Short Communication

Simulating fatigue in squat jumps: A preliminary investigation

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Previous research has shown that fatigue is associated with decreases in performance and may result in joint instability that is associated with injury.

Objectives: The purpose of this study was to determine if lightly loaded jumps could simulate fatigue from a lower body kinematic perspective.

Design and Methods: Seventeen NCAA DI baseball players (height 1.8 m ± 0.7, body mass 87.5 kg ± 7.9) performed unloaded and lightly loaded (20 kg) squat jumps, while 3D motion capture data were collected via six infrared cameras and reflective markers. Kinematic data included range of motion (ROM), peak angular velocity (PV), position at PV (PPV), peak angular acceleration (PA), and position at PA (PPA) for both the hip and knee as well as jump height (JH). Comparisons between conditions were completed with paired samples t tests, along with Cohen's *d* effect sizes and 95% confidence intervals.

Results: Statistical differences were noted between condition's PV at both joints (hip ($p = 0.00$, $d = 0.63$); knee ($p = 0.000$, $d = 0.65$) and for PA of the hip ($p = 0.002$, $d = 0.55$). A decrement in JH was also noted ($p = 0.000$, $d = 1.13$).

Conclusions: The results of the current investigation indicate that a 20 kg load is enough to cause jump performance changes similar to those seen with previous research associated with fatigue. This may be particularly useful for coaches and sport scientists seeking to understand how athletes will perform while fatigued.

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Key words: stretch-shortening cycle ■ performance ■ loaded jumps

INTRODUCTION

Kinetic and kinematic changes in jumping performance have been observed with various loads and amounts of fatigue.[1-4] Research has shown that adding a load of 20 kg was enough to statistically alter the force, velocity, power and displacement in untrained individual's squat jump performance.[1] The previously mentioned sample had a mean body mass of 80.8 kg, therefore the 20 kg load represented an additional mass of 24.75%, causing decrements of 13.69% in peak power and 22.22% in jump height. Even in populations of physically trained male and female athletes, similar results have been shown when adding a 20 kg load.[2]

Concerning fatigue, research has shown that acute fatigue can result in altered jump performance as measured during 30 and 60 second continuous jump protocols. Fatigue may be accompanied by decreases in jump height, flight time, eccentric force production, power, vertical stiffness, and knee flexion angles.[4-6] Fatigue has also been associated with increases in ground contact time and with decreases in angular velocities and accelerations in jumps.[4, 6-7] Furthermore, fatigue has been associated with knee joint stability decreases, that may increase the risk of injury in both males and females.[8,9]

The above-mentioned research has shown that performance decreases in loaded conditions and in fatigued situations. Simulations of fatigue may be useful for coaches who wish to know how their athletes will respond in a fatigued state. Doing so with a relatively light load may specifically benefit them when they do not want to cause fatigue or add significantly to their current training load. While research has shown that the addition of a 20 kg load results in decrements of performance variables such as jump height and peak power, it is not known if the addition of a load is sufficient to elicit alterations in kinematic variables and simulate a fatigued situation in athletes. Therefore, the purpose of this investigation was to evaluate the effect of adding a relatively light load (20 kg) on squat jump performance from a lower body kinematic perspective and to determine if any alterations are consistent with fatigued situations previously reported.

METHODS

This study included 17 NCAA Division I baseball players (height 1.8 m ± 0.7, body mass 87.5 kg ± 7.9) between the ages of 18 and 23 who read and signed informed consent documents approved by the University's Institutional Review Board. Prior to activity, all athletes performed a standardized warm up, which consisted of 25 jumping jacks and four sets of mid-thigh pulls (1 × 5 @ 20 kg and 3 × 5 @ 60 kg). Reflective markers were then placed on the athletes according to the Vicon full body Plug-in Gait model for the upcoming motion capture data collection.

Athletes then completed unloaded (0 kg) followed by lightly loaded (20 kg) squat jumps (SJ). Jumps were performed without an arm swing as athletes held either a negligible load PVC

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pipe (1.01 kg) or a 20 kg weightlifting bar behind the neck in similar to a squat positioning. The SJ starting knee position was standardized at 90° of flexion, measured by a goniometer. Prior to maximal effort jumps, athletes completed warm-up and familiarization trials at 50 and 75% of perceived maximum for both conditions. For the maximum effort jumps, athletes descended to the starting position and waited for a "3, 2, 1, Jump" command to be given. Jumps were considered successful as long as no observable countermovement was noted. Unsuccessful trials were excluded and the variable averages of two trials were used for analysis. Rest periods between trials and conditions was approximately 60 seconds. The total time between unloaded and loaded maximal effort trials was approximately 3 minutes, when including the two familiarization trials.

Kinematic data collection was completed with an infrared motion capture system (Vicon Nexus, ver. 1.86, Centennial, CO) that included six cameras collecting data at 200 Hz. Each camera was positioned at approximately 7 m from the athlete in a circular pattern. Camera calibration was completed after camera setup and prior to athlete arrival with an error rate of less than 1%. Raw position data were smoothed via a Woltring filter using an optimized pre-programmed cut-off frequency in the motion capture software.[10] Variables of interest included range of motion (ROM), peak angular velocity (PV), peak angular acceleration (PA), and the positions which PV and PA occur (PPV, PPA). These variables were expressed for the hip and knee. Jump height (JH) was also evaluated and was calculated as the difference between the athlete's center of mass during static calibration and the athlete's maximum vertical center of mass position during the jump.

All statistical analyses were performed in R (R version 3.6.1, Vienna, Austria). Comparisons of unloaded and loaded SJ trials were completed with paired samples t tests. In an effort to reduce the risk of Type I error due to running multiple comparisons, a Holm-Bonferroni sequential adjustment was applied, and the initial statistical significance was set at $p \leq 0.05$. Meaningfulness of differences was evaluated with Cohen's *d* effect size estimates and were interpreted with the scale provided by Hopkins.[11]

RESULTS

Descriptive statistics, results of comparisons, and Cohen's *d* effect size estimates are shown in Table 1. Adding a 20 kg load produced statistically significant decreases in PV at both joints (hip 9.56%, knee 8.09%) and PA of the hip (13.02%). Decreases in JH were also noted between conditions (17.39%, 0 kg = 0.46 m ± 0.06 [0.40,0.52], 20 kg = 0.38 m ± 0.05 [0.33, 0.43], $p = 0.000$, $d = 1.13$).

DISCUSSION

The purpose of this study was to evaluate the effect of adding a 20 kg load on SJ performance from a lower body kinematic perspective and to determine if any alterations are consistent with fatigued situations previously reported. In relation to the 0 kg condition, the 20 kg loaded condition elicited statistical differences with moderate effect size estimates in peak velocities of the hip and knee (hip ($p = 0.00$, $d = 0.63$); knee ($p = 0.000$, $d = 0.65$) and peak acceleration of the hip ($p = 0.002$, $d = 0.55$). Changes in hip and knee kinematics associated with fatigue have previously been reported. Previous research has indicated decreases in maximal hip and

Table 1. Descriptive data for unloaded (0 kg) and loaded (20 kg) jump conditions (value ± standard deviation [95% confidence interval range]) along with *p* values and Cohen's *d* effect size estimates for the hip (A) and knee (B).

A. Hip

	0kg	20kg	*p*	*d*
ROM (°)	77.0 ± 10.7 [66.8,87.1]	78.9 ± 9.6 [69.8,88.1]	0.159	0.19
PV (rad/s)	9.6 ± 1.3 [8.4,10.9]	8.0 ± 1.2 [7.3,10.1]	0.000*	0.63
PPV (°)	148.5 ± 34.8 [115.4,181.5]	149.0 ± 34.5 [116.2,181.7]	0.357	0.02
PA (rad/s)	308.4 ± 77.5 [234.7,382.0]	268.1 ± 64.7 [206.7,329.6]	0.002*	0.55
PPA (°)	163.0 ± 41.5 [123.5,202.4]	162.5 ± 40.6 [124.0,201.1]	0.345	0.01

*denotes statistically significant differences

B. Knee

	0kg	20kg	*p*	*d*
ROM (°)	102.2 ± 10.6 [92.2,112.2]	104.9 ± 10.8 [94.7,115.1]	0.092	0.26
PV (rad/s)	17.2 ± 2.2 [15.1,19.2]	15.8 ± 1.9 [14.0,17.6]	0.000*	0.65
PPV (°)	164.2 ± 7.1 [157.4,170.9]	164.9 ± 5.9 [9.5,20.7]	0.304	0.11
PA (rad/s)	629.4 ± 177.7 [460.6,798.2]	573.6 ± 153.2 [428.1,719.1]	0.030	0.34
PPA (°)	185.0 ± 5.8 [179.5,190.6]	184.4 ± 5.9 [178.8,190.1]	0.108	0.11

*denotes statistically significant differences

ROM (°) = range of motion in degrees, PV (rad/s) = peak velocity in radians per second, PPV = position at peak velocity, PA = peak acceleration, PPA = position at peak velocity knee flexion occur when acutely fatigued.[4] This was not observed in the current investigation as total range of motion and did not produce any statistical differences between conditions. This may be due to protocol differences, continuous jumps versus simulating fatigue with a load. A measure of ROM may not be sensitive enough to show alterations in a single repetition, while angular velocities and accelerations may be. Changes in angular velocities of jumps and other stretch-shortening cycle movements have been observed previously in fatigued situations.[7,12]

It is interesting that while peak velocity of the knee was statistically different, peak acceleration was not ($p = 0.030$). Adjusting for type 1 error reduced the needed p value required to achieve statistical significance due to the usage of multiple comparisons. Even so, the practical significance was also lower ($d = 0.34$) compared to the hip measures. From a practical standpoint, this could lead to the suggestion that the load influenced the hips more so than the knees, but further research would be needed to validate this notion. Somewhat contradictory to the current investigation, previous research by Rodacki and colleagues evaluated joint specific changes after fatiguing the knee flexors and extensors but found differences in the peak velocities of both the hip and the knee.[7] Another interesting attribute of the previously mentioned study is temporal changes that may occur with fatigue. The current investigation did not evaluate temporal shifts of phases, but it did compare the positions at which instantaneous variables (PV and PA) occurred and found no statistical or practical differences. Future researchers may wish to include temporal phases in analyses as it is possible for variable magnitudes to remain similar, while the time which they occur differs.

While it is possible that the load in the current investigation was not sufficient to simulate fatigue, it seems unlikely as a statistical decrease in JH with moderate effect size ($p = 0.000$, $d = 1.13$) was observed. This is in agreement with previous research as decreases in JH and flight time have consistently been reported with fatigue.[4-6] It is interesting that Pupo and colleagues noted larger decreases in JH, after the 30s continuous jump test (26% versus 17.4% in the current study). This raises the question of if the load's relative intensity is associated with the fatigue magnitude to be simulated. Future researchers may wish to evaluate this research question.

While kinetic measurement was not utilized in the current investigation, one might assume that power also decreased in the current investigation. Decrements in joint velocity were observed, which would result in decrements in power unless the force produced increases. The previously established association between JH and power and the shown decrease in JH of the current study also point a decrease in power.[13]

CONCLUSION

The results of the current preliminary investigation indicate that a relatively light load (20 kg) is enough to cause jump performance changes similar to those seen with fatigue. Coaches and sport scientists endeavoring to understand how their athletes will perform while fatigued, without having to cause fatigue may find this information particularly useful. Adding a light load, such as a 20 kg weightlifting bar to current jump testing may be a feasible and practical option to simulate situations of fatigue. Future researchers may wish to evaluate the association with the intensity of the load and level of fatigue as well as other jump types.

CONFLICT OF INTEREST

The authors declare no conflicts of interest.

REFERENCES

1) Cormie P, McBride J, McCaulley G. Power-time, force-time, and velocity-time curve analysis during the squat jump: Impact of load. *J Appl Biomech* 2008;24:112-120.
2) Kraska JM, Ramsey MW, Haff GG et al. Relationship between strength characteristics and unweighted and weighted vertical jump height. *Int J Sports Physiol Perform* 2009;4:461-473.
3) Peng HT. Changes in biomechanical properties during drop jumps of incremental height. *J Strength Cond Res* 2011;25:2510-2518.
4) Pupo JD, Dias JA, Gheller RG et al. Stiffness, intralimb coordination, and joint modulation during a continuous vertical jump test. *Sports Biomech* 2013;12:259-271.
5) McNeal J, Sands W, Stone M. Effects of fatigue on kinetic and kinematic variables during a 60-second repeated jumps test. *Int J Sports Physiol Perform* 2010;5:218-229.
6) Trinkuñas E, Buliuolis A, Sadzevicîené R et al. Dynamics of muscular performance indices during the 30-s vertical jump test in endurance and sprint cohorts. *Sportas* 2011;4:77-82.
7) Rodacki A, Fowler N, Bennett S. Vertical jump coordination: fatigue effects. *Med Sci Sports Exerc* 2002;34:105-116.
8) Ortiz A, Olson S, Etnyre B et al. Fatigue effects of knee joint stability during two jump tasks in women. *J Strength Cond Res* 2010;24:1019-1027.
9) Rozzi S, Lephart S, Fu F. Effects of Muscular Fatigue on Knee Joint Laxity and Neuromuscular Characteristics of Male and Female Athletes. *J Athl Train* 1999;34:106-114.
10) Woltring H. On optimal smoothing and derivative estimation from noisy displacement data in biomechanics. *Hum Mov Sci* 1985;4:229-245.
11) Hopkins WG. A new view of statistics. Available at http://www.sportsci.org/resource/stats/effectmag.html 2013; Retrieved 09/24/2019.
12) Golhoffer A, Komi P, Miyashita M et al. Fatigue during stretch-shortening cycle exercises: Changes in mechanical performance of human skeletal muscle. *Int J Sports Med* 1987;8:71-78.
13) Sayers S, Harackiewicz D, Harman E et al. Cross-validation of three jump power equations. *Med Sci Sport Exer* 1999;31:572-577.