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The effect of acute fatigue on reactive strength index in modern dancers

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THE EFFECT OF ACUTE FATIGUE ON REACTIVE STRENGTH INDEX

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ABSTRACT

Purpose: The purpose of this study was to evaluate the effects of acute fatigue on stretch shortening cycle (SSC) performance measured by the Reactive Strength Index (RSI) derived from a drop jump. ***Methods:*** Twelve professional modern dancers (8 female, 4 male) participated in this study. Two force plates were utilized to record the force-time data during drop jumps (DJ) before and after an acute, fatiguing protocol. Dancers performed a 5-10 minute self-selected warm up followed by 3-5 practice trials of DJs onto the force plates. Three trials were recorded from each dancer with 30-60 seconds (s) of rest between trials. Following the first 3 trials dancers underwent 2 minutes of continuous rope jumping. After 30s of rest following rope jumping dancers performed 3 more trials of drop jumps. Cronbach's alpha was used to assess reliability across trials, and a paired t-test was used to determine differences in RSI before and after the rope jumping protocol. ***Results:*** There was no significant difference between best non-fatigued reactive strength index (NFRSI) and best fatigued reactive strength index (FRSI) when compared ($p = 0.136$). ***Conclusions:*** Elite modern dancers are able to maintain jump performance following acute fatigue. Future research should investigate the effect of specific training for lower body power in modern dancers. Research to guide understanding the importance of supplemental training in modern dance performance could be key in preparing future dancers for the demands of elite dance requirements.

Keywords: RSI, bounce drop jump, dance, fatigue

The Effect of Acute Fatigue on Reactive Strength Index in Modern Dancers

INTRODUCTION

Performing artists, including circus acrobats, musicians, and dancers are increasingly being recognized for their amazing athleticism (Dick, R. W., Berning, J. R., Dawson, W., Ginsburg, R. D., Miller, C., & Shybut, G. T.,2013; Gorski, 2014; Ritsema, 2009). The National Athletic Training Association (NATA) has identified the performing arts as an 'emerging setting' for professional expansion, even including specific conference workshops devoted to this population (National Athletic Training Association, 2020). In recognition of the change in perception of performing artists as athletes, the National Strength and Conditioning Association has developed a Special Interest Group (SIG) focused solely on the physical performance concerns of the performing artist-athlete (NSCA, 2020).

Dancing is a performing art that requires high levels of physical aptitude and body control in order to complete the many complex and intense artistic elements required in training, recital, and performances. Although discussion of the 'dancer-as-athlete' has been around for over a decade (Koutedakis & Jamurtas, 2004), popular recognition of this was greatly enhanced by the displays of athleticism from American ballerina Misty Copeland in an Under Armour commercial in 2014 (ABC News, 2014; Varley, n.d.). While many traditionalists resist acknowledging dancers as athletes, it is clear that today's dancer is more athletic than dancers of the past.

There are several genres of dance including traditional ballet, hip-hop, ballroom, and modern, to name a few. Modern dance is a discipline that focuses on emotional expression through movement of the body, and that prides itself on 'breaking the rules' often associated with other disciplines such as ballet (Bodensteiner, 2019). Modern dance performances are characterized by multiple artistic 'pieces' put together to make an entire performance (Wyon, M. A., Twitchett, E., Angioi, M., Clarke, F., Metsios, G., & Koutedakis, Y., 2011). Compared to ballet dancers, contemporary modern dancers may spend more time actually dancing during performances, but exhibit fewer jumps and pliés (Wyon et al., 2011).

Most research attention in the dance arts has focused on the ballet dancer-athlete, with much less attention paid to the modern dancer. The discrepancy in research attention between ballet and modern dance could be due to the relatively larger number of ballet dancers that make up a company (up to 60 or more vs 5-10 modern dancers). In addition, modern dancers often 'freelance' and move about to different companies or productions frequently (Weiss, Shah, & Burchette, 2008), further reducing the ability to acquire sufficient subjects for research. Performance aspects of modern dance research have focused mostly on injury (Bronner, McBride, & Gill, 2018; Fuller, Moyle, Hunt, & Minett, 2019; Henn, Smith, Ambegaonkar, & Wyon, 2020), with a smaller representation of the physiological demands of training or performance (Angloi, Metsios, Twitchett, Koutedakis & Wyon., 2009). Supplementary strength and jump training on top of dance-specific training has been shown to be beneficial in enhancing jump performance, routine performance and aesthetic competence in dancers (Angloi et al., 2009). Considering dance performance research has shown supplementary training to be beneficial, understanding the physiological adaptions that take place in the stretch shortening cycle during practice and supplemental training is important when guiding future research and training programming.

The stretch shortening cycle (SSC) is the muscular function where a preactivated muscle is first stretched with an eccentric action, followed by a concentric action of shortening

(Cavagna, Saibene, & Margaria, 1965). The SSC has been explained using two models: mechanical and neurophysiological. In the mechanical model elastic energy is increased and stored in the musculotendinous regions of the area that are being rapidly stretched. This elastic energy can be used to increase total force production if the rapid stretch is immediately followed by a concentric action. Within the mechanical model it is the series elastic component (SEC) that induces the greatest production to total force output. The SEC has many components, but it is the tendons that constitute the majority of the SEC. When the tendons release stored elastic energy at the appropriate time, total force production will be influenced (Haff & Triplett, 2016). The SSC also has neurophysiological origins, whereby a rapid eccentric stretch activates muscle spindles within the stretched muscle, initiating a stretch reflex and potentiating the concentric phase of the SSC (Haff & Triplett, 2016).

The SSC is unique, because it does not come only from one form of muscle action. Nicol and colleagues (2006), characterized SSC as having three important aspects including the pre-activation, the breaking phase and the push off parts of the movement. Both pre-stretch and pre-activation of a muscle can affect the performance of the concentric phase utilizing a combination of storage of elastic energy and the stretch reflex activation of the muscle (Wilk, Voight, Keirns, Gambetta, Andrews, & Dillman, 1993). The pre-activation and pre-stretch is strongly related to the SSC effect due to the tendon elongation and increased residual force (Fukutani, Kurihara, & Isaka, 2015). If an individual steps off of a box for a drop jump, their muscles pre-activate and pre-stretch prior to landing. The amortization phase is the time delay of generating force to overcome the eccentric action of the lengthening and switching to muscle contraction in the plyometric movement (Davies, Riemann, & Manske, 2015). Utilizing the drop jump example, this is the contact phase of the movement, where the individual makes contact with the ground after stepping off of a platform. The final push off or concentric phase of a plyometric exercise is the interaction of the released stored elastic energy and muscle spindle system to shorten the muscle and produce contraction in the agonist muscle (Davies et al., 2015). In the final phase of the drop jump example, this is where the individual would begin their vertical ascent after making contact.

The SSC demonstrates fatigue quickly (Komi P. V., 2000) and influences various muscle actions (eccentric, amortization and concentric) phases associated with performance. The SSC is commonly utilized when assessing fatigue because this transition time between the eccentric and concentric action is strongly influenced by the ground contact phases during activities such as running and plyometrics (Nicol, Avela, & Komi, 2006). Muscular fatigue has been defined as the bodies inability to maintain the required or expected force (Gandevia, 2001). This occurs when the SSC action of a muscle group is repeated for long enough at a high intensity, causing structural and mechanical disruption. Exhaustive plyometric exercises that utilize the SSC are known to contribute to SSC fatigue and immediate performance decrements due to this neural, mechanical and metabolic loading (Nicol et al., 2006). Though damage and fatigue effects of exercise are reversible and may result in minor physical symptoms such as joint and muscle stiffness (Komi P. V., 2000), it can also contribute towards immediate to delayed performance impediment (Horita T., Komi, Nicol, & Kyrolainen, 1996). Monitoring fatigue is a common way to not only address gaps in recovery from training but allow for coaches to monitor trainable characteristics of the stretch shortening cycle. A way for coaches to monitor this fatigue is by utilizing the drop jump.

Drop Jumps are utilized to evaluate SSC performance and fatigue because they mimic common ballistic action in sport (McClymont, 2003). Drop jumps (DJ) have been described as a cornerstone exercise in developing a fast SSC and are commonly utilized as a readiness-to-train tool and for injury-risk screenings (Pedley, Lloyd, Read, & Moore, 2017). Drop jumps consist of an athlete stepping off of an elevated height, descending, contacting, taking off into a jump and then landing, where the athlete's goal is to minimize contact time and maximize jump flight time (Pedley et al., 2017). A way to quantify the performance variables of the drop jump is by utilizing the reactive strength index (RSI) (Kipp, Kiely, Giordanelli, Malloy, & Geiser, 2018) .

RSI describes the athlete's ability to change quickly from an eccentric to concentric muscular contraction during a drop jump. RSI can be utilized to evaluate athlete's plyometric performance (Ebben & Petushek, 2010), find ideal height for drop jumps in training as well as monitor fatigue and performance through contact time and performance (Flanagan, Ebben, & Jensen, 2008). RSI is calculated as drop jump height / ground contact time, this gives a ratio of how high an athlete jumps to their ground contact time (Kipp et al., 2018).

Though RSI is typically evaluated utilizing the drop jump, many researchers have modified RSI to allow for monitoring of explosiveness in other types of plyometric activities (Ebben & Petushek, 2010). RSI-modified has been utilized to monitor fatigue utilizing a countermovement (CM) jump in Division I volleyball players analyzing the ratio of jump height to time-to-takeoff, where the take-off was considered as the initiation of the downward phase of the CM. RSI-modified as well as CM jump height was shown to be a reliable tool for intra- and inter- session monitoring for decision making in athlete performance (Carroll, Wagle, Sole, & Stone, 2019). RSI has also been utilized to profile stretch-load tolerance and to identify appropriate platform heights for the performance of drop jumps (Byrne, Moran, Rankin, & Kinsella, 2010; Struzik, Juras, Pietraszewski, & Rokita, 2016). In 2001, Read and Cisar conducted a study evaluating rest intervals sufficient for recovery in a depth jump. There were no significant differences in jump height or ground reaction forces between groups, suggesting that 15 seconds of rest was sufficient recovery period for consistent performance in the depth jump heights and vertical ground reaction forces (Read & Cisar, 2001). Not only has RSI been utilized to identify proper training parameters such as drop height and rest intervals for training purposes, but it has also been utilized as a means to understand how fatigue acutely affects the SSC.

Gollhofer and colleagues found that following fatiguing exercise of maximal drops onto the floor, there was a reduced electromyography (EMG) during the active pre-stretch (eccentric) phase of the stretch shortening cycle potentially due to a fatigue effect on the muscle spindles (Gollhofer, Komi, Fujitsuka, & Miyashita, 1987). In a later study, Strojnik and Komi evaluated sledge jumps at 60% of maximal height until exhaustion with 12 physically active males. This exhaustive exercise resulted in low frequency fatigue. This is potentially due to the changes in muscle metabolism such as pH and structural fatigue from muscle damage experienced during exhaustive exercise (Strojnik & Komi, 2000). Fatiguing SSC exercise may lead to changes in physiological, neural and structural components of the contractile muscle units. When these normally functioning SSC systems are fatigued it may negatively influence drop jump performance (Horita, Komi, & Hamalainen, 2003). As dance performance is generally evaluated based on aesthetics, evaluating jumps is a quantifiable way to monitor performance (Brown, Wells, Schade, Smith, & Fehling, 2007).

The purpose of this study was to evaluate the effects of acute fatigue on SSC performance measured by the RSI derived from a drop jump. The outcomes of this study can provide insight into the performance characteristics of these types of athletes and guide future supplemental training.

METHODS

This study represented a pre-post intervention design conducted on a targeted sample. An anonymized dataset comprised of force-time records from various jumping performances by twelve dancers from a professional modern dance company was used for this study. Eight females (Age: 32.6 ± 3.29yrs, Height: 163.54 ± 6.15cm, Weight: 53.75 ± 6.01kg) and four males (Age: 35.33 ± 8.02yrs, Height: 175.93 ± 7.08cm, Weight: 78 ± 9.96kg) completed a battery of medical, nutritional, and performance tests as part of a larger, multi-center study on health correlates and performance in elite athletes (J. McNeal, unpublished data). The following description of the data collection and research methods from which the dataset was generated is based on conversations with the study's primary investigator for the performance data (J. McNeal, personal communication).

To assess lower body power unilaterally, the dancers completed a series of jump tests performed on side-by-side force plates. Data extracted for this thesis investigation included the force-time records from only the drop jump test. Of particular interest to the researchers was the effect of acute fatigue on stretch-shortening cycle performance in these subjects, therefore drop jump performance was assessed before and following a 2 minute exercise bout designed to induce acute fatigue of the muscles of the lower extremity (Caroline & Komi, 2003).

All testing took place in a private fitness club where the dancers often performed auxiliary training exercises and classes. Jump testing took place in the morning for all dancers. Dancers performed a 5-10 minute self-selected warmup during which they were instructed to prepare themselves for various tests of maximal jumping performance. Since this was an elite dance company composed of dancers with a minimum of 10 years of professional dance training, the warmup was not specifically prescribed. Dancers were however instructed not to perform any static stretches of their lower extremity during their warmup (McNeal & Sands, 2006). Following the warmup, dancers were instructed by the investigator on how to perform a bounce-type drop jump (Marshall & Moran, 2013). They were instructed to 'ricochet' off the force plates as fast as possible 'as if the force plate was hot', with minimal bending of the hips and knees. They then performed between three and five practice trials, dropping from a plyometric box whose surface was twelve inches above the force plates (UCS Plyo-Safe Plyo Boxes: https://www.ucsspirit.com/strength-speed/product-detail.cfm/category/Plyosafe/product/Plyosafe-Elite-Plyoboxes). Dancers performed the jumps barefoot, and were required to keep their hands on their hips throughout the jump. Force-time records of each jump were generated from two, 2-axis force plates (model PS-2142, Pasco Scientific, Roseville, California) sampling at 1000 Hz. Three trials were recorded from each dancer. A rest period of 30-60 s was required between trials.

After completion of the first three trials of drop jumps, dancers underwent 2 minutes of continuous jump roping, performed on rubber flooring (unknown dimensions or company, but typical of a resistance training facility). There was no control over the style of jumping (single vs double contact). Following the rope jumping intervention subjects rested for 30 sec, during which time they were required to remain standing and were allowed to walk but could not sit or stretch. Following the rest period, the dancers again performed three trials of drop jumps.

Analysis

The individual force plate data were summed to a single signal, and only the vertically-directed forces were analyzed. Data were smoothed using a 10-sample simple running average (Kennedy, Charles, Villano, & Schmiedeler, 2016). Contact time and flight time for each trial were previously calculated and included in the raw dataset. RSI was calculated as flight time/contact time (Pietraszewski & Rutkowska-Kucharska, 2011, Struzik, Pietraszewski, & Bober, 2016).

Cronbach's alpha was used to assess contact time, flight time, and RSI consistency across each set of three trials (Cronbach, 1951; Flanagan, Ebben & Jensen., 2008) and one-way ANOVA was used to test for significant differences across the trials. Based on the results from these analyses, a single representative score was determined for each subject. Normality of the representative data was assessed using Shapiro-Wilks test. Two-tailed paired t-tests were used to evaluate the data for differences between non-fatigued and fatigued conditions. Statistical significance for all tests was achieved when p :S 0.05.

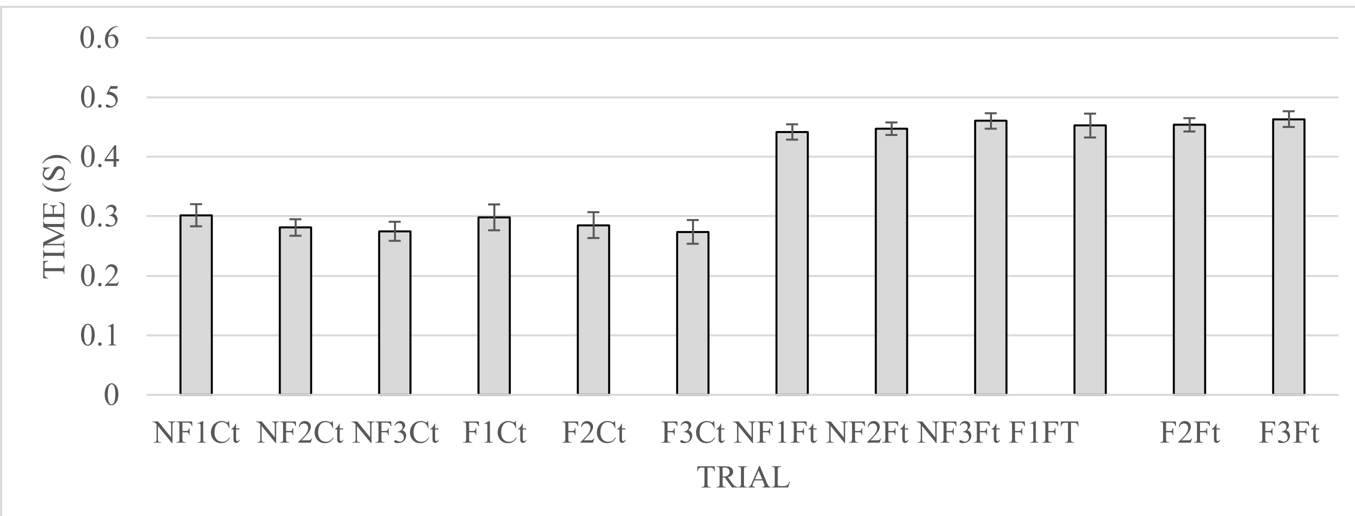
RESULTS

Cronbach's alpha reliabilities were all $\alpha > 0.82$ for repeated trials data of the non-fatigued and fatigued conditions, indicating good-to-excellent reliability (Glen, 2014). Significant differences between trials were found for NFFT ($F = 3.999$; $p = 0.033$) and NFRSI ($F = 7.434$; $p = 0.003$). Least significant difference post-hoc comparisons showed that for both variables the first trial represented significantly worse performance than the third trial (NFFT Trial 1 value vs NFFT Trial 3, $p = 0.021$; NFRSI Trial 1 value vs NFRSI Trial 3, $p = 0.004$). Figure 1 and Figure 2 graphically display the group means and standard error for each variable across trials and by condition. Upon further examination of the trends across trials for all data, it was decided that the first jumping trial was the poorer score, with jumps two and three demonstrating trends toward improved performance. In light of this consistent trend, and despite high Cronbach's alpha and several non-significant ANOVA tests across trials, it was decided to use each subject's 'best' RSI score as the criterion score for each condition. (Best Non-Fatigued RSI Trail 2, $n = 2$

participants, Best NFRSI Trial 3, *n*=10 participants, Best Fatigued RSI Trial 2, *n*=7 participants, Best FRSI Trial, *n* = 6 participants). Despite arguments between statisticians and applied researchers on the topic, best scores are often used vs averaged scores when evaluating performance in athletic populations (Barr & Nolte, 2011).

Figure 1.

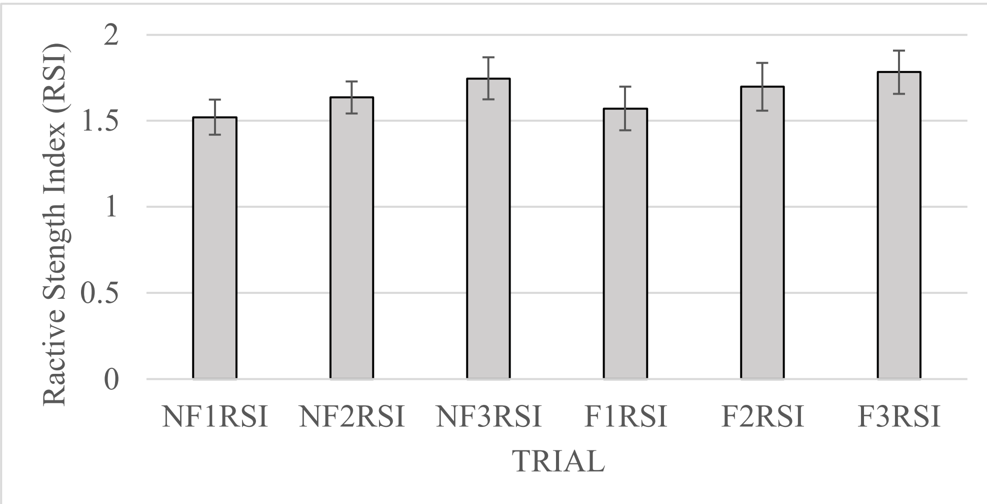
Trial Means and Standard Errors for Contact Time (CT) and Flight Time (FT) across three trials



Note. NF = non-fatigued; F=fatigued

Figure 2.

Trial Means and Standard Errors for RSI across three trials



Note. NF = non-fatigued; F=fatigued

Non-fatigue RSI and Fatigued RSI demonstrated non-significant differences from a normal distribution, therefore meeting the assumption of normality for parametric statistical analyses. A two-tailed paired t-test conducted on the non-fatigued RSI and fatigued RSI scores resulted in non-significant differences (Table 1).

Table 1

T-Test Best NFRSI with FRSI

	M	*SD*	*t*	*p*
NFRSI	1.767	± 0.40		
FRSI	1.881	± 0.445		
Best DJRSI to Best FDJRSI	-0.103	± 0.222	-1.609	0.136

Note. NF = non-fatigued; F=fatigued

DISCUSSION

Elite modern dancers are required to maintain excellent technique and amplitude in their movements throughout both training and during performances. It is necessary that even under fatigued conditions they be able to perform dance movements at the end of a performance as optimally as the beginning. In this study we investigated how RSI scores changed following a 2 minute bout of continuous jump roping in a sample of elite modern dancers. Our results failed to demonstrate a significant change in RSI score following the jump roping intervention. Reasons for these results could be due to the elite level of our dancers, lack of control over jump roping technique, or subject unfamiliarity with the drop jump test leading to a learning or even potentiating effect in the post-intervention trials.

The elite nature of our sample may have led to a non-significant effect of the fatiguing protocol on drop jump performance. It has been shown that jumping ability is correlated with aesthetic competence in dancers from multiple disciplines (Angioi, Metsios, Twitchett, Koutedakis, & Wyon, 2009). Similarly, lower extremity muscular strength has been shown to be greater in professional ballet dancers compared to collegiate level, (Twitchett, Koutedakis, & Wyon, 2010) and greater muscular power has been demonstrated in professional level modern dancers compared to university level (Brown et al., 2007). It is difficult to correctly place the drop jump performances of our sample of modern dancers along the range of reported performances in other sports due to large variations in drop jump protocols and conditions. No other drop jump results have been reported in dancers so direct comparison cannot be achieved. The average flight time across all six trials for these dancers was 0.456 sec, yielding an average jump height of 0.25 m (using time in the air to calculate jump height). Given the advanced experience of the sample (> than 10 years of professional training), it is possible that the jump roping protocol used in this study was not difficult enough to induce fatigue for this sample of elite dancers, or that it was dissimilar to the type of fatigue experienced by dancers at the end of an entire dance performance. Future research should aim to create a fatigue protocol that challenges the dancers in a way that mimics fatigue experienced in an entire dance routine.

Another limitation to this study that may have been a lack of control over the execution of the fatiguing protocol. Communication with the primary investigator indicated that it was not possible to supervise every dancer while they were jumping rope, as there were multiple tasks being undertaken by the investigator during data collection. This may have led to some participants jumping more vigorously than others or using a greater number of single foot contacts versus double foot, which increases the load experienced during the SSC (Haff & Triplett, 2016). Future studies using a rope jumping protocol would benefit from more closely defining and rigorously controlling jump rope technique.

It has been reported that across styles, dancers may perform more than 200 jumps during a typical class (Liederbach, Richardson, Rodriguez, Compagno, Dilgen, & Rose, 2006) however a time motion analysis of modern and ballet dancers (Wyon et al., 2011) showed that in a typical performance modern dancers perform fewer jumps than ballet dancers (1.71 jumps/min vs 4.99). No research has been conducted that has described the distribution of jump types across different dance styles, therefore it is unknown to what degree modern dancers perform jumps representing slow vs fast SSC actions (Bobbert, Mackay, Schinkelshoek, Huijing, & van Ingen Shenau, 1986). If the nature of jump performance in modern dance is more representative of slow SSC, then it may be that the bounce-type drop jump used in this study represented a relatively novel jumping technique for modern dancers. Literature on the learning effect related to repeated trials of drop jumps is scarce. Costley and colleagues (2018) investigated the reliability of bounce drop jump performance in male rugby players and showed that no familiarization is needed. Flanagan and colleagues (2008) reported the reliability of measures derived from repeated trials of depth jumps in Division I track and field athletes and determined that a single trial was sufficient in this population. Finally, excellent reliability was shown for drop jump parameters across three trials in professional basketball players (Markwick, Bird, Tufano, Seitz, and Haff, 2015). Whether or not this is true for modern dancers is not known.

Interestingly, nine of the twelve dancers had their best RSI score following the jump roping intervention, although the differences in RSI before and after the intervention did not reach significance. It has been shown that modern dancers train primarily at light to moderate exercise intensities (Wyon, et al., 2011), therefore the jump roping intervention used in this study may have been an intensity of SSC to which they were not accustomed, leading to a post-activation potentiation (PAP) response. Post-activation potentiation is characterized in recent literature as xf (RFD), which is a driving factor of the SSC which can potentially increase participants RSI (Hodgson, Docherty, & Robbins, 2005) While PAP is most commonly accomplished through maximal voluntary contractions (George, Mavvidis, Kosmadaki, Tsoumani, & Dallas, 2019; Scott & Docherty, 2004; Zimmermann, MacIntosh, & Dal Pupo, 2020), rope jumping may have served the dancers the purpose of another warmup, one at an intensity that may have contributed to performance enhancement in the fatigued drop jump trials.

A limitation of this study is the lack of background on the supplemental training programs utilized by this group of dancers. It is suggested that dancers include supplementary training to reduce amount of injuries and increase the key fitness parameters required for aesthetic performance (Koutedakis & Jamurtas, 2004). Research has shown that in self-reported supplemental training in ballet dancers (primarily resistance training for males and cardiovascular training for females) has no significant effect on jump height, however it was noted that training specifically for lower body power development may have shown greater differences (Wyon, Allen, Angioi, Nevill, & Twitchett, 2006). Understanding the type of training they participate in outside of regular dance practice could lead to insight into how they were able to maintain RSI values under fatigue.

Research involving modern dancers is fairly scarce when compared to the literature found on ballet performance. Future research should investigate the effect on lower body power specific training intervention and its effect on RSI values in elite modern dancers. Understanding the importance of supplemental training in modern dance performance could be key in preparing future dancers for the demands of elite dance requirements.

References

ABC News. (2014, August 5). Retrieved from https://www.youtube.com/watch?v=52tc3STY3fc

Angioi, M., Metsios, G. S., Twitchett, E., Koutedakis, Y., & Wyon, M. (2009). Association between selected physical fitness parameters and aesthetic competence in contempoary dancers. *Journal of Dance Medicine & Science, 13*(4), 115-123.

Angloi, M., Metsios, G., Koutedakis, Y., & Wyon, M. (2009). Fitness in contemporary dance: A systematic review. *International Journal of Sports Medicine, 30*(7), 475-484.

Barr, M. J., & Nolte, V. W. (2011). Which measure of drop jump performance best predicts sprinting speed? *Journal of Strength and Conditioning Research, 25*(7), 1976-1982.

Blazevich, A. J., & Babault, N. (2019). Post-activation potentiation verses post-activation performance enhancement in humans: Historical perspective, underlying mechanisms, and current issues. *Frontiers in Physiology, 10*(1359), 1-19.

Bodensteiner, K. (2019, September 27). *Dancing to different rules.* Retrieved from The Kennedy Center : https://www.kennedy-center.org/education/resources-for-educators/classroom-resources/media-and-interactives/media/dance/dancing-to-different-rules/

Bronner, S., McBride, C., & Gill, A. (2018). Musculoskeletal injuries in professional modern dancers: A prospective cohort study of 15 years. *Journal of Sport Sciences, 36*(16), 1880-1888.

Brown, A. C., Wells, T. J., Schade, M. L., Smith, D. L., & Fehling, P. C. (2007). Effects of plyometric training versus traditional weight training on strength, power and aesthetic jumping ability in female collegiate dancers. *Journal of Dance Medicine & Science, 11*(2), 38-44.

Byrne, P. J., Moran, K., Rankin, P., & Kinsella, S. (2010). A comparison of methods used to identify 'optimal' training height for early phase adaptions in depth jump training. *The Journal of Strength and Conditioning Research, 24*(8), 2050-2055.

Caroline, N., & Komi, P. V. (2003). Stretch-shotrening cycle fatigue and its influence on force and power production. In *Strength and Power in Sports* (pp. 203-228). Blackwell Science Ltd. .

Carroll, K. M., Wagle, J. P., Sole, C. J., & Stone, M. H. (2019). Intrasesson and intersession reliability of countermovement jump testing in division-I volleyball athletes. *Journal of Strength and Conditioning Research, 33*(11), 2932-2935.

Cavagna, F. P., Saibene, F. P., & Margaria, R. (1965). Effect of negative work on the amount of positive work performed by an isolated muscle. *Journal of Applied Physiology, 20*(1), 157-158.

Cronbach, L. J. (1951). Coefficient alpha and the internal structure of the tests. *Psychometrika, 16*, 297-334.

Cuenca-Fernandez, F., Smith, I. C., Jordan, M. J., MacIntosh, B. R., Lopez-Contreras, G., Arellano, R., & Herzog, W. (2017). Nonlocalized postactivation performance enhancement (PAPE) effects in trained athletes: A pilot study. *Applied Physiology, Nutrition, and Metabolism, 42*(10), 1122-1125.

Davies, G., Riemann, B. L., & Manske, R. (2015). Current concepts of plyometric exercise. *International Journal of Sports Physical Therapy, 10*(6), 760-786.

Dick, R. W., Berning, J. R., Dawson, W., Ginsburg, R. D., Miller, C., & Shybut, G. T. (2013). Athletes and the arts - The role of sports medicine in the performing arts. *Current Sports Medicine, 12*(6), 397-403.

Ebben, W. P., & Petushek, E. J. (2010). Using the reactive strength index modified to evaluate plyometric performance. *Journal of Strength and Conditioning Research, 24*(8), 1983-1987.

Fitt, S. (1981). Conditioning for dancers: Investigating some assumptions. *Dance Research Journal, 14*(1), 32-38.

Flanagan, E. P., & Harrison, A. J. (2006). Lower limb performance in anterior cruciate ligament reconstructed individuals. *ISBS-Conference Proceedings Archive, 24*, 1-4.

Flanagan, E. P., Ebben, W. P., & Jensen, R. L. (2008). Reliability of the reactive strength index and time to stabilization during depth jumps. *Journal of Strength and Conditioning Research, 22*(5), 1677-1682.

Fukutani, A., Kurihara, T., & Isaka, T. (2015). Factors of force potentiation induced by stretch-shortening cycle in plantarflexors. *PLOS ONE, 10*(6), 1-12.

Fuller, M., Moyle, G. M., Hunt, A. P., & Minett, G. M. (2019). Ballet and contemporary dance injuries when transitioning to full-time training or professional level dance: A systematic review. *Journal of Dance Medicine & Science, 23*(3), 112-125.

Gandevia, S. C. (2001). Spinal and supraspinal factors in human muscle fatigue. *Physiological Reviews, 81*(4), 1725-1789.

George, D., Mavvidis, A., Kosmadaki, I., Tsoumani, S., & Dallas, K. (2019). The post actvation potentiaion effect of two different conditioning stimuli on drop jump parameters on young female artistic gymnasts. *Science of Gymnasts Journal, 11*(1), 103-113.

Glen, S. (2014, December 8). *Cronbach's alpha: Simple definition, use and interpretation*. Retrieved from StatisticsHowTo.com: Elementary Statistics for the rest of us!: https://www.statisticshowto.com/cronbachs-alpha-spss/

Gollhofer, A., Komi, P. V., Fujitsuka, N., & Miyashita, M. (1987). Fatigue during stretch-shortening cycle exercises. II. Changes in neuromuscular activation patterns of human skeletal muscle. *International Journal of Sports Medicine, 8*(1), 38-47.

Gorski, C. (2014, June 13). *Performance artists as athletes.* Retrieved from Inside Science: https://insidescience.org/news/performance-artists-athletes

Haff, G., & Triplett, N. T. (2016). Plyometric mechanics and physiology. In *Essentials of Strength Training and Conditioning* (Vol. Fourth edition., p. 472). Champaign, IL: Human Kinetics.

Henn, E. D., Smith, T., Ambegaonkar, J. P., & Wyon, M. (2020). Low back pain and injury in ballet, modern dance, and hip-hop dancers: A sysematic review. *International Journal of Sports Physical Therapy, 15*(5), 671-687.

Hodgson, M., Docherty, D., & Robbins, D. (2005). Post-activation potentiation: Underlying physiology and implications for motor performance. *Sports Medicine, 35*(7), 585-595.

Horita, T., Komi, P. V., Nicol, C., & Kyrolainen, H. (1996). Stretch shortening cycle fatigue: interactions among joint stiffness, reflex, and muscle mechanical performance in the drop jump. *European Journal of Applied Physiology and Occupational Physiology, 73*(5), 393-403.

Horita, T., Komi, P., & Hamalainen, A. J. (2003). Exhausting stretch-shotening cycle (SSC) exercise causes greater impairment in SSC performance than in pure concentric performance. *European Journal of Applied Physiology, 88*(6), 527-534.

Kennedy, M. W., Charles, R., Villano, M., & Schmiedeler, J. P. (2016). Effects of filtering the center of pressure feedback provided in visually guided mediolateral weight shifting. *PloS One, 11*(3), 1-17.

Kipp, K., Kiely, M. T., Giordanelli, M. D., Malloy, P. J., & Geiser, C. F. (2018). Biomechanical detriments of the reactive strength index during drop jumps. *International Journal of Sports Physiology and Performance, 13*(1), 44-49.

Komi, P. V. (2000). Stretch-shortening cycle: A powerful model to study normal and fatigued muscle. *Journal of Biomechanics, 33*(10), 1997-2006.

Koutedakis, Y., & Jamurtas, A. (2004). The dancer as a performing athlete. *Sports Medicine, 34*(10), 651-661.

Koutedakis, Y., & Jamurtas, A. (2004). The dancer as a performing athlete- Physiological considerations. *Sports Medicine, 34*(10), 651-661.

Marshall, B. M., & Moran, K. A. (2013). Which drop jump technique is most effective at enhancing countermovement jump ability, "countermovement" drop jump or "bounce" drop jump? *Journal of Sports Science, 31*(12), 1368-1374.

McClymont, D. (2003). Use of the reactive strength index (RSI) as an indicator of plyometric training conditions. In Reilly, T., Cabri, J., & Araújo, D. (2005). *Science and Football V: The Proceedings of the Fifth World Congress on Sports Science and Football* (pp.408-415). Routledge.

McNeal, J. R., & Sands, W. A. (2006). Stretching for performance enhancement. *Current Sports Medicine Reports, 5*(3), 141-146.

National Athletic Training Association . (2020, November 22). *Athletic trainers in performing arts: Exciting opportunity for growth*. Retrieved from National Athletic Training Association : https://www.nata.org/professional-interests/emerging-settings/performing-arts

Nicol, C., Avela, J., & Komi, P. V. (2006). The stretch-shortening cycle. *Sports Medicine, 36*(11), 977-999.

NSCA. (2020, November 22). *Special Interest Groups*. Retrieved from National Strength and Conditioning Association: https://www.nsca.com/professional-development/special-interest-groups/

Pedley, J., Lloyd, R., Read, P., & Moore, I. S. (2017). Drop jump: A technical model for scientific application. *Strength and Conditioning Journal, 39*(5), 36-44.

Pietraszewski, B., & Rutkowska-Kucharska, A. (2011). Relative power of lower limbs in drop jump. *Acta of Bioengineering and Biomechanics, 13*(1), 13-18.

Read, M., & Cisar, C. (2001). The influence of varied rest interval lengths on depth jump performance. *Journal of Strength and Conditioning Research, 15*(3), 279-283.

Ritsema, N. M. (2009, November 17). *Contemporary versions of athleticism*. Retrieved from The Manitoban : http://www.themanitoban.com/2009/11/contemporary-versions-of-athleticism/525/

Scott, S., & Docherty, D. (2004). Acute effects of heavy pre-loading on vertical and horizontal jump performance. *Journal of Strength and Conditioning Research, 18*(2), 201-205.

Strojnik, V., & Komi, P. V. (2000). Fatigue after submaximal intensive stretch-shortening cycle exercise. *Medicine & Science in Sports & Exercise, 32*(7), 1314-1319.

Struzik, A., Juras, G., Pietraszewski, B., & Rokita, A. (2016). Effect of drop jump technique on the reactive strength index. *Journal of Human Kinetics, 52*, 157-164.

Struzik, A., Pietraszewski, B., & Bober, T. (2016). Relationships between the H/Q ratio and variables describing CMJ and DJ jumps. *Journal of Human Kinetics, 66*(2), 123-133.

Varley. (n.d.). *Black athletes that inspire.* Retrieved November 2020, from Varley: https://www.varley.com/blogs/well-said/black-athletes

Weiss, D. S., Shah, S., & Burchette, R. J. (2008). A profile of the demographics and training characteristics of professional modern dancers. *Journal of Dance Medicine & Science, 12*(2), 41-46.

Wilk, K. E., Voight, M. L., Keirns, M. A., Gambetta, V., Andrews, J. R., & Dillman, C. J. (1993). Stretch-shortening drills for the upper extremeties: Theory and clinical application. *Journal of Orthopaedic and Sports Physical Therapy, 17*(5), 225-239.

Wyon, M. A., Twitchett, E., Angioi, M., Clarke, F., Metsios, G., & Koutedakis, Y. (2011). Time motion and video analysis of classical ballet and contemporary dance performance. *International Journal of Sports Medicine, 32*(5), 851-855.

Wyon, M., Allen, N., Angioi, M., Nevill, A., & Twitchett, E. (2006). Anthropometric factors affecting vertical jump height in ballet dancers. *Journal of Dance Medicine & Science, 10*(3), 106-110.

Zimmermann, H. B., MacIntosh, B. R., & Dal Pupo, J. (2020). Does postactivation potentiation (PAP) increase voluntary performance? *Applied Physiology, Nutrition, and Metabolism, 45*(4), 349-356.

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