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EFFICACY OF DEPTH JUMP PARAMETERS AS A RECOVERY MONITORING TOOL FOLLOWING EXERCISE INDUCED MUSCLE DAMAGE

by

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A plan B research project submitted in partial fulfillment
of the requirements for the degree

of

MASTERS OF SCIENCE

in

Kinesiology

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Abstract

Background: Fatigue monitoring is an important aspect for athletic coaches to monitor the level of readiness of an athlete. Monitoring of an athlete's fatigue status helps identify the need to adjust one's training program, identify injury risk, and help attain an athlete's peak performance when it is most advantageous for them. More research is warranted that examines the effects of a comprehensive set of jump parameters to track recovery from muscle impairing exercise. This study focused on the onset of muscle soreness through eccentric resistance exercise. **Purpose:** The purpose of this project was to examine the efficacy of force plate GRF-derived data from depth jump (DJ), and peak force (PF) by maximum voluntary isometric contraction tests as a means to track neuromuscular recovery following a bout of eccentric exercise. A secondary aim was to evaluate soreness markers during the recovery phase. **Methods:** Thirty college aged, recreationally active students participated in this study. This study was a repeated measures design where each subject participated in 5 visits including a familiarization visit, an experimental visit (when the eccentric exercise was performed), and three follow up visits. The second visit included subjects performing the eccentric exercise intervention where they performed a 3 minute workout at 50% intensity. Testing including maximal voluntary isometric contractions MVICs and was done at pre- and post-exercise as well as 24, 48, and 96 h following the exercise session. Testing involved MVICs on the dynamometer (to determine peak force; PF), followed by DJ tests. Also, each subject was asked to complete a visual analog scale (VAS) to determine soreness upon arrival of each visit. All post intervention visits were identical in format except they did not do the exercise intervention. **Results:** There were no changes in DJ GRF variables nor PF, but there was a significant difference in soreness across the visits, suggesting that the eccentric exercise intervention on the Eccentron succeeded in inducing muscle damage. **Conclusion:** Data from this study suggest that despite participants experiencing significant soreness in the period that followed the eccentric protocol, there were no changes in ground reaction force parameters from a DJ performance nor in PF variables. Greater impairments to force generating capacities than what were found herein are required from an eccentric exercise intervention to determine whether DJ measures can adequately monitor fatigue characteristics.

Keywords: Delayed onset muscle soreness, muscle strength, peak force, visual analog scale, rate of force development

Introduction

The physical demands on athletes associated with competitive sports settings, particularly at the higher levels, are substantial. Performance reductions resulting from intense and/or high-volume workload bouts of activity, training, and/or competitions are common in athletic settings. Due to these repetitive and often ongoing physically demanding bouts, acute fatigue, and subsequent muscle damage-based performance declines are commonly occurring features in athletes across their training and competitive seasons. Fatigue has been defined as a temporary loss in force or torque-generating ability due to recent muscle contraction (Keeton et al. 2006). Hence monitoring ground reaction forces (GRF), for example, as a testing approach may show potential to give insight of how fatigued an athlete might be over follow up visits.

Throughout the calendar year for an athlete, different phases of training and maintenance will alter the magnitude of fatigue experienced by an athlete. An annual cycle for most athletes typically consists of an off-season, pre-season, in-season, and post-season period. Each athlete may experience different profiles and classifications of fatigue at different times within or across seasons. These classifications are described as acute fatigue, functional overreaching, nonfunctional overreaching, and overtraining syndrome (Haff et al. 2016). It is the responsibility of coaches to help athletes manage their fatigue and associated performance declines to help them adapt accordingly to maximize performance at critical times. It is commonly accepted that planned changes in training load and volume throughout the year are necessary for muscular adaptation, decreased risk of injury, and avoidance of overtraining (Watkins et al. 2017). For these reasons, it is essential to identify fatigue levels of an athlete at any point of the season via regularly monitoring an athlete's performance status. In order to effectively do this, the method would require the fatigue-centered performance assessment to be comprehensive, cost-effective, timely, convenient, and not invasive to the athlete. These factors become amplified and are more important from a logistical standpoint, as the number of athletes that are on a team increases. Common ways to monitor fatigue are self-report measures such as questionnaires, biochemical markers measured through blood or saliva, surface electromyography (EMG), sprint, and jump tests. (Alba-Jimenez et al. 2022)

Self-reported measures such as questionnaires and subjective assessments are an indirect measure of an athlete's fatigue. These measures give a self-appraised insight into the athlete's mental state and perceived ability to perform. While an athlete's perception of circumstance and their rating of perceived exertion (RPE) may be important to take note of, it can be heavily influenced by other factors such as the stress of daily life from personal or professional-related issues. It is important to note that mental fatigue drives athletes to downregulate their exercise capacity, which is known to be the maximum amount of physical exertion that an athlete can sustain (Walker et al. 1990). Other key factors to consider when using self-reported measures is questionnaire fatigue and soreness. There are many different questionnaires that are available for coaches to use but the time to have each athlete frequently fill them out and to review their answers can be burdensome, unrealistic, and too subjective in nature.

There are other techniques to monitor fatigue including biochemical markers and EMG. Biochemical markers can reveal fatigue and/or muscle damage during the recovery period following bouts of exercise (Twist et al. 2013). The most common biochemical markers that are monitored are testosterone, cortisol, and creatine kinase levels (Edwards et al., 2018). EMG monitors fatigue by measuring the collective electrical signal from the muscles controlled by the nervous system that is produced during muscle contraction (Chowdury et al. 2013). EMG can be monitored using intramuscular probes or surface probes placed on the skin. While this gives direct feedback of neuromuscular performance, reliability and lack of standards for configuration and electrode placement make this method potentially unreliable (Hogrel et al. 2005). A major limiting factor of biochemical markers and EMG is the requirement of equipment not commonly found in strength and conditioning facilities, and the time it takes to conduct the tests and analyze the data.

Because sports performance is largely centered on force or power measures, it would stand to reason that force or power measures would be well suited as measurement tools for assessing performance declines and the restoration of performance following an observed decline. Therefore, jump tests are an ideal way to monitor fatigue and performance outcome measures. Countermovement jump (CMJ) tests are common for coaches to administer because the outcome is strongly correlated with lower body power, strength, and speed performance (Barker et al. 2017). The jump tests in general are also a convenient, readily available, and simple test to administer and so it is a suitable tool to use on a repeated basis. Coaches often use CMJ as a performance indicator that their training is working, however, the data that can be taken from the most common CMJ measuring devices, such as the Vertec or jump mat, are limited to the outcome measures of jump height alone. Jump data can be maximized such that it can provide more comprehensive feedback data when using force plate-derived data due to the availability of ground reaction force (GRF) data. (Barker et al. 2017). Using these GRF-based variables, jump-specific force plate data could give insight into more specific and comprehensive force-, velocity-, or power-based fatigue profiles, patterns, and levels of force loading profiles to determine how effectively the athlete is generating force across a multitude of parameters. Notably, while the CMJ has been used the most in the prior literature to monitor fatigue in a jump context, the DJ may offer some advantages to be used to give greater insight into recovery that can directly translate to sport. The reason for this is the greater neuromuscular loading that occurs from the DJ versus the CMJ. It is possible that the increased loading characteristics of the DJ may better elucidate underlying fatigue and impairment issues, that perhaps may not be revealed by the lower intensity CMJ.

When performing a DJ the stretch-shortening cycle (SSC) is amplified and put under a greater amount of stress. The combination of eccentric and concentric actions forms a naturally occurring SSC, which is more neurally taxing that due to is complexity of pre-activation before landing impact and variable activation of the muscles preceding the functional phase of the movement (Komi et al. 2000). Indeed, the DJ is commonly used to assess and train an athlete's stretch-shortening cycle (SSC) capacities. The DJ is performed by standing on a box, dropping from the box, and then performing an explosive rebound jump upon contacting the ground. The goal of this jump method is to minimize the contact time, maximize the jump height, and then finish by landing in a controlled manner on the ground (Machmon et al. 2021). A key difference between the CMJ and DJ is the high load braking component of the DJ that takes place after stepping off the box to make forceful ground contact just before takeoff. This part of the DJ mimics demands of sport such as jumping, forcefully landing then reacting, and change of direction which is common in the field of play across a variety of sport activities. Not only are these kinds of movements demanding but it is a common scenario for injury to occur. By identifying GRF patterns associated with reduced neuromuscular performance, coaches would be better able to monitor neuromuscular-based changes across time points, which would lead to providing better recovery and training insight and protocol implementation to minimize the effect of fatigue and fully restore performance. For example, it would be plausible that in some instances, jump height may return to baseline while other, potentially more sensitive variables may still be affected by fatigue. Being able to identify the effects of fatigue or muscle damage from a comprehensive set of GRF data derived from the DJ could better provide the ability to track fatigue and to give specific feedback regarding how the athlete may still be lacking in their performance ability relative to their baseline or “normal” performance level and to effectively monitor recovery from acute fatigue/muscle damage.

In past studies, groups have induced fatigue through various modalities including standard weight training such as back squat and deadlift, plyometric training, weighted box jumps and downhill running. For the purpose of this study, we chose to induce muscle soreness by an eccentric-based resistance protocol on a multi-joint eccentric using an Eccentron dynamometer machine. We chose this modality due to the safety it provides movements patterns, and the relatively short duration of time it takes to cause muscle impairment in participants. In past studies as well, many groups have attempted to monitor recovery using CMJ data. (Engles et., al 2017) Contrary to this study which induced fatigue eccentrically to monitor fatigue with CMJ tests, we chose to use a DJ because of its applicability to sport in jumping, landing and change of direction as seen in sport (Sabnis et. al 2011), and the increased activation of SSC. DJ does not only simulate sport performance but also improves the mechanical output of the knee extensors and plantar flexors and has a higher neuromuscular specificity than CMJ tests (Sabnis et. al 2011).

Therefore, the primary objective of this research project was to examine the efficacy of force plate GRF-derived data from DJ tests as a means to track performance-reduced recovery following a bout of eccentric exercise. The study examined performance declines across multiple jump variables (reactive strength index, RSI; rate of force development, RFD; jump height, JH) as well as soreness (via visual analog scale; VAS). Providing more clear insight regarding the jump variables that may be more or less affected by eccentric-based acute fatigue and muscle damage and the temporal characteristics relating to how jump-based outcomes recover from acute fatigue with be the central focus of this study.

Methods

Participants

Thirty recreationally active adults were recruited from the Utah State University campus by flyers and word of mouth (see Table 1 for demographics). Based on a priori power analysis using G-Power software, an effect size was calculated using Cohen's *d* and it was found that to detect a large effect size of 0.8 at a statistical power level of β=.95, that a minimum of 25 participants would be needed to complete the study. These effect size values are estimated from a research study that employed a repeated measures design with jump tests as the outcome measure (Engels, 2017).

Upon inclusion in the study three participants were found ineligible to participate due to their maximal eccentric force surpassing the capabilities of the Eccentron, two participants dropped out due to failure to return for follow up visits and one participant had their data excluded from the analysis due to corrupted data. Thus, the final study sample was n = 25.

Eligibility criteria to be included in the study required participants to be between the ages of 18-30 years. The study also required participants to be currently performing strength training of their lower body regularly at least once a week, but no more than two times per week. Participants were excluded from the study if they had any lower body injury, were pregnant or planned on becoming pregnant within two weeks of the study, had surgery within the past year, had any neuromuscular disease (e.g., muscular dystrophy), or weighed over 220 pounds (Haff et., al 2016). During the course of the study, all participants were instructed to refrain from performing any strength training of the lower body within 3 days of starting the study, and throughout the duration of the study. Participants were also required to refrain from taking any non-steroidal anti-inflammatory (NSAIDs) drugs within two weeks and through the duration of the study. All participants read and signed an informed consent form that was approved by the Institutional Review Board, prior to study participation.

Experimental Design

This study used a single cohort, repeated measures research design. Each participant reported to the lab on five occasions. The first visit was used to complete paperwork including an informed consent form and a health history questionnaire. This visit was also used to familiarize the participants with the warm up, eccentric resistance exercise intervention, maximal voluntary isometric contraction (MVIC) and DJ testing. Visit 2 was baseline testing, the experimental eccentric exercise and posttest (Post) session. The Pretest was performed immediately before the eccentric exercise bout and immediately after (Post). Visits 3, 4, and 5 took place at 24-, 48-, and 96-hours post-exercise intervention (Post24, Post48, and Post96, respectively) at the same time of day ± 2 hours. The testing involved VAS soreness, DJ, and MVIC. All jump testing was conducted on a force plate (model FP4080, Bartec Corporation, Columbus, OH, USA). The outcome measures included jump height (JH), reactive strength index (RSI), rate of force development normalized (RFDNorm), average positive power normalized (APPNorm), and ground contact time (GCT), derived from the DJ trials. The MVICs on the Eccentron provided isometric peak force (PF). The follow-up visit times were established from examples in literature that explored pain and fatigue after concentric and eccentric muscle contractions. These previous studies found delayed onset muscle soreness (DOMS) was found approximately 8 hours after exercise and reached its maximal intensity between 24 and 48 hours and soreness and tenderness had subsided 96 hours after exercise (Newham et al 1982).

Procedures

Day 1: Familiarization

Each participant read and signed an informed consent form and a health history questionnaire as they arrived at the laboratory. After the paperwork was complete, their height and weight were taken. Prior to all sessions participants participated in a 5-minute warm-up cycling on an ergometer at 50 watts while maintaining a pace of 50-60 rpm (Spencer et al., 2023), followed by ten body weight squats to parallel. After the warm up, participants participated in a familiarization session which introduced them to the Eccentron. Participants were instructed to sit on the Eccentron with one pedal extended completely. The seat was then adjusted to where their knee joint angle was between 35 and 45 degrees of flexion. When this position was found, the seat position was noted and used in all subsequent visits. Participants were then introduced to the Eccentron dosing instructions which included the resistance of motorized pedals for a total of 12 repetitions, 6 repetitions per leg each dosing trail. As their muscle contractions became consistent, the intensity which they were asked to work was increased based on Rate of perceived exertion (RPE), from 5 to 6 out of 10 then 7 to 8 out of 10 and then to a max effort 10 out of 10 effort. The maximal effort trial consisted of the maximal eccentric strength test where participants were instructed to resist the alternating eccentric load of the machine “as hard as possible” (Crane et al., 2022). This effort indicated their maximal eccentric force and was then used for the working intensity for the experimental session. Participants then performed 3 practice trials of MVIC on the Eccentron. This was done by placing blocks under the foot pedals of the Eccentron making the foot pedals equal distance from the seat. Participants then performed 3 MVICs for which they were instructed to hold the isometric contraction for approximately 3 seconds. Following the Eccentron familiarization and MVICs, participants were then introduced to the DJ test. To perform the DJ, participants were instructed to stand on top of a 38.1cm box and to walk directly off the front of the box and then to quickly and forcefully jump as high as they could with as little ground contact time as possible. Participants performed the DJ with feedback from the investigator, until the jumps were completed properly.

Day 2: Experimental session

Upon arrival to the laboratory each participant completed a visual analog scale (VAS) of soreness. Participants then completed the warm up as explained in the familiarization visit. The baseline (Pre) data collection protocols follow that as was described above in the familiarization protocol. Briefly, 3 MVICs were performed on the Eccentron with one minute of rest between trials. This was followed by 3 DJs, with one minute of rest between trials. Following the baseline tests, participants performed the Eccentron training protocol which has been established by past research projects at Utah State University. This protocol incorporated a 1 minute warm up at 25%, a 3 minute exercise phase at 50%, and a 1 minute cool-down at 25% of the baseline maximal eccentric strength value that was recorded in the familiarization visit the Eccentron was set at 23 rpm (Weeks et al. 2022) After completing the Eccentron exercise protocol they completed a VAS scale to provide perceived soreness levels, and then performed 3 MVIC followed by3 DJ tests.

Days 3, 4, and 5:

Post-exercise assessments were performed at 24, 48 and 96 hours ± 2 hours of the initial visit. For each of these sessions, subjects again filled out a VAS of soreness. For these testing sessions, participants performed the same warm up as the first two sessions and the testing followed the same protocol as on day 2.

Data Reduction

The processing and analysis of force platform data was performed in MATLAB. GRF data was passed through a low-pass, 4th order, zero phase Butterworth filter (100 Hz cut-off frequency). JH, RSI, RFDNorm, APPNorm, GCT, and PF were calculated from the GRF data in order to examine jump-related performance declines across the testing periods. The Eccentron PF data was collected via Biopac data acquisition system (Biopac, MP150), and processed offline. The signal was passed through a low-pass (50 Hz cut-off frequency), 4^{th} order, zero phase Butterworth filter. The highest 100 ms epoch across the force-time curve was calculated as the PF value.

Repeated measures ANOVAs were performed to evaluate the effects of the exercise protocol on all variables across all time points. When significant interactions were found, Bonferroni-corrected pairwise comparisons were performed. Statistics were performed using SPSS. An alpha value of $P \leq 0.05$ was used to determine statistical significance.

Results

The means (SD) for all outcome measures are presented in Table 2. The results from this intervention showed that there was no main effects for JH ($p = 0.603$), RSI ($p = 0.848$), RFD Norm ($p = 0.549$), APPNorm ($p = 0.898$), GCT (p = (0.919), and isometric PF ($p = 0.170$)

variables. There was, however, a significant main effect for VAS Soreness ($p < 0.001$) such that post24 and post48 were higher ($p < 0.001$) than Pre and post24 and post48 were also both higher than post96 ($p < 0.001$).

Table 1: Demographic data of the participants. Mean(SD)

Variable	Male (n=14)	Female (n = 10)
Age (yrs)	21.5(2.5)	21.8(1.6)
Height (cm)	1.787 (.053)	1.640 (.059)
Weight (kg)	81.83 (8.15)	61.37 (8.81)
BMI (kg/m^2)	25.63 (2.41)	22.84 (3.22)

Table 2. Mean (SD) for all variables of depth jumps and visits. (n=24)

Variable	Pre Test	Post Test	24 Hours Post	48 Hours Post	96 Hours Post
JH	.346(.987)	.348(.099)	.327(.064)	.330(.072)	.333(.826)
RSI	.911(.413)	.909(.381)	.859(.305)	.897(.353)	.897(.364)
RFDNorm	517.611(299.831)	592.270(340.905)	545.986(187.779)	498.150(231.324)	502.116(255.523)
APPNorm	15.240(6.407)	15.325(6.255)	14.545(4.696)	14.799(5.564)	14.833(5.321)
GCT	.426(.130)	.426(.131)	.424(.125)	.416(.146)	.417(.115)
ECCIPF	2265.158(574.615)	2349.821(635.113)	2368.173(654.946)	2406.666(587.816)	2371.769(574.930)
VAS	.613(.562)	N/A	4.167(1.687)*	3.667(2.061)*	1.329(1.397)

Note: JH = Jump Height; RSI = Reactive Strength Index; RFDNorm = Rate of Force Development Normalized; APPNorm = Average Positive Power Normalized; GCT = Ground Contact Time; ECCIPF = Eccentric Isometric Peak Force. *The mean difference is significant at the .05 level.

Discussion

The primary objective of this research project was to examine the efficacy of force plate GRF-derived data from depth jump tests as a means to track performance-reduced recovery following a bout of eccentric exercise. We hypothesized that there would be changes in muscle soreness and in force plate DJ data. However, upon analysis of the data that was collected there were significant changes in muscle soreness during the 24 hours follow up visit and the 48 hours follow up visit, but no significant changes found in depth jump performance GRF variables.

The jump height variable during this study did not significantly change from pre- post-, or in the 24, 48, or 96 hours follow up visits. In past research where monitoring of fatigue was the primary purpose, they found that JH decreased after the workout and remained 8% less than baseline 48 hours later (Watkins et., al 2017). It is interesting to see that fatigue levels were noted in this study. In the Watkins et al. paper there were a very wide range of movements that were included in their training protocol including hang cleans, push press, RDL, leg press and back squat. The RDL, leg press, and back squat were performed to failure for 4 sets each at 85% 1RM. Their design was concentric in nature and aimed to induce full body fatigue. This may give a better idea as to why their participants had a decline in performance. The intervention targeted several muscle groups, and the intensity and volume were significantly higher than what the participants in this study performed.

While the project that was conducted did not yield any results that were statistically significant in regards to RSI, there have been several instances where RSI has been shown to be affective in monitoring fatigue. In a study that included male and female athletes after 6 days of intensified full body strength training where RSI was a major variable in their intervention, it showed that RSI statistically decreased in from the baseline test to the 24 hours, and 72 hours posttest periods. The interesting part about their finding is that other variables in their study including CMJ height, and DOMs returned back to baseline at 24 hours. Their findings suggest that RSI gives further insight to what performance decrements are still present while other tests may suggest recovery has taken place (Raeder et., al 2016). A major difference as to why their study may have showed effects of jump height could be that their intervention was much longer in duration and the volume of training was significantly higher than the protocol that we had in place. The GCT and APPNorm variables also seem to be variables that may not hold much significance in other fatigue monitoring studies. After further research, it has been shown that there were small reductions in GCT 24 hours after the intervention. APPNorm seems to show a little more feedback in comparison to CGT but only small decreases were displayed at 72 hours (Gathercole et., al 2015).

RFD has also been examined in regard to its capacity to monitor fatigue in recovery from a muscle impairing intervention. In a study done on professional rugby players before and after a rugby match, RFD values were lowered at 30 minutes and 24 hours post match. RFD values returned to 24 hours pre match values 48 hours post-match, however 72 and 96 hours post-match RFD values were significantly higher than both pre match values (McLellan et., al 2011). The MVIC has been looked at in several instances to monitor fatigue. However, it seems to be a measurement that may not give as much insight to recovery status as other, more dynamic and/or sport specific tasks or variables. While our study did not show any statistical changes in MVIC throughout the intervention, other studies which had much more strenuous interventions had shown that MVIC had been significantly changed 24 hours after the intervention but had returned back to baseline upon other follow up visits (Raeder et., al 2016). While other variables had been shown to be significantly changed much longer after the intervention. MVIC does not seem to be an effective way to monitor lower levels of fatigue, particularly from eccentric-induced muscle damage.

The soreness data in the present study did show some statistically significant changes. It has been suggested that DOMs can negatively affect performance by reducing joint range of motion, shock attenuation, peak torque, alteration in muscle sequencing and recruitment patterns (Cheung et., al 2003). In this study there was no evidence that any of these negative affects took place. As mentioned above, a potential reason for this occurring is that our participants might not have received sufficient muscle damage in the prime movers for a depth jump alteration, or their fatigue levels were not high enough to cause a decline in DJ performance or perhaps the height of the DJ in this study was not high enough to cause identifiable performance related declines. In a former study that observed the effects of muscle soreness on vertical jump height and ground reaction forces they also did not show that there was any reduction in vertical ground reaction force profiles during the vertical jump and landing (Engels, 2017). In their study they had two groups of participants including an experimental group that performed eccentric exercise to induce DOMS and a control group that performed concentric exercises to induce DOMS. This study supported our rational of using eccentric exercise due to the greater effect of causing soreness following exercise. However, in Engels (2017) study they also did not record any significant differences in ground reaction force variables that they were observing. This provides support for the current study's findings, such that eccentric exercise induced muscle damage, that likely yields relatively low-level impairments, may not induce a large enough impairment response to be captured by jump-related tasks or MVICs, even when soreness is present. The disconnect observed herein between the lack of changes in muscle performance from eccentric exercise, and significantly occurring soreness, is interesting and should be explored further in future work.

As reported in the results section of this paper VAS Soreness was effectively induced on the participants by the 24 hours follow up visit and the 48 hour follow up visit. This is consistent with what is often seen in research (Cheung et., al 2003). Considering the evidence of soreness being induced, one might assume that jump performance might significantly be affected due to the soreness that took place. However, in this study there was not any data recorded on the specific location where the participants were experiencing muscle soreness. It was initially assumed that the participants would be sore in the muscle groups that were expected to be highly activated while exercising using the Eccentron, including the quadriceps, gastrocnemius, hip adductors, and hamstrings.

However, while conducting the study and having participants talk about their experience in follow up visits, there were several instances where participants mentioned that although they were sore, the soreness was “mostly sore” or “only sore” in the gluteus medius muscle group area. If this study were to be repeated it is suggested to examine soreness in these more specific muscles as done by (Willems et al. 2009). These authors monitored DOMS in individual muscles including the quadriceps femoris, vastus medialis, vastus lateralis, and rectus femoris muscles. Other muscle groups that might be a good idea to monitor would be the biceps femoris, semitendinosus, and semimembranosus, gluteus maximus, and gluteus medius. The purpose for monitoring soreness in specific muscle groups, rather than just more generally (i.e, lower body region), would give greater insight to muscle damage to muscles that are the more involved prime movers for the depth jump test.

When designing this study, it was decided that eccentric exercise performed on the Eccentron would be an optimal intervention that would be time effective as well as capable of inducing soreness and muscle damage, as compared to concentric exercise, given that muscle can resist 30-40% more force eccentrically than they can produce force concentrically. (Johnson n.d.) The Eccentron was ultimately selected for the resistance protocol, because of the nature of eccentric training by being able to overload the body in a neuromuscular manner with minimal risk. (Site the passive nature of eccentric overload). The multi-joint, closed kinetic chain movement of the Eccentron seemed to be ideal when designing a project that incorporated DJ as testing measurements due to the muscle activation required to perform effective DJ and high, closed kinetic chain loading pattern of this task.

One practical observation from these findings may bet that given there was a statistically significant increase in muscle soreness but not a statistical change in depth jump performance, it could indicate that eccentric exercise on the Eccentron may be a way to incorporate resistance training concurrently with other training methods without compromising the ability to perform vertical jumping tasks. Although caution should be given as it is important to incorporate training methods that are specific to the adaptation that athletes are training for. A lack of performance decline does not indicate that eccentric resistance training would be the best option for every athlete at any given time of the training cycle.

Conclusions

The results of this study show that participants experienced a statically significant increase in soreness following the eccentric training protocol on the Eccentron. However, there were no statistically significant changes in depth jump performance including jump height, reactive strength index, rate of force development normalized, average positive power normalized, ground contact time, or isometric peak force. Therefore, we suggest that the lack of statistical differences in depth jump variables may have been due to lack of control outside of the study, differences in training ages or status from prior studies, or lack of data concerning specific muscle groups that were affected by the training protocol. Future recommendations for this study would be a more intensive, comprehensive lower body resistance protocol, and a strict protocol of activities that can take place outside of the study including restrictions of recovery exercises such as stretching, foam rolling, or active recovery including long walks, and identifying soreness of prime movers rather than a general soreness VAS measurement.

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