# LONGITUDINAL VERTICAL JUMP ASSESSMENT FOLLOWING NONCONTACT ANTERIOR CRUCIATE LIGAMENT INJURY IN A COLLEGIATE SOCCER PLAYER

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**INTRODUCTION:** Recent research has identified altered neuromuscular control of the hip and knee as a potential predictor of re-injury following anterior cruciate ligament (ACL) repair (Paterno et al., 2010). Altered movement strategies may be due, in part, to a decreased ability of the involved limb to produce and accept force compared to the uninvolved limb (Ernst, Saliba, Diduch, Hurwitz, & Ball, 2000; Paterno, Ford, Myer, Heyl, & Hewett, 2007). Therefore, while common assessments such as hop tests and isokinetic tests are useful in assessing an athlete during the return-to-play process, vertical jump force-time characteristic analysis may provide a more complete understanding of the mechanisms underlying the athlete's performance. The purpose of this study was to report the training outcomes of an 18-year-old male collegiate soccer player whose vertical jump force-time characteristics were monitored as part of his return-to-play following ACL reconstruction.

**METHODS:** The subject was an 18-year-old male collegiate soccer player who had undergone ACL reconstruction approximately four months prior to the period of interest. In the interim, the athlete had participated in rehabilitation with an outpatient physical therapy clinic and the university's athletic medicine staff. Data were collected as part of an ongoing athlete monitoring program. This retrospective analysis was approved by the East Tennessee State University Institutional Review Board with the athlete providing consent for the analysis of his data.

Training Protocol. The athlete performed an individualized strength training protocol 3 days per week for 11 weeks in conjunction with a 3-day-per-week plyometric training protocol (Table 1). Each training session was approximately 30 minutes to one hour in length and was the only training the athlete performed.

The strength training program was separated into three phases: familiarization, "introductory strength," and "hypertrophy." The familiarization phase emphasized re-acquisition of proper lifting mechanics that would be the basis for the remainder of the program. Lower-body lift intensity remained low during this period, and no plyometric training was carried out. The four-week introductory strength phase was similar to the familiarization phase; however, the intensity and total volume of lower body exercises increased. Furthermore, low volumes of no- or low-impact bilateral hopping drills were included with an emphasis on proper mechanics. The final three-week hypertrophy phase was dedicated to development of muscle mass via higher volumes of strength training. Additionally, low volumes of single-leg hopping exercises and more aggressive bilateral plyometric exercises were undertaken.

Testing. At three points during the training program (prior to the familiarization phase, following the familiarization phase, and following the hypertrophy phase), the athlete completed a series of weighted countermovement jumps (CMJ) on two force plates (PS-2141, PASCO Scientific Inc., Roseville, CA, USA) sampling at 1000 Hz. The athlete completed two jumps at 0kg (PVC pipe) and two jumps at 11kg prior to completing two measured trials with a 20kg bar held across the shoulders. Weighted vertical jumps have previously been suggested to mimic alterations in technique brought on by fatigue (Bailey et al., 2014). Therefore, weighted vertical jump testing allowed for examination of the athlete's ability to produce and accept force in a "fatigued" state without exposing him to undue risk. Four force-related variables (net impulse

[NI], peak force [PF], average rate of force development [RFD], and peak landing force [PLF]) were calculated with a custom R script, both as combined values and for the individual limbs, in addition to jump height calculated from flight time (JH). Average values for the two trials were retained for analysis.

Statistical analysis: Practical descriptions of changes in NI, PF, RFD, and JH were inferred via a spreadsheet (Hopkins, 2004), and symmetry index (SI) scores were calculated for each force-related variable as a measure of asymmetry between limbs.

Table 1. Training Progression

| | Strength Training Volume | Intensity Range (%) | VRI (AU) | Lower Body VRI (AU) | Plyometric Volume |
|---|---|---|---|---|---|
| Familiarization | | | | | |
| Week 1 | 3x5 | 65 – 75 | 95 | 52 | — |
| Week 2 | 3x5 | 70 – 80 | 103 | 56 | — |
| Intro. Strength | | | | | |
| Week 3 | 5x5 | 65 – 80 | 183 | 121 | 32 |
| Week 4 | 3x5 | 70 – 85 | 119 | 78 | 40 |
| Week 5 | 3x5 | 73 – 88 | 123 | 81 | 48 |
| Week 6 | 3x3 | 70 – 85 | 78 | 51 | 36 |
| Hypertrophy | | | | | |
| Week 7 | 3x10 | 65 – 80 | 180 | 119 | 24 |
| Week 8 | 3x10 | 70 – 85 | 198 | 131 | 36 |
| Week 9 | 3x10 | 73 – 88 | 207 | 137 | 48 |

**VRI**, volume repetition intensity (total repetitions * relative intensity); **AU**, arbitrary units
Strength training intensity is the percentage relative to set-rep maximum
Plyometric volume is the total number of repetitions performed per week

**RESULTS:** The athlete's NI, PF, and RFD saw likely to almost certain increases from the first to final testing session, whereas changes in JH were almost certainly trivial (Table 2). Peak landing force increased during the training period, but no reliability measures were available to infer practical descriptions of the changes. All variables maintained similar SI values between the first and last testing sessions, save RFD which increased.

**DISCUSSION:** The purpose of this study was to report the training outcomes of an 18-year-old male collegiate soccer player whose vertical jump force-time characteristics were monitored as part of his return-to-play following ACL reconstruction. The findings demonstrate that while an individualized strength and plyometric training program enhanced CMJ performance, 11 weeks of training were unable to reduce force production asymmetries in a meaningful way.

While improvements in the athlete's force-time characteristics were expected, the lack of changes in asymmetry are not surprising. Previous research has suggested that a high number of repetitions may be required to retrain complex motor patterns (Elias, Kinney, & Mizner, 2015). Therefore, the low volume of plyometric exercises and short intervention period may have contributed to the lack of changes in SI scores for PF and NI.

Of note was the increase in RFD asymmetry. The increase in SI scores may have been due to fatigue of the involved limb, as RFD is extremely sensitive to increases in training volume (Gathercole, Sporer, & Stellingwerff, 2015). As the athlete had been relatively inactive (in comparison to the training protocol) prior to initiation of training, the involved limb may have been more sensitive to the increased volume of training. This is especially relevant for the final testing session, which was carried out at the conclusion of the high-volume hypertrophy phase.

Future research is needed to investigate the relationship between the variables presented here and established methods of testing, such as hop tests and isokinetic tests.

Table 2. Changes in Measured Variables

| Testing variable | Testing session 1 | Testing session 2 | Testing session 3 |
|---|---|---|---|
| Mean values | | | |
| NI (N·s) | 170.1 | 176.5 | 183.7 |
| PF (N) | 1491.4 | 1614.2 | 1794.9 |
| RFD ($N \cdot s^{-1}$) | 942.7 | 1048.2 | 1871.2 |
| JH (cm) | 22.5 | 23.2 | 26.9 |
| PLF (N) | 1988.4 | 2108.1 | 2216.4 |
| Change from 1st session | | | |
| NI (N·s) | | 6.4 | 13.6 |
| | | (24/12/64) | (10/7/83) |
| PF (N) | | 122.8 | 303.5 |
| | | (5/0/95) | (0/0/100) |
| RFD ($N \cdot s^{-1}$) | | 105.5 | 928.5 |
| | | (46/0/54) | (18/0/82) |
| JH (cm) | | 0.7 | 4.4 |
| | | (0/100/0) | (0/100/0) |
| PLF (N) | | 119.7 | 228.0 |

| | | | |
|---|---|---|---|
| Symmetry index scores | | | |
| NI (%) | 32.2 | 33.4 | 34.3 |
| PF (%) | 13.2 | 15.4 | 17.8 |
| RFD (%) | 14.9 | 15.1 | 34.1 |
| PLF (%) | 0.8 | 1.0 | 2.6 |

**NI**, net impulse; **PF**, peak force; **RFD**, average rate of force development; **JH**, jump height calculated from flight time; **PLF**, peak landing force

Change scores are presented as the absolute change from the 1st testing session in addition to odds of a negative, trivial, or positive change, respectively

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