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The Effect of Load on the Kinetics and Kinematics of the Lower Extremity during Landing

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THE EFFECT OF LOAD ON THE KINETICS AND KINEMATICS OF THE LOWER EXTREMITY DURING LANDING

MICHAEL SULLIVAN

29 Pages

Purpose: To understand the differences in the lower extremity kinetics and kinematics as load increases during jump landings. **Methods:** Ten male participants (20.4 years ± 2.41 years, 108.8kg ± 14.02kg) took part in two testing sessions. The first testing session involved testing each participant's 1-repetition max in the hexagonal barbell deadlift. The second testing session involved the data collection of the jumping trials for each participant. Participants performed their countermovement jumps under seven randomized conditions. Six of the conditions involved the hex bar using loads equivalent to 10, 20, 30, 40, 50, and 60% estimated 1-repetition max of the hexagonal barbell deadlift. The seventh condition was an unloaded (bodyweight or 0%) countermovement jump. Peak values for joint powers, moments, angles, and velocities were recorded for the ankle, knee, and hip for all participants and conditions. A repeated measures ANOVA was used to compare differences among results. **Results:** Significant differences ($p < .05$) were found in the joint powers and moments but no differences were found in any condition or joint for the peak angles or velocities. The greatest absolute values for both the peak powers and moments were found at the unloaded condition and decreased as load increased.

Conclusion: This investigation has largely supported the previous research that has been done regarding loaded landings. The current findings support the previous notions that jump heights and joint velocity seem to have direct effect on joint moments and powers. Implications for injury risk and sports performance can also be drawn from these results, but more research would need to be done in order to fully understand loaded landings as they relate to either of those topics. Additionally, as the landscape of loaded landings is still quite shallow, any research regarding the effects to the lower extremity at landing with load would continue to create a more robust understanding of such an important aspect of jumping.

KEYWORDS: Jumping, Landing, Load

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M.S.

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CHAPTER I: INTRODUCTION

Jump performance has been a topic of research within the performance community since its inception. Furthermore, loaded jumping, due to its documented ability to increase unloaded jump performance, has been intensely researched and extensively used within the sports performance setting. However, the research regarding the inevitable consequence of loaded jumps, loaded landings, has fallen behind. Landing research gives practitioners insight into the stress, demands, and forces that are experienced by the lower extremities during such a common and fundamental movement. Understanding the demands of landing gives insight into the potential for both injury risk and performance improvement.

Current research on jump landing, loaded and unloaded, has examined how the kinetics and kinematics are affected during landing. Janssen et al (2012) compared loaded and unloaded landings for elite volleyball players. The researchers were trying to determine if loaded jumping (9.89kg vest) increased the risk of injury to the lower extremity. Similar to the present study, the researchers identified loaded jumping as a common method of training and hypothesized that increased load would increase risk of injury during landing. However, the only difference in either kinetic or kinematic variable found for their study from loaded to unloaded was the hip flexion angle at initial contact (unloaded was significantly greater). The researchers concluded that such similar landing patterns do not increase injury risk.

In 2020, Yom et al completed a study whose goal was to understand the effect to the lower extremity of military personnel who had to complete physically demanding tasks with external load. The researchers had ROTC cadets do drop landings with a weighted vest of 35%

bodyweight load and without load and compared the flexion angles and vertical ground reaction forces. The researchers found that when the load was added, the participants had significant increases in the maximal flexion angles of the lower extremity but significantly decreased vertical GRFs. Similarly, Fritz et al (2019) studied how different landing strategies effected the lower limb kinetics during loaded landings. Before each of the jumping trials, the researchers had the participants adopt one of four separate landing strategies, soft, super soft, stiff, or super stiff. The results saw no significant change regarding joint moments or powers among any of the landing strategies. However, as joint flexion decreased (as landings went from soft to stiff) there was a significant increase in peak vertical force. This was similar to the Yom et al (2020) study as there were decreases in vertical force with increased flexion of the lower extremity.

Yin et al (2015) and McNitt-Gray (1991) both studied the how the forces at landing effected the lower extremity without load. Yin et al (2015) had the goal of describing the landing strategies for both males and females. They found significant reductions in impact force if active hip and knee flexion motions were used for both male and female participants. McNitt-Gray (1991) compared elite gymnasts to recreational athletes and found that as impact velocity at landing increased (using different landing heights) so too did joint angular velocity, joint flexion, and impact forces. The authors concluded that as joint moments increased at landing then the potential for injury at those joints also increased.

The current research on landings has largely concluded that joint moments increase as joint velocities and height of landing increase. Furthermore, it appears that as flexion angles of the lower extremity increase, vertical forces decrease. Researchers who have done loaded landing studies have largely hypothesized that there would be an increase in injury risk to the lower extremity as load increases, but the research has yet to fully support that hypothesis. The current research on loaded landings has largely investigated a singular load and compared to unloaded trials. There has yet to be a study that looks at a range of loads and compares multiple loaded conditions to an unloaded condition. Very few sports performance practitioners, if any, use one set load for all athletes during loaded jumping and landing movements and, therefore, it is difficult to draw conclusions from the current research on the effect of loaded landings. Interestingly, none of the current literature on loaded landings attempts to understand how landings can improve sports performance. However, as documented by Cal Dietz (2012), the ability of athletes to produce power concentrically is largely dictated by their ability to absorb power eccentrically. Understanding the eccentric powers of the lower extremity during landing may provide insight into potential performance improvement.

The lack of research on such an important part of the jumping process could discount the potential benefits associated with the take-off portion if the landing is not fully understood. Especially as loaded jumping becomes a mainstream movement within sports performance settings, understanding all phases of such a movement seem necessary before fully investing in such a training method. Therefore, the aim of this study is to understand the differences in the lower extremity kinetics and kinematics as load increases during jump landing. Furthermore, this study aims to understand the point (or load) at which the landing strategy significantly differs from the unloaded strategy. Based upon previous research, it is hypothesized that as load increases peak joint flexion of the hip, knee, and ankle will increase as well. However, significant changes will not occur until the 20% 1RM load condition. Additionally, peak joint velocity will decrease as load increases and, finally, both peak powers and moments will be significantly lower during all loaded trials compared to the unloaded condition.

CHAPTER II: REVIEW OF LITERATURE

Jumping is a common and critical part of sports. Most every sport involves some type of jump take-off and, consequently, jump landing. This popularity has made jump training a staple within strength and conditioning and sports performance programs for many years. Studies have been done to clarify the importance of the take-off portion of the jump. For example, Makaruk and Sacewicz (2010) found that in a group of students who were given a bodyweight plyometric program (countermovement, depth, and repeat jumps), in six weeks their relative maximal power output significantly increased from initial testing. There is a general understanding that plyometric training lends itself to increased athletic performance. However, less understood is the effect of landing to the lower extremity or at is pertains to injury and performance. Understanding the landing phase of jumping is critical in fully accepting the benefits of jumping as a whole.

Yin et al (2015) studied the effect of the forces placed on the lower extremity during the landing phase of a jumping task. The goal of the study was to describe the differences found between the landing strategies of males and females. They found data on the ground reactions forces (GRFs) and joint flexion angles. They established that active hip and knee flexion motions significantly reduced impact force at landing for both male and female participants. These conclusions indicated, to the authors, that there would be a decrease in injury risk of the lower extremity if active flexion of the hip and knee were used at jump landing to dissipate the forces at those joints. As mentioned by the authors, many overuse injuries were connected to these high forces exhibited during landing. McNitt-Gray (1991) studied the effect of landing tasks on lower extremity kinetics and kinematics among elite level gymnasts compared to recreational athletes.

The authors had both groups of participants do drop landings from three drop heights and their landings were characterized by description. Findings revealed that as impact velocity at landing increased then so too did joint angular velocity, joint flexion, impact forces, and joint moments. These increases in impact velocity also coincided with increases in the height of the drop. The author concluded that as joint moments increase at landing then the potential for injury at those joints does too.

Similarly, Zhang et al (2000) did a study to understand the changes in the lower extremity joint energy absorption for different landing heights and techniques. The participants of this study were instructed to perform step-off landings from three different heights using different landing techniques (soft, normal, and stiff). The researchers found general increases in peak GRFs, joint moments, and joint powers with increases in landing height and stiffness. These results were along the same lines as the previous studies mentioned and, again, concluded that as these kinetic and kinematic variables increased then so too would the risk for lower extremity injury at those joints.

As the performance community has continued to understand unloaded jumping benefits, sights have been shifted to the use of loaded jumping as a means of training sports performance. The use of loaded jumping within the performance community has, in recent years, gained increasing traction and, therefore, increasing amounts of research. In a 2017 study, Ullrich, Pelzer & Pfeiffer, studied the effect of using loaded jumping on a group of participants within two types of periodization models (traditional linear and daily undulating). Jump trials were used with 0, 15, and 30 percent of participant’s body mass. The authors found similar increases in preto-post-test results within both groups. Both groups of periodization had significant increases in COM jump height, leg extensor maximal voluntary contraction, and muscle architecture.

Additionally, there has been research done to examine what is the most efficient type of loading pattern to create the most positive adaptations in a loaded jump. Swinton et al (2012), compared the use of the hexagonal barbell (hex bar) jump and the straight barbell (across the back) jump (Two of the more popular loading methods). The authors used loads of 0 (unloaded), 20, 40, and 60% of the participants 1RM squat to load both the hex bar and the straight barbell for jumping trials. The authors found that the hex bar jump resulted in significantly greater values for jump height, peak force, peak power, and peak rate of force development compared with the straight barbell jump. Significantly greater peak power was produced when using the hex bar with a 20% 1RM load compared with every other (unloaded and straight barbell) conditions. One of primary reasons that the authors concluded that the participants performed superiorly with the hex bar as opposed to the straight barbell was because the straight barbell across the back changed the natural motion of the jump too much. The researchers found that when placing the bar across the back, the participants adopted a much more vertical take-off position to account for the added load and a raised center of mass position. However, with the hex bar jumps (the weight held down at arms-length), the natural motion of the jump more closely resembled that of an unloaded jump. The authors state that training a jumping method that more resembles an unloaded take-off is more applicable in the performance setting, and therefore the straight barbell should be avoided especially when the hexagonal barbell is available.

In summary, the research pertaining to loaded jump take-offs is wide ranging. However, there are still many unanswered questions about how the landing strategies change as the load increases. A few studies try to answer some of these questions. Janssen et al (2012) compared landing techniques of elite volleyball players during a jump landing with and without a weighted vest (9.89kg). The authors wanted to know if increased load during landing would increase the risk of injury to the athlete. The researchers found that hip flexion at initial contact was significantly greater in the unloaded condition compared with the loaded condition. There was no significant difference in any other kinematic or kinetic variable measured between the loaded and unloaded conditions. The authors concluded that landing from a loaded jump does not increase risk of injury compared to unloaded.

In another study, Dempsey (2014) studied the effect of load on jump landing performance and ground reaction forces. The author wanted to understand how landing performance would change as load did. Using a pool of 52 males, the author measured peak vertical GRF and jump height using bodyweight jumps and a load of 7.65kg. He found that compared to the jumps without load, the loaded condition decreased mean jump height by an average 12% and increased peak GRFs by 13-19%. The author concluded that adding load to landings may also increase the chance that injury occurs as well. However, these conclusions are in opposition of other studies, including Janssen et al (2012). Yom, Redinger, Grooms, & Simon (2020) created a study in which they had college ROTC cadets wear 35% of their body weight and perform jumping tasks. Their goal was to understand biomechanical challenges that military personnel faced when constantly training and performing with extensive external load. They were trying to determine if this external load would affect lower extremity kinetics and kinematics during jump landing task.

The authors found that compared to baseline landing, the loaded landing resulted in decreased knee and hip flexion at initial contact and increased maximal joint flexion displacements for the ankle, knee, and hip. Furthermore, there was a significant reduction in GRFs with load at landing. The takeaways from this study indicate that although loads are increased during landing, the potential increase in forces seemed to be offset by the increased joint flexion which is similar to findings from the unloaded landing research.

Fritz, Schwameder, Seiser, & Kroll (2019) wanted to understand the effect of using different landing strategies on landing kinetics during loaded jumps. The ten participants within this study performed countermovement jumps with 50% of their body weight added as external load (straight barbell). The participants were instructed to adopt one of four landing strategies upon impact (super stiff, stiff, soft, and super soft) . The differences between the four types of landing were investigated. The authors use of an external load of 50% body weight is one of the heaviest loaded landing studies that has been published. The results of the study found that peak vertical force increased up to 50% with decreasing joint flexion during landing. Whereas no changes to peak joint moments or peak powers were found in any of the four landing strategies. This study was the first that analyzed the effect of different landing strategies on the kinetics during loaded jumps. The authors concluded that different body tissues are exposed depending on the landing strategy adopted by the athlete/participant.

There are a number of voids that are left in the literature regarding loaded landings. Foremost, the lack of research comparing multiple loaded conditions to each other and an unloaded condition leaves room for current and future research. Current research has tended to look at one load and examine how that load compares to the unloaded condition. From there, conclusions are drawn based on the changes with that singular load. However, no study has yet sought to understand exactly what load creates those significant kinematic and kinetic changes and which do not. Similarly, understanding those differences would further both the understanding of loads to use to improve sports performance and avoid injury. As mentioned by Fritz et al (2019), some researchers have hypothesized that with increasing load in landing studies, so too would there be an increase in overuse injury risk to the lower extremity. Inversely, others have hypothesized that those potential increases in overuse injuries would be offset by load-based reductions in jump height. Furthermore, understanding which loads create the highest power outputs, moments, and velocities at landing are important in drawing connections as they effect sports performance. As Cal Dietz wrote about in his book on the triphasic nature of muscle action, athletes' ability to produce concentric power is largely dictated by their ability to absorb eccentric power. Furthermore, Zhang et al (2000) concluded that high eccentric strength and neuromuscular control of the lower extremity muscle groups are developed with these high exposures and critical to the integrity of the lower extremity. However, the biggest need for literature within loaded landings is the continued research that investigates what happens to the lower extremity as load increases. More research on this topic will create a more robust understanding of this specific phase of jumping and practitioners and researchers alike will be able to continue to draw more concrete connections to both injury and performance.

CHAPTER III: METHODS

Participants

Ten male participants were recruited for this study (20.4 years ± 2.41 years, 108.8kg ± 14.02kg). Participants were collegiate athletes (football) and had a minimum of two years of resistance training with the deadlift and countermovement jump. Subjects could not have had an injury to the lower extremity or spine in the last two years. Written informed consent was obtained from all subjects prior to testing.

Table 1. Participant Characteristics.

Variables	**Mean**	**± SD**
Age (y)	20.4	± 2.41
Body Mass (Kg)	108.8	± 14.02
Height (m)	1.8	± 0.057
1RM Deadlift (Kg)	216.6	± 10.9

**RM = Repetition Maximum*

Experimental Protocol

Participants reported for two testing sessions. Testing sessions were separated by a minimum of 48 hours to ensure that fatigue from the first session was not a factor in the second. The first testing session was to test the participants on their 1-repetition max (1RM) hexagonal barbell (hex bar) deadlift to assign the specific loading conditions for the jumping trials in session two. Participants reported a previous 1RM deadlift and that number was used to guide loading parameters for the first session. The first session included six total sets of increasing load until a 1-repeition max was estimated using the Epley formula. The Epley formula is a prediction formula to estimate 1RM. The formula is (0.33 * number of repetitions * weight lifted) + weight lifted. In their study of seven 1RM equations, Wood et al (2002), found that the Epley formula had the lowest average error and highest relative accuracy of the equations examined.

The first set was an empty hex bar deadlift which was taken for ten reps by each participant. The second set was loaded with 20% of reported maximum and taken for eight reps by each participant. The third set was loaded with 40% of reported maximum and taken for five reps by each participant. The fourth set was loaded with 60% of reported maximum and taken for five reps by each participant. Finally, the last two sets were used to determine a weight that the participants could only lift for five reps, beginning with 80% of reported maximum. After the final set, a 1-repetition max was estimated using the Epley formula.

The second testing session involved the data collection of the jumping trials for each participant. All athletes were instructed to wear compression clothing and had thirty-three reflective markers attached to the lower extremity. The markers were place at the sacrum, iliac crests, trochanters, thighs (four marker clusters), knees (medial and lateral epicondyles), shank (three marker clusters), ankle (medial and lateral malleoli), and foot (calcaneus, first metatarsal, and fifth metatarsal). Participants performed their countermovement jumps under seven randomized conditions. Six of the conditions involved the hex bar using external loads equivalent to 10, 20, 30, 40, 50, and 60% of estimated 1-repetition max of the hex bar deadlift. The seventh condition was an unloaded (0%) bodyweight countermovement jump. For each trial, participants were instructed to perform the task with their feet positioned on separate force plates which were aligned side-by-side. Participants performed five trials at each condition. Order of condition was randomized for each participant, and each trial was separated by a minimum of two-minutes and thirty seconds to promote adequate recovery between trials. For each trial, participants were instructed to descend to a height relative to their unweighted vertical jump depth and jump as high as possible. Two wooden boxes were used to hold the hex bar off the ground and at a safe height that allowed the participants to initially lift the weight off the ground. Only data from the landing portion was collected. The landing portion was defined as one frame before foot contact until the lowest point of the participant's COM.

Instrumentation

Subjects performed the countermovement jumps on a two-force plate platform (ATMI; Wattertown, MA), while also using a 10-camera motion capture system (Vicon; Denver, CO) sampling at 200Hz. All trials were run through a biomechanical analysis software (Visual 3D; Germantown, MD) and filtered at 13Hz using a low-pass Butterworth filter.

Data Processing and Analysis

Marker position and force plate data from each trial was imported into analysis software (Visual 3D; Germantown, MD) and filtered at 13Hz using a low-pass Butterworth filer. A three-dimensional model of the lower extremity was constructed for each participant. Joint moments were calculated using an inverse dynamics approach and joint powers were calculated as the product of joint angular velocity and joint moments. Time series were normalized to 101 points, representing 0-100% of the eccentric phase, for graphical purposes. A MatLab script was used to calculate peaks of each variable – joint powers, moments, angles, and velocities.

Statistical Analysis

A statistical analysis was conducted using IBM SPSS statistics 26 (Chicago, IL) with data being organized into mean joint powers, moments, angles, and velocities for each of the three joints (ankle, knee, and hip) investigated. A repeated measures analysis of variance (ANOVA) was used to compare across loaded conditions for each variable measured. Post-hoc tests with Bonferroni adjustments were conducted if significant main effects were observed. An alpha level of statistical significance was set at $p < 0.05$.

CHAPTER IV: RESULTS

Ankle moment at the unloaded condition (-1.93 Nm/kg) had the greatest absolute value of all conditions and was significantly greater than the 30 percent ($p = .037$, C.I. -1.23, -.028) 40 percent ($p = .002$, C.I. -1.29, -.29) 50 percent ($p = .001$, C.I. -1.4, -.38), and 60 percent ($p = .000$, C.I. -1.5, -.53) conditions. Ankle moment at the 10 percent condition had the second highest absolute value and was significantly greater than the 30 percent ($p = .002$, C.I. -.55, -.12), 40 percent ($p = .000$, C.I. -.73, -.27), 50 percent ($p = .000$, C.I. -.88, -.33), and 60 percent ($p = .000$, C.I. -1.08, -.37) condition. Additionally, the 20 percent condition was significantly greater than the 40 percent ($p = .024$, C.I. -.59, -.03), 50 percent ($p = .002$, C.I. -.69, -.15), and 60 percent ($p = .001$, C.I. -.86, -.22) conditions. The ankle moment at the 30 percent condition was significantly greater than the 50 percent ($p = .02$, C.I. -.5, -.04) and the 60 percent ($p = .001$, C.I. -.7, -.08) conditions. Finally, the ankle moment at the 40 percent condition was only significantly greater than the 60 percent condition ($p = .02$, C.I. -.43, -.03).

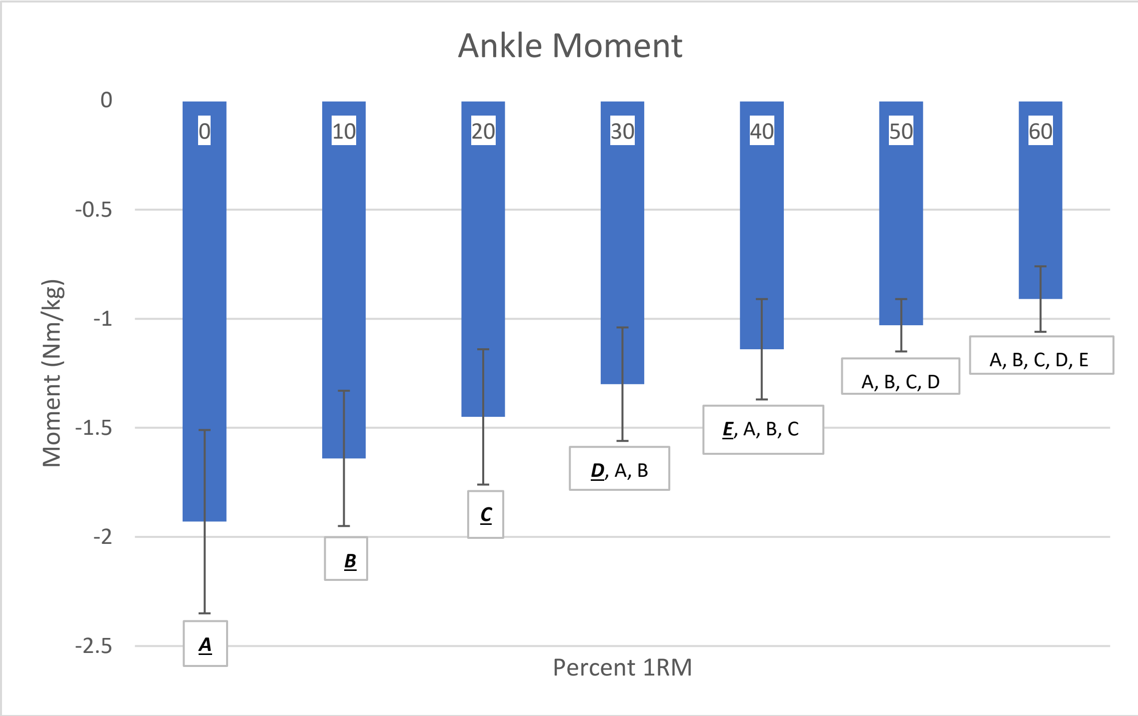

Figure 1. Ankle moment peak values and standard deviations. Moments were normalized to total system mass at each condition (Nm/kg).

Similarly, the maximum value of the knee moment at the unloaded condition (2.5 Nm/kg) had the greatest value of all conditions and was significantly greater than 30 percent (p = .001, C.I. .39, 1.53), 40 percent (p = .000, C.I. .63, 1.82), 50 percent (p = .000, C.I. .83, 2), and 60 percent (p = .000, C.I. .83, 2.2) condition. The 10 percent condition had the second highest value and was also greater than the 30 percent (p = .002, C.I. .25, 1.11), 40 percent (p = .000, C.I. .54, 1.35), 50 percent (p = .000, C.I. .74, 1.54), and 60 percent (p = .000, C.I. .73, 1.7) condition. Furthermore, the 20 percent condition was significantly greater than the 40 percent (p = .001, C.I. .24, .97), 50 percent (p=.001, C.I. .34, 1.27), and 60 percent (p = .001, C.I. .41, 1.34) conditions. The 30 percent condition was significantly greater than the 40 percent (p = .035, C.I.

.01, .51). 50 percent (p = .005, C.I. .13, .79), and 60 percent (p = .007, C.I. .13, .92) condition. The 40 percent condition was only significantly greater than the 60 percent (p = .01, C.I. .06, .48) condition.

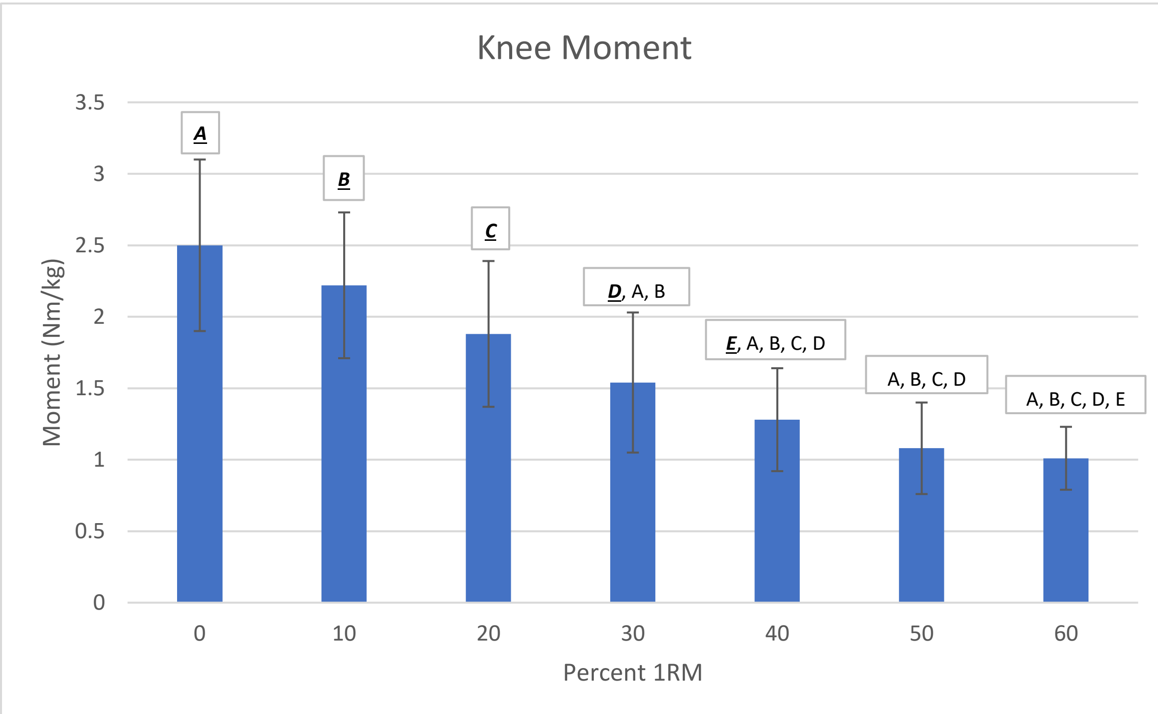

Figure 2. Knee moment peak values and standard deviations. Moments were normalized to total system mass at each condition (Nm/kg).

Finally, the hip moment absolute maximum value was, again, greatest in the unloaded condition (-4.57 Nm/kg). However, unloaded condition was only significantly greater than the 40 percent (p = .047, C.I. -4.3, -.02) and 60 percent (p = .02, C.I. -5.31, -.45) condition. The 10 percent condition, which has the second greatest absolute maximum value, was significantly greater than the 30 percent (p = .045, C.I. -2.13, -.02), 40 percent (p = .015, C.I. -2.79, -.25), 50 percent (p = .041, C.I. -3.74, -.06), and 60 percent (p = .002, C.I. -3.67, -.83) condition. The 20 percent condition was only significantly greater than the 60 percent condition (p = .004, C.I. -2.67, -.51). Similarly, the 30 percent condition was also only greater than the 60 percent (p = .016, C.I. -2.16, -.19).

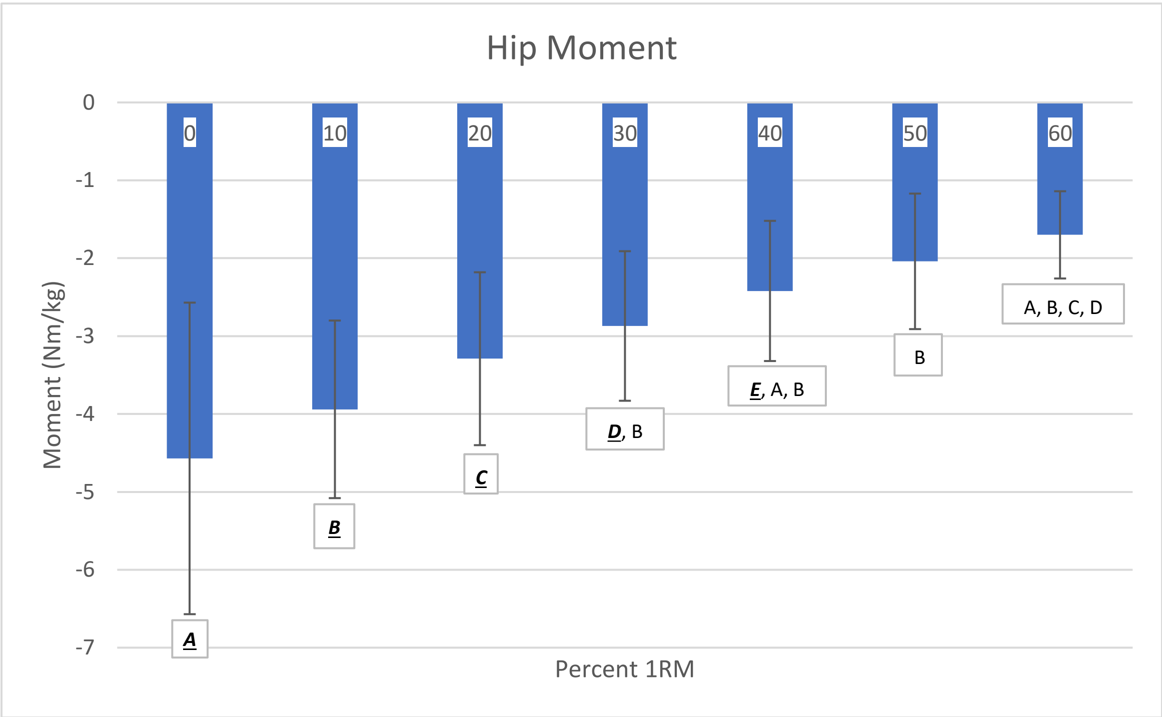

Figure 3. Hip moment peak values and standard deviations. Moments were normalized to total system mass at each condition (Nm/kg).

Ankle power at the unloaded condition (-23.51 W/kg) has the greatest absolute maximum of any of the loaded conditions. However, the unloaded condition was only significantly greater than the 60 percent condition (p = .038, C.I. -31.04, -.69). The ten percent condition, although the second highest absolute maximum value, was significantly greater than the 50 percent (p = .007, C.I. -17.06, -2.42) and 60 percent condition (p = .005, C.I. -22.31, -3.85). The 20 percent condition was significantly great than the 60 percent condition (p = .022, C.I. -21.57, -1.35). Similarly, the 30 percent condition was also significantly greater than the 60 percent condition (p = .004, C.I. -12.61, -2.23).

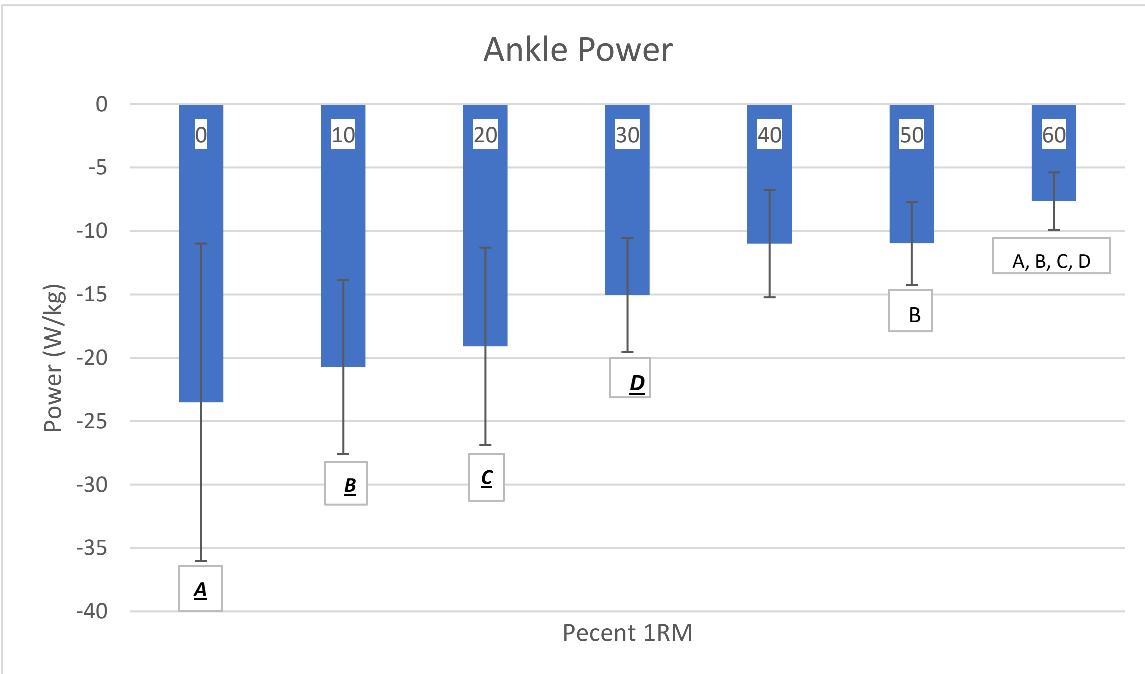

Figure 4. Ankle power peak values and standard deviations. Powers were normalized to total system mass at each condition (W/kg).

The knee power had the greatest absolute maximum at the unloaded condition, however was only significantly greater than the 40 percent condition (p = .036, C.I. -28.31, -.73). The 10 percent condition, which had the second highest absolute maximum value, was significantly greater than the 30 percent (p = .023, C.I. -17.77, -1.09), 40 percent (p = .003, C.I. -20.75, -4.21), 50 percent (p = .001, C.I. -20.93, -5.9), and 60 percent (p = .007, C.I. -28.69, -4.29) condition.

The 20 percent condition was significantly greater than the 40 percent (p = .003, C.I. -15.09, -3.08), 50 percent (p = .004, C.I. -16.86, -3.18), and 60 percent (p = .021, C.I. -16.86, -3.18) condition. The 30 percent condition was only significantly greater than the 60 percent condition (p = .026, C.I. -13.44, -.67).

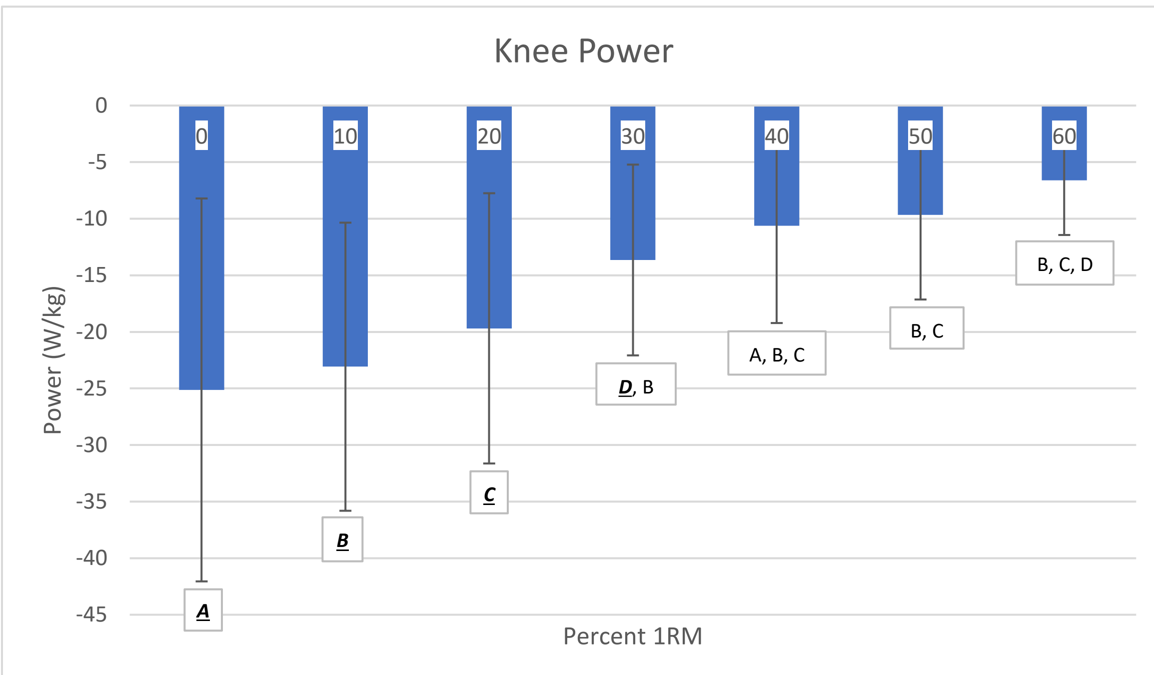

Figure 5. Knee power peak values and standard deviations. Powers were normalized to total system mass at each condition (W/kg).

Finally, the hip power followed a similar trend. The unloaded condition had the absolute greatest maximum value (-38.61 W/kg) than any other condition. However, the unloaded condition was not significantly greater than any other condition. The 10 percent condition, which had the second greatest absolute maximum value, was significantly greater than the 30 percent (p

= .005, C.I. -25.93, -4.52), 40 percent (p = .003, C.I. -34.55, -7.07), and 60 percent (p = .001, C.I. -41.55, -10.22) condition. The 20 percent condition was significantly greater than the 40 percent (p = .048, C.I. -22.23, -.09) and 60 percent condition (p = .029, C.I. -31.12, -1.36). The 30 percent condition was only significantly greater than 60 percent condition (p = .011, C.I. -19.15, -2.17).

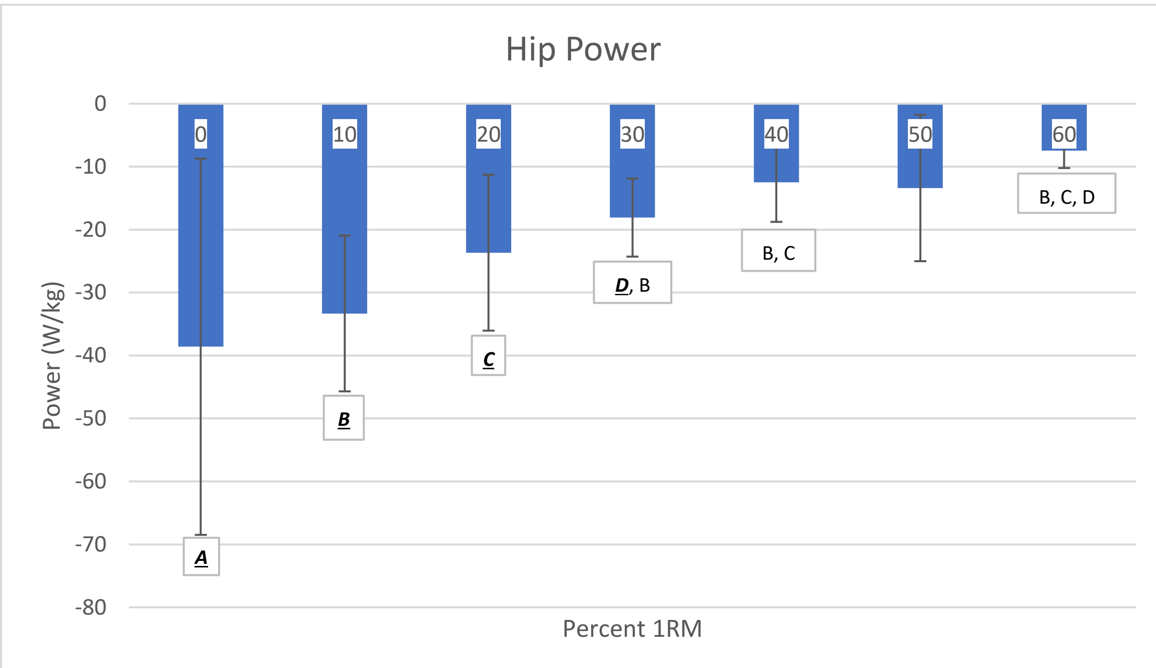

Figure 6. Hip power peak values and standard deviations. Powers were normalized to total system mass at each condition (W/kg).

Although significant differences were found among the joint moments and joint power peak values, no significant differences were found among either the peak joint angles or joint velocities.

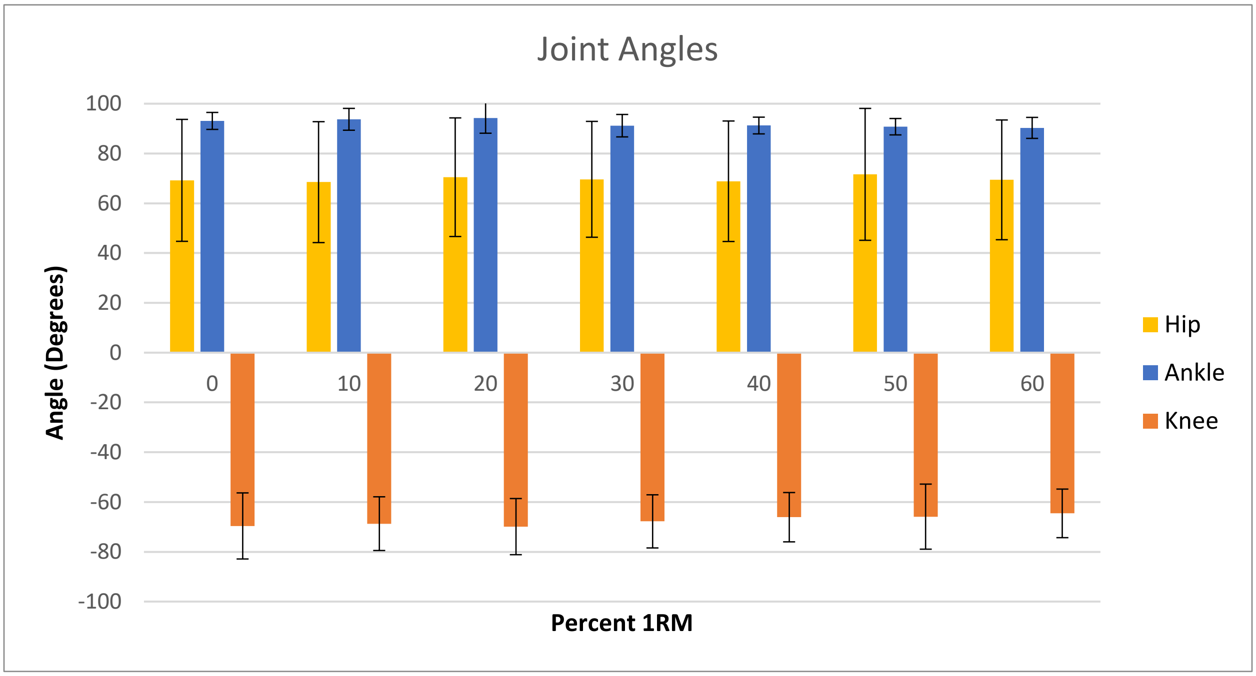

Figure 7. Joint angles peak values and standard deviations for all joints. Positive values for hip and ankle represent flexion. Negative values for knee represent flexion.

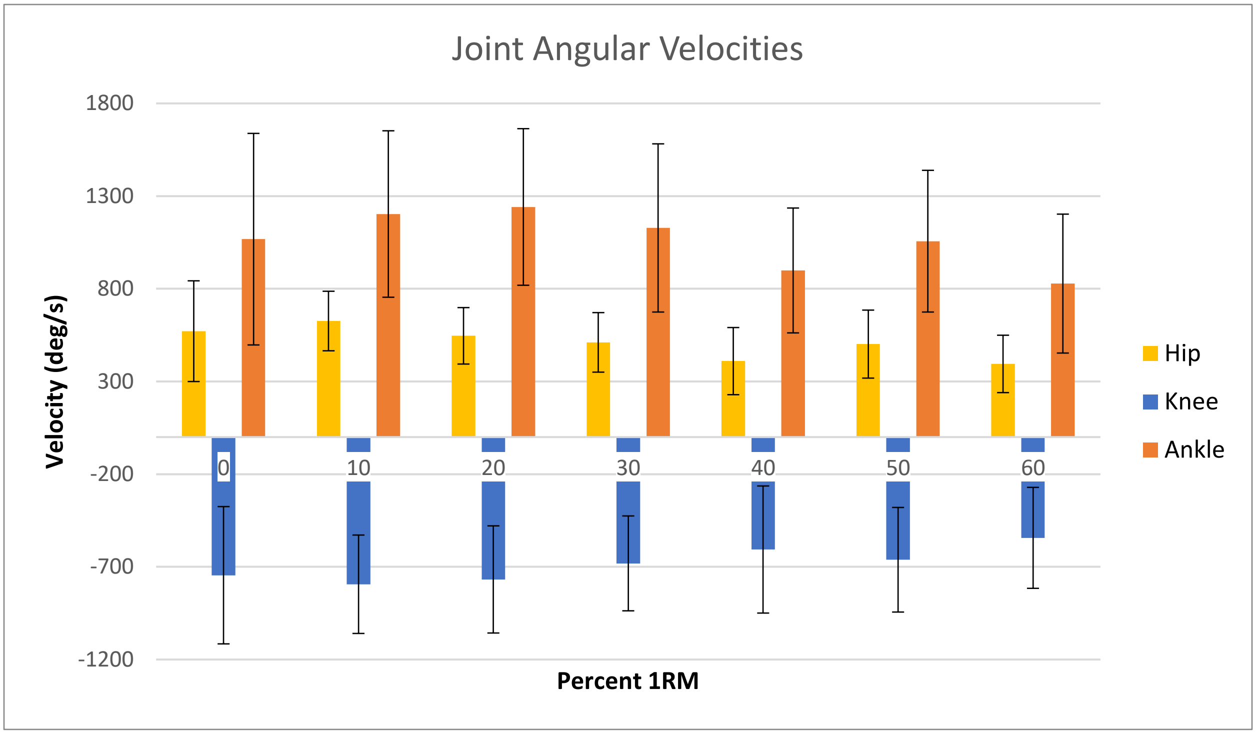

Figure 8. Joint angular velocity peak values and standard deviations for all joints. Positive values for hip and ankle represent flexion. Negative values for knee represent flexion.

CHAPTER V: DISCUSSION

The purpose of this study was to understand how increasing load changed the kinetics and kinematics of the lower extremity at landing. It was hypothesized that the lower extremity joints would increase in flexion as load increased. It was also hypothesized that joint velocities would decrease as load increased and that joint powers and moments would be lower during all loaded trials than the unloaded condition. While the hypothesis was correct in assuming that the unloaded trial would produce the greatest absolute maximum for peak powers and moments, it was incorrect that it would be significantly different than every condition. Furthermore, neither of the peak joint velocities or joint angles found any significant difference at any joint or condition. The joint powers were significantly higher at the lighter conditions and decreased as the load increased. Joint moments followed the same pattern as the joint powers, having their greatest peaks at the lightest loads and decreasing as the load increased.

The results regarding the joint powers and the joint moments within the study are tied closely together. These results are in line with Fritz et al (2019). Although their study found no differences within the moments or powers across their conditions, the values found for both peak moments and powers were very similar to the values of the present study. Similarly, the results regarding the moments followed similar patterns to that of Janssen et al (2012). In the Janssen et al (2012) study, the researchers depicted their moments based off of the heights of the participants. However, the trends in the joint moments were the same as the present study. Peak joint moments at the hip had the greatest values compared to the knee (second highest), and ankle (lowest). This seems logical because, as Fritz et al (2019) states, “the joint moments allow for the assessment of the maximum effort of the muscles spanning the joint in energy dissipation." Therefore, it would be reasonable that the hip has the highest moments followed by the knee and ankle. The proximal muscles of the lower extremity are larger and have a greater capacity for energy absorption and dissipation compared to the distal muscle groups like the ankle plantar flexors. These results regarding the decrease in joint moments as load increases are also in line with Zhang et al (2000) and McNitt-Gray (1991). Both studies showed evidence of height and velocity-based changes to joint moments. Within the present study, it is documented that as load increases then jump height and joint velocity decrease (although changes in joint velocity are not significantly so). Both Zhang et al (2000) and McNitt-Gray (1991) document that as jump height, joint velocity, or both decrease then so too do joint moments. Additionally, these decreases to joint velocity are supported by both of these referenced studies as an effect of decreasing jump height (although, again, the decreases to joint velocity as load increases is not significantly different).

In contrast to the current study, Yom et al (2020) did find significant differences among joint angles in participants who landed with no load compared with the same participants landing with 35 percent bodyweight load. However, those differences were likely attributed to the landings for each trial being from the same height. Their study had all participants land off a set height box within both the unloaded and loaded condition. This is dissimilar to the present study where the height of the landing decreased as the load increased and no change in joint angles were found. This load-based reduction in jump height may be a factor in the lack of joint angle change in the present study.

Limitations

Limitations of the present study include only investigating maximum absolute values of the studied variables of the landing portion of the jump. A number of previous landing studies have investigated changes to kinetic and kinematic variables at initial contact of landing as opposed to peak value. Both are important and this omission leaves room for future research. Similarly, the exclusion of ground reaction forces at landing also leave room for future research. How ground reaction forces change as load changes is a topic that is continually studied in the performance and injury prevention realm. Additionally, joint moments and powers were normalized to the total system mass (body mass + external load) for each condition. It is possible this technique altered the physiological magnitudes of joint moments and powers. Future studies should assess how the normalization techniques impact trends in joint moments and powers when external load in implemented. Finally, all data collected for the present study came from the right side of the participants. Due to an error in the force plate (found after data collection), all left side data had to be omitted for this study.

Conclusion

Previous literature regarding loaded landings had largely compared one standard load to an unloaded condition or different heights of landing. The present research shows significant changes (from 0 to 60% 1RM) occurring from unloaded conditions at 30% 1RM load for joint moments and powers and no changes occurring within the kinematic variables measured across any condition or joint. More research is needed to fully understand the effect of loaded landings. Connections can be drawn to both topics of injury prevention and sports performance. It would appear, based on previous literature, that the highest risk of injury within loaded landings actually comes at the unloaded condition, where joint moments are highest. That unloaded condition also seems to have the highest potential for helping to increase sports performance thanks to the greatest joint powers being recorded. However, for both of these topics, performance and injury, more research is needed to fully understand and draw concrete connections to loaded landings.

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