findings cannot support this proposition. Nonetheless, the analysis of loaded jump in this group showed less changes compared to male participants.
in two major perspectives: first changes within the loaded jumping phase and second, changes between loaded and post-exercise phase of the treatment session.

1- No immediate adaptation during the loaded jump exercise was seen in terms of the increase of jump height.

2- We failed to find a decrease in the pre-take off time in female participants in post exercise jumps. As will be discussed later, this could be an important parameter in the effectiveness of the treatment.

Another possible explanation could be the difference of muscle stiffness between men and women. Kubo et al [18] compared tendon stiffness, joint stiffness and EMG activity of ankle plantar flexors for both drop jump and counter movement jump. They concluded that tendon elasticity, manifested by a tendon stiffness index, was significantly correlated to jump performance and this relation was more pronounced during drop jump. However, they did this experiment only on a group of 24 men. Nonetheless, this can support the idea of the importance of joint and tendon stiffness in jump height and its possible difference between genders. Komi et al [19] have suggested the existence of “the general difference between men and women in strength speed type performance”. In a separate study, Komi et al, [20] have observed that males have much better performance during both drop jumps from various heights and counter movement jump. They raised the possibility of difference in elastic energy storage between the genders. However, they could not support this hypothesis with enough evidence.
Jumping with Loaded Vest

Countermovement jump performance with weighted vest showed substantial changes in certain aspects compared to that without a vest. First, the absolute duration of pre-take off phase increased. This increase, although observed in both genders, was statistically significant in male participants only. Second, joint velocity of hip, knee and ankle significantly decreased during the loaded jumping. In males the observed changes in moment, power and velocity were in respect to both pre and post exercise values. These changes might be an indicative of the effectiveness of the extra load to induce subsequent enhancement.

However, one finding which was unexpected and unexplained is the reduction in peak ankle moment and ankle power in jumping with the west after the bout of loaded. This significant reduction of peak power and moment of the ankle joint was only observed in the males, and we could not determine a logical reason for this finding. Nevertheless, it suggests that exercising with a loaded vest might negatively affect ankle joint output. However, we did not find the same phenomenon in female subjects which makes any interpretation more complicated. This topic is open to more investigation.

Pre and Post Loaded Exercise Comparison

Some possible causes associated with increased jump height were examined in this study. Study of peak values of joint angle, moment, power and velocity have been previously used in the interpretation of jumping data. Van Soest at al. [21] used these parameters to describe the changes associated with one-legged countermovement jump. In this study, we could not find any statistically significant change in the peak values between post and
pre-loaded values. However, the key point is that all joint velocity peak values showed non-significant increases in the post exercise jump. Interpreting this finding with the finding that the duration of pre-take off was reduced suggests that a non-significant increase in joint velocity could be able to be the cause of increase in jump height. A striking piece of evidence found in this study to support this idea is the fact that the initial vertical velocity of body center of mass was significantly increased after the bout of the exercise.

Therefore, the results of this study could not support the idea that loaded vest exercise increases muscle output after the defined protocol presented in this study. Rather, there is evidence to support that using weighted vest changed the style and the timing of the jump and thus optimizing the velocity-force relationship or the coordination and timing of the movement.

**Conclusion and Suggestions for Future Research**

The current study investigated the effect of a treatment procedure, exercising with a vest weighted with 15% of body mass on the subsequent jumps. The results of this study did not support our null hypothesis regarding the increase of joint velocities and/or powers after the treatment. Instead we found evidence to show that after this treatment, the skill and the technique of jumping is being affected insofar as to enhance the outcome of the movement. This novel idea, while needing more investigation, suggests a new mechanism for acutely increasing the jump height. Further research is needed to strengthen not only this idea but also answer the question that whether other methods
which have been shown to be effective in increasing the jump height could also entail this mechanism.

Notably, it was found that the end result of the protocol is gender dependent. In this study we were not able to describe the possible causes of the difference in the effectiveness, but this does open lines for further research to examine different protocols with various amplitudes and durations and their influence on gender.

The current treatment, due to its effect on the subsequent movements, could have different applications. Rehabilitation protocols where carrying extra loads is not contraindicated, this treatment can increase the performance of the patients at least for a short time. Using weighted vests for treatment purposes such as enhancing gait functionality and reducing ataxia is a common practice in rehabilitation, though it is not very well backed by the scientific evidence [22]. The current study could give some insight about the importance and efficacy of this practice. The long term effects of this treatment, if applied on regular basis, are a question subject to further investigation.

This treatment can also be used as a warm up method with the aim of acutely increasing the performance of athletes. Many sports activities require jumping movements and a 5% increase in jump height could be very important for many athletic events. Using a similar method of incorporating loaded vests, Burkett et al. suggested “The best warm-up for vertical jump in college-age athletic men”. They have suggested that a one set of 5 countermovement jumps with a load equal to 10% of the body yields the greatest benefits [8]. However, based on our observations in this study we would not be able to infer whether this best method will have the same advantage for women. Current literature
lacks research that considers the optimum warm-up protocol for each gender separately. As stated previously, we were not able to find any work which has compared one protocol in the two genders.

Most, if not all, papers that have introduced exercising with weighted vest have justified their findings based on PAP mechanism. While the existence and effects of PAP have been confirmed in many experiments, we speculate that other mechanisms other than PAP could take place in enhancing the outcome. We have observed that the timing of the jump is manipulated in loaded exercise. This gives some evidence to the idea that enhancing the coordination of movement could be one possible factor in enhancing the outcome, one which has not been introduced in the literature for this specific type of athletic activity.

It is not known whether the changes observed in the timing are due to the effect of specific exercise or if it can be seen after other types of dynamic-nonspecific methods as well as static stretching methods. Additional research on this topic based on this idea will provide more understanding about the necessity and/or benefit of specific type of protocols.

One noteworthy finding in this study was the significant decrease of ankle joint moment and power with the continuation of jumping with the vest. We observed that after a few jumps with the weighted vest, ankle moment and power showed significant reduction in their peak values compared to the first loaded jump. This finding could be a potential indication of possible deteriorating effects. More work should be done to examine this possibility. Also, it may be manifested by more careful study of the coordination pattern.
of jumping with a loaded vest. It would be important to know whether or not applying the vest does affect the stability of the movement. For this purpose, different durations of loaded exercise shall be compared to better identify this idea. Changes in coordination pattern and stability of the movement along with the changes in ankle joint moment and power could be potential rate and amplitude limiting factors for loaded exercise phase.
REFERENCES


VITA

Behdad Tahayori, who is of Persian decent, was born and raised in Shiraz, Iran. He got his master’s in physical therapy from Iran University of Medical Sciences in Tehran, Iran in 2006. After graduation he worked in the PT School of Shiraz University of Medical Sciences as a research officer. In 2008 he moved to Baton Rouge to join the Department of Kinesiology at Louisiana State University. Based on his interest in the effect of stretch-shortening cycle on performance, he started an independent study with Dr. Arnold Nelson. The results of reviewing the papers through that study led to a proposal for master’s in kinesiology. He aims to continue this field of study as one of his interest areas of research.