International Journal of Strength and Conditioning

Rebold, M. J., Kobak, M. S., Ward, H., & Muirhead, W. (2023). The Effects of Various Modes of High-Intensity Anaerobic Exercise on Dynamic Balance Performance. International Journal of Strength and Conditioning
https://doi.org/10.47206/ijsc.v3i1.140

The Effects of Various Modes of High-Intensity Anaerobic Exercise on Dynamic Balance Performance

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ABSTRACT

This study assessed the effects of various modes of high-intensity anaerobic exercise (e.g., *sprinting*, *squatting*, and *jumping*) on dynamic balance performance. Twenty-five college-age student-athletes participated in three, high-intensity anaerobic exercise conditions (treadmill *sprint*, barbell *squat*, and vertical *jump*) on three separate days with only one condition being performed per week in a randomized order. Dynamic balance became significantly ($t = 2.21$, $p = 0.04$) worse from pre- to post-testing after completing the vertical jump protocol (5.24 ± 2.29 and 6.1 ± 1.92, respectively). There were no significant ($t < 1.75$, $p < 0.19$) differences in dynamic balance from pre- to post-testing after performing the treadmill *sprint* (5.68 ± 1.68 and 6.28 ± 2.06, respectively) and barbell *squat* (5.18 ± 1.64 and 5.69 ± 1.81, respectively) protocols. While Tabata sprint and barbell squat protocols revealed no significant effects on dynamic balance, a similar-intensity Tabata vertical jump protocol produced a significant detriment in dynamic balance performance. These findings suggest that the vertical jump may uniquely hinder subsequent sport performance and increase risk of balance-related injury when compared to intensity-matched sprinting or squatting. These results may be attributable to an increased propensity to fatigue when performing bouts of vertical jump compared to sprinting or squatting, thus reducing the proprioceptive capability of the body.

Keywords: Tabata Sprint, Barbell Squat, Vertical Jump, Fall Risk, Dynamic Balance

INTRODUCTION

In many sports, dynamic balance is necessary to achieve the highest competitive level and to avoid lower-body musculoskeletal injuries (e.g., knee and ankle sprains). The musculoskeletal systems work together to allow athletes to maintain their dynamic balance during competitive play (Hrysomallis, 2011). Dynamic balance can be thought of as the ability to maintain postural stability whilst performing a dynamic physical task, and this is a product of multiple kinesthetic receptors present in the body (Ricotti, 2011; Proske 2012). The totality of postural awareness is not a single awareness of the entire body, but rather the cumulative awareness of our joints' positions. Perhaps the most crucial source of this awareness are the muscle spindles, which sense a muscle's changes in length as well as the rate at which these changes occur. Lying in series with their respective musculature, these sensory structures are apt to deliver robust positional information. The anatomical grouping of muscles into antagonistic pairs, such as the biceps and triceps brachii, creates a relationship such that as one muscle contracts, its antagonist counterpart will stretch, thus reliably providing a stimulus for muscle spindles to receive and translate into proprioceptive information (Proske, 2012).

Another structure believed to contribute to proprioception are the Golgi tendon organs (GTOs), which lie in the tendons. Rather than sense rate and magnitude of stretch, these structures serve to sense the force within the musculotendinous unit. While undoubtedly an important function for preventing injury via over-exertion, the usefulness of sensory information provided by GTOs appears less obvious for spacial awareness through proprioception than that of the muscle spindles (Proske, 2012).

Proprioceptors are also present outside of musculotendinous tissue, within the joints themselves. Receptors sited at the joints respond to local compression, as well as mechanical tension at the joint, although they tend to be uniquely receptive at the extremes of the joint's range of motion, both at the very beginning and the very end of the anatomical range. As joint receptors tend to be latent within a normal range of motion, it is believed that they are secondary to muscle spindles in their proprioceptive contribution (Proske, 2012).

Another group of proprioceptors lie cutaneously, and consist of a variety of receptor types. While all are responsible for providing tactile sensation such as vibration, tapping, or pressure; two are thought to be suitable for producing proprioceptive information: slowly adapting type 2 receptors (Ruffini endings) and rapidly adapting type 2 receptors (Pacinian corpuscles). Notably, skin receptors seem to be particularly useful for providing proprioception in motor units responsible for fine motor patterns, such as those in the phalanges or facial muscles, whereas the aforementioned musculotendinous receptors provide the bulk of the sensation in proximal muscles that carry out gross motor patterns (Proske, 2012).
Muscular fatigue is defined as the inability to generate force, or the loss of force production capability; although the mechanisms through which muscular fatigue affects dynamic balance are unclear. Cetin and colleagues examined the impact of lower-body and trunk muscle fatigue on dynamic balance (Cetin, 2008). Thirty healthy, young sedentary adults engaged in stair climbing exercise to induce lower-body fatigue and had their dynamic balance assessed via the Kinesthetic Ability Trainer (SportKAT 3000, Vista, CA). Results indicated that dynamic balance from pre- and post-testing scores for the right, left, and front were not significantly different ($p = 0.29$, $p = 0.6$, and $p = 0.77$, respectively). However, results were significant for the backwards direction ($p = 0.05$) (Cetin, 2008). This may be due to the fatigue protocol utilized by the research, as the activity of stair-stepping will predominantly fatigue the hip extensors over the hip flexors. It may be that if fatigue were produced globally, a greater impact would have been observed in all directions.

Strength and conditioning programmes for athletes, as well as rehabilitation programs for older adults and injured populations have been designed to improve dynamic balance function. However, understanding what muscles are responsible for maintaining dynamic balance is imperative in the successful design of these balance programs, thereby improving sport performance and/or decreasing the risk of injuries (Aman, 2015). Inoue and colleagues (Inoue, 2013) determined associations between fatigue of individual muscle groups in the lower limbs and balance. Forty-two limbs of twenty-one healthy young adults were assessed by having the participants engage in voluntary isometric contractions via a multi-mode Biodex System 3 dynamometer (Biodex, Shirley, NY) for groups of flexor and extensor muscles (e.g., hip, knee, and ankle) and the effects on balance were analyzed via a Gravicorder GS5500 stabilometer (Anima Corp, Tokyo, Japan). Results indicated that fatigue in the hip, knee, and ankle can significantly ($p < 0.05$) decrease balance function (Inoue, 2013). These results suggest that both hip and ankle strategy are important when trying to maintain balance.

Sport performance is highly dependent on both health- and sport-related components (e.g., body composition, balance, etc.) (Powers, 2011). Hrysomallis conducted a systematic review that examined balance performance amongst athletes from different sports and athletes at different levels of competition within the same sport (Hrysomallis, 2007). It was found that athletes generally have superior balance performance when compared to control participants, and also elite level athletes have greater balance performance when compared to non-elite athletes. These findings infer that sport participation has the potential to improve balance performance. More specifically, athletes' participation in sports allows for improved body composition, coordination, strength, and range of motion (ROM) which all contributes to improving balance performance and being able to counteract external forces (e.g., gravity, drag, friction, etc.) and muscle fatigue to be able to maintain balance performance while engaging in competitive play.

While resistance to muscle fatigue may improve balance performance in sport, it remains unclear on how various modes of high-intensity anaerobic exercise affects dynamic balance performance in athletes (Cetin, 2008; Hrysomallis, 2011). Based on several needs analysis', it can be concluded that common anaerobic movements that many team sports athletes engage in are *sprinting*, *squatting*, and *jumping* (Haff, 2016). To the best of our knowledge, the effects of various modes of high-intensity anaerobic exercise on dynamic balance performance has not been investigated. Therefore, the purpose of this study was to assess the effects of various modes of high-intensity anaerobic exercise on dynamic balance performance. This study utilized a between-participants design to compare dynamic balance performance pre- and post-testing during the following conditions: *sprinting* on a treadmill, performing repetitive barbell *squats*, and performing repetitive vertical jumps (collectively referred to as 'test conditions' henceforth). It was hypothesized that dynamic balance would become significantly worse from pre- to post-testing after completing the sprinting condition, followed by the *squatting* condition, and then the *jumping* condition.

METHODS

Experimental Approach to the Problem

This study was conducted to investigate the effects of various modes of high-intensity anaerobic exercise (e.g., *sprinting*, *squatting*, and *jumping*) on dynamic balance performance in collegiate student-athlete participants.

All test conditions were completed in the Integrative Exercise Science laboratory at Hiram College. Participants recruited for this study were collegiate student-athletes from various sports (e.g., 3 baseball, 4 basketball, 2 cheer and stunt, 5 football, 9 soccer, and 2 volleyball). Before each condition, participants completed a condition-specific warm-up that adhered to the National Strength and Conditioning Association (NSCA) guidelines (Haff, 2016). All conditions (treadmill *sprint*, barbell *squat*, and vertical *jump*) followed the Tabata training protocol (Terry, 2003), which required participants to complete 20-second bouts of high-intensity anaerobic exercise with a 10-second rest period in-between for eight rounds, totaling four-minutes. The Biodex Balance System SD (Biodex, Shirley, NY) was used to perform Pre- and Post-Fall Risk Tests (Pre- and Post-FRT) to assess dynamic balance. The FRT protocol consisted of three trials, 20-seconds each, with 10-second rest periods in-between each trial. The initial platform setting was set at 12 and the ending platform setting was at 8. The cursor on the screen was off and a piece of paper was used to cover the Biodex screen to prevent the participants from having any visual feedback while engaging in the FRT. In addition to assessing dynamic balance, participants completed a fatigue visual analog scale and the adult OMNI-resistance exercise rating of perceived exertion scale (OMNI-RES) (Lagally, 2016; Tabata, 1996) immediately after each test condition to assess fatigue and perceived difficulty levels.

Participants

Twenty-five college-aged student-athletes (n =11 females, n =14 males, age 20.05 ± 1.4 years, Table 1) each participated in three high-intensity anaerobic exercise conditions (treadmill *sprint*, barbell *squat*, and vertical *jump*) on three separate days with only one condition being performed per week. The order of the three conditions was randomized in which participants were asked to draw pieces of paper from a hat. Participants were excluded if they did not play on a collegiate sports team or if they had any contraindications to exercise (i.e., lower-body orthopedic injuries). One-week prior to the initiation of the study, participants were instructed about the benefits and risks, to refrain from strenuous activity 48-hours prior to their visit and to also refrain from caffeinated related-substances (e.g., drinks, foods, supplements) 24-hours prior to their visit, and became familiarized with the assessment equipment and protocols. This study was approved by the Hiram College Institutional Review Board.

Procedures

For each of the test conditions, the participants reported to the Integrative Exercise Science lab. Prior to starting any condition, the Biodex Balance System SD (Biodex, Shirley, NY) was used to perform a Pre-Fall Risk Test (Pre-FRT) to assess dynamic balance. The FRT protocol consisted of three trials, 20-seconds each, with 10-second rest periods in-between each trial. Participants were instructed to maintain their balance as the platform became progressively more unstable. The initial platform setting was set at 12 and the ending platform setting was at 8. This was done since the aim of this study was to assess dynamic balance. The cursor on the

Table 1. Average height, weight, and age of the participants.

	Males (*n* = 14)	Females (*n* = 11)
Height (cm)	182.14±6.1 cm	164.19±4.98 cm
Weight (kg)	87.56±11.04 kg	66.45±8.9 kg
Age (years)	20.36±1.45 years	19.73±1.35 years

All data are means ± SD

screen was off and a piece of paper was used to cover the Biodex screen to prevent the participants from having any visual feedback while engaging in the FRT. Visual feedback during the FRT was eliminated because it simulated a more realistic environment, such as during sport, when athletes must make motor adjustments without visual cues. After the pre-FRT, participants performed the specific warm-up for each condition. The treadmill *sprint* warm-up consisted of running on the treadmill at 6.2 miles·hour^{-1} and with a zero percent incline for two-minutes. The barbell *squat* warm-up consisted of performing one set of five repetitions of the barbell squat at 30% one repetition maximum (1RM) and then performing two sets of five repetitions each at 50% 1RM. Finally, the vertical *jump* warm-up consisted of performing 30-seconds of the following dynamic stretches: alternating forward lunges, toe jogging, straight leg jogging, alternating "butt-kickers", alternating skipping, shuffling, and carioca. All warm-ups were based on the National Strength and Conditioning Association (NSCA) guidelines (Haff, 2016) and warm-ups that were previously used in other studies (Fry, 2014; Luebbers, 2015). After the warm-up, participants were given a one-minute rest period before engaging in the high-intensity anaerobic exercise condition. Finally, immediately after the high-intensity anaerobic exercise condition was completed, participants were asked to complete a fatigue visual analog scale and the adult OMNI-resistance exercise rating of perceived exertion scale (OMNI-RES) (Lagally, 2016; Tabata, 1996) and perform their post-FRT while utilizing the same procedures.

Treadmill Condition

Following the two-minute warm-up, participants were given a one-minute rest. The treadmill was then set at 9 miles·hour^{-1} with a 15% incline (Cunningham, 1969). This protocol was selected since our participants were collegiate athletes who engaged in sports that involved the anaerobic energy system. Previous literature indicated that the sprint test was valid and reliable for measuring anaerobic capacity (Cunningham, 1969). The participants then performed the Cunningham and Faulkner sprint test (Cunningham, 1969) while using the Tabata training protocol (Terry, 2003). Tabata training is a form of high-intensity interval training (HIIT) with a protocol that required participants to complete 20-second bouts of high-intensity sprinting with a 10-second rest period in-between for eight rounds, totaling four-minutes.

Squat Condition

Once the warm-up was completed, participants were given a one-minute rest. Squat depth consisted of participants lowering themselves until thighs were parallel to the ground to maximize the length-tension relationship and ensure adequate binding between actin and myosin contractile filaments. This condition consisted of participants performing 70% of their system mass (Fry, 2014; Luebbers, 2015) at a consistent pace while using the Tabata training protocol (Terry, 2003). System mass was calculated by using the following formula (Fry, 2014; Luebbers, 2015):

$$System\ Mass = ([body\ mass + 1RM] \times 0.70) - body\ mass$$

The 10-second rest did not start until the participant had re-racked the barbell on the squat rack. Fatigue index was assessed by using the Tendo Unit (Tendo Sport, Trencin, Slovak Republic) while the strap was placed on the end to the barbell. The fatigue index was found by using the following formula (Beam, 2019):

$$Fatigue\ Index = [\frac{(highest\ power\ in\ watts - lowest\ power\ in\ watts)}{highest\ power\ in\ watts}] \times 100$$

Vertical Jump Condition

Following the warm-up, participants were given a one-minute rest. This condition consisted of participants performing the repeated vertical jump test (Bosco, 1983) while using the Tabata training protocol (Terry, 2003). The repeated vertical jump test required participants to place their hands on their hips, squat down until 90° and then jump vertically as high as possible, and then land back down with both feet at the same time. Participants would repeat these jumping procedures while jumping continuously while engaging in the Tabata training protocol (Bosco, 1983; Terry, 2003). Participants also had the Tendo Unit strap around their wrist so that data collected could be used to calculate their fatigue index (Beam, 2019).

Statistical Analysis

Data was analyzed using SPSS version 20.0 (SPSS Incorporated, Chicago, IL) with an a-priori α level of ≤ 0.05. Fatigue, OMNI-RES, and fatigue index scores were also compared using independent samples t-tests. Because there were no hypotheses based upon sex and sport, it was not included as an independent variable in the subsequent analysis of variance (ANOVA) model. Three conditions repeated-measures ANOVAs was utilized to examine differences in dynamic balance. Post-hoc analyses for all significant main effects were completed using paired samples t-tests with the Benjamini and Hochberg False Discovery Rate correction (Benjamini, 1995).

RESULTS

FRT Balance Scores

There was a significant ($F = 3.94$, $p = 0.005$) main effect of condition for dynamic balance. Paired samples t-tests revealed that dynamic balance became significantly ($t = 2.21$, $p = 0.04$, $d = 0.59$) worse from pre- to post-testing after completing the vertical *jump* condition (5.24 ± 2.29 and 6.1 ± 1.92, respectively (Figure 1). Paired samples t-tests revealed no significant ($t < 1.75$, $p < 0.19$, $d < 0.21$) differences in dynamic balance from pre- to post-testing after performing the treadmill *sprint* (5.68 ± 1.68 and 6.28 ± 2.06, respectively) and barbell *squat* (5.18 ± 1.64 and 5.69 ± 1.81,respectively) conditions (Figure 1). There was a 16.41%, 10.56%, and 9.85% worsening of dynamic balance after performing the vertical *jump*, treadmill *sprint*, and barbell *squat* conditions, respectively.

Fatigue Scores

Independent samples t-tests revealed a significantly

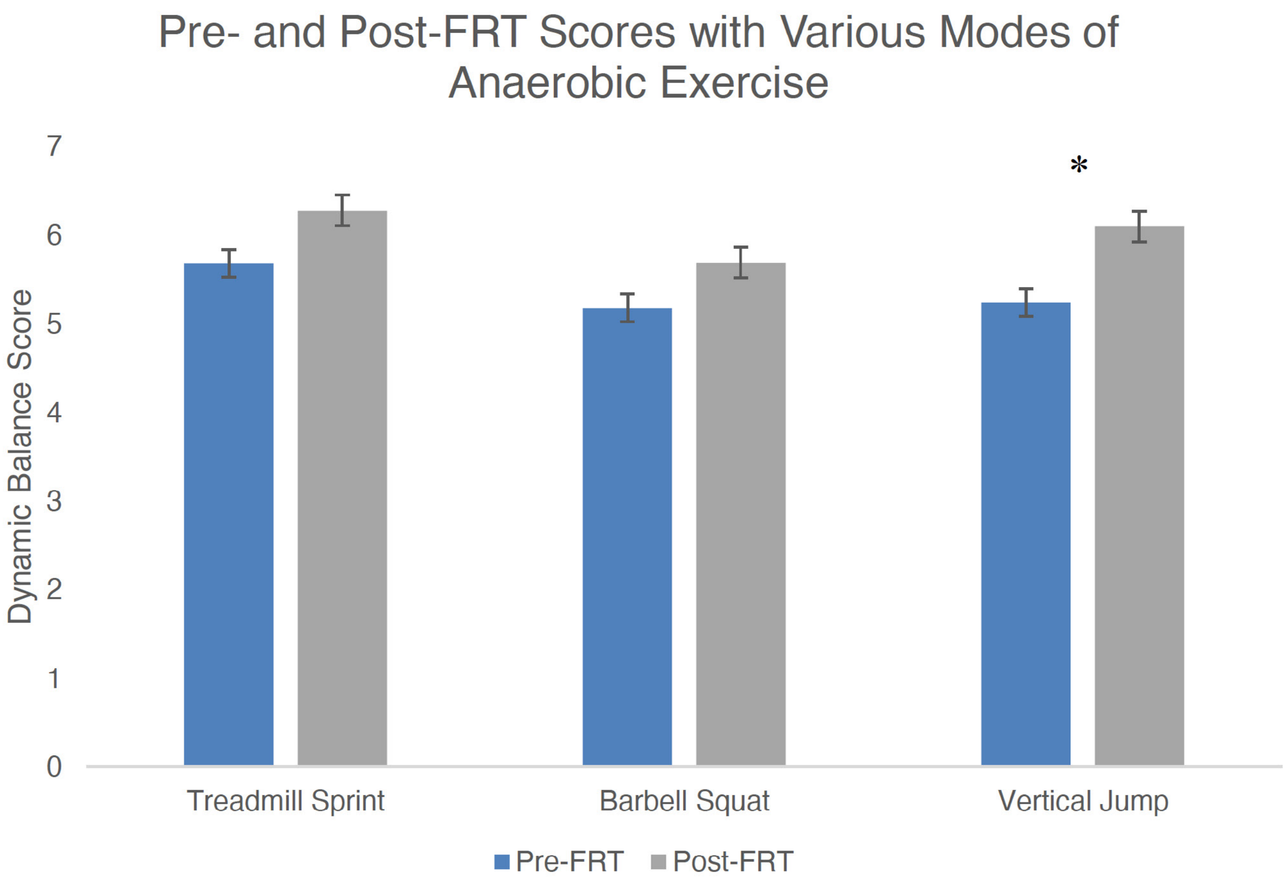

Figure 1. Pre- and post-FRT dynamic balance scores between the various modes of anaerobic exercise (treadmill *sprint*, barbell *squat*, and vertical *jump*) conditions.
*FRT balance score significantly ($p = 0.04$) worsened from pre- to post-testing after completing the *vertical jump* condition.

($t < 2.44$, $p < 0.02$, $d < 0.67$) higher fatigue score for the treadmill *sprint* (7.35 ± 1.55) condition when compared to both the barbell *squat* (5.52 ± 1.81) and vertical *jump* (6.16 ± 1.88) conditions. There was no significant ($t = 1.23$, $p = 0.23$, $d = 0.2$) difference between the barbell *squat* and vertical *jump* conditions. A higher fatigue score indicated a greater amount of perceived fatigue.

OMNI-RES Scores

Independent samples t-tests revealed no significant ($t < 4.64$, $p < 3.4$, $d < 0.09$) differences in OMNI-RES scores for the treadmill *sprint* (7.9 ± 1.35; hard) condition when compared to both the barbell *squat* (5.4 ± 1.76; somewhat hard) and vertical *jump* (5.66 ± 2; somewhat hard) conditions. A higher OMNI-RES score indicated a greater amount of perceived exertion. OMNI-RES scores were 8.8 ± 0.9 for males and 8.4 ± 1.1 at 90% 1RM in a study conducted by Lagally and Robertson (18). Relating this to our findings, it can be said that the participants did not perceive the three protocols to be as intense as lifting 90% of their 1RM.

Fatigue Index Scores

Independent samples t-tests revealed no significant ($t < 6.04$, $p < 2.14$, $d < 0.11$) difference in fatigue index scores between the barbell *squat* (48.03 ± 13.38) and vertical *jump* (70.12 ± 12.44) conditions. The fatigue index indicates the rate at which power output declines for an athlete, with a higher rate correlating with a decreased ability of athletes to maintain power (Inbar, 1996). According to a study conducted by Atan (1), the Wingate Anaerobic Test (WAnT) resulted in a 77.8 ± 10.2 fatigue index score. Relating this finding to our findings, it can be said that the vertical *jump* condition induced similar, but not as much fatigue as the WAnT protocol.

DISCUSSION

This study utilized a between-participants design to compare the effects of various modes of high-intensity anaerobic exercise on dynamic balance performance. There have been studies that have examined dynamic balance training programs on injury prevention (Davlin, 2004; Hrysomallis, 2011; Hrysomallis) and how muscle fatigue affects balance (Cetin, 2008; Inoue, 2013), but to the best of our knowledge there have been no studies that have investigated how different modes of high-intensity anaerobic exercise effects dynamic balance performance. These modes of high-intensity anaerobic exercise resemble sport-specific movements (e.g., sprinting and jumping) that are commonly executed by athletes during competitive play (e.g., sprinting to first base, jumping for a rebound, etc.). These previous studies came to similar conclusions finding that muscle fatigue affects balance; however, these studies induced muscle fatigue by having participants engage in stairclimbing exercise and isometric contractions (Cetin, 2008; Inoue, 2013). This is where the current study comes in and focuses on sport-specific movements and investigates how these modes of high-intensity anaerobic exercise affects dynamic balance performance, which is crucial for sport performance (Powers, 2011) and injury risk (Davlin, 2004; Hrysomallis, 2011; Hrysomallis, 2007).

There was a 16.41%, 10.56%, and 9.85% worsening of dynamic balance after performing the vertical *jump*, treadmill *sprint*, and barbell *squat* conditions, respectively. It was originally hypothesized that the dynamic balance would become significantly worse from pre- to post-testing after completing the *sprinting* condition, followed by the *squatting* condition, and then the *jumping* condition. Our findings do not agree with our original hypothesis, but valuable information was still acquired on how these sport-specific movements affect dynamic balance. In previous studies, Cetin (2008) and Inoue and colleagues (2013) implemented exercises that were aimed at fatiguing muscles associated with the calves, hamstrings, quadriceps, and glutes. It was demonstrated in both of these studies that when these muscle groups were fatigued, balance performance worsened. These same muscle groups were recruited during the modes of high-intensity anaerobic exercise that were implemented in the current study contributing to muscle fatigue and negatively affecting dynamic balance; however, this still does not explain why greater disturbances in dynamic balance from pre- to post-testing were seen in the vertical *jump* condition. When examining the protocols that were implemented, more repetitions were performed by the participants in the vertical *jump* condition than the barbell *squat* condition, so this could have led to greater muscle fatigue in the vertical *jump* condition when compared to the barbell *squat* condition. Also, sprinting is considered a whole-body movement in which athletes can use their upper-body to generate momentum, maintain body balance, and counterbalance the vertical angular momentum of the lower extremities (Hamner, 2010; Hinrichs, et al, 1987; Hinrichs, 1987; Potteiger, 2011). These above-mentioned reasons may explain why the vertical *jump* condition was the only condition that had a significantly worse dynamic balance performance from pre- to post-testing when compared to the treadmill *sprint* and barbell *squat* conditions.

While the current study does provide useful information, it is not without limitations. Student-athlete participants were recruited from a variety of sports (e.g., baseball, basketball, cheer and stunt, football, soccer, and volleyball) to participate in this study. This was considered a limitation because depending on the sport season, student-athletes were engaging in workouts, practices, and/or competitions. This means that some of the student-athlete participants were only engaging in workouts while others may have been engaging in workouts, practices, and competitions. To control this, participants were asked to refrain from strenuous activity 48-hours prior to each condition; however, the concern was still there for those student-athlete participants who were engaging in workouts, practices, and competitions and being at an increased risk for overreaching and having performance decrements. Future research should consider only recruiting fall or spring sport student-athletes and/or utilizing objective and/or subjective tools (e.g., Recovery Stress Questionnaire, Profile of Mood States, etc.) to determine if participants are experiencing negative effects of overreaching (Kellmann, 2001; Yaggie, 2006). Another limitation was the use of the fatigue visual analog scale and the adult OMNI-resistance exercise rating of perceived exertion scale (OMNI-RES) (Lagally, 2006; Tabata, 1996) to determine the extent of muscle fatigue after each of the three test conditions. This was considered a limitation because even though these scales have been validated and scores compared to previous studies (Lagally, 2006; Tabata, 1996) to determine the extent of muscle fatigue, electromyography (EMG) could be used with the fatigue index scores to assess muscle fatigue. This would provide an objective assessment of muscle fatigue.

PRACTICAL APPLICATIONS

Dynamic balance plays an important role in sport performance and injury prevention. This study allows strength and conditioning professionals and coaches to understand how different modes of high-intensity anaerobic exercise affects dynamic balance. As described previously, balance in sport is largely a product of one's proprioceptive capability. As suggested by our results, fatigue generated during exertion may have a role in acute proprioceptive decline during activity, manifesting itself as hindered postural stability (Abd-Elfattah, 2015). Postural stability is crucial for forming cohesive motor patterns such as those executed during sport, and also for preventing or correcting errors in motor patterns. The relationship between proprioception and postural stability is profound, with deficient proprioception having utility as a predictor of injury risk in sport (Payne, 1997). This also allows strength and conditioning professionals to develop training programs aimed at allowing athletes to better withstand fatigue and be able to maintain their dynamic balance and sport performance, while decreasing their risk for injury. Perhaps utilizing the protocols mentioned in this manuscript should be further investigated to allow professionals to better understand training adaptations that may occur (e.g., delayed onset of fatigue).

DISCLOSURE OF FUNDING RECEIVED:

No funding was provided for this study

REFERENCES

1. Abd-Elfattah, H.M., Abdelazeim, F.H. and Elshennawy, S. (2015) "Physical and cognitive consequences of fatigue: A Review," Journal of Advanced Research, 6(3), pp. 351–358. Available at: https://doi.org/10.1016/j.jare.2015.01.011.
2. Aman, J.E. et al. (2015) "The effectiveness of proprioceptive training for improving motor function: A systematic review," Frontiers in Human Neuroscience, 8. Available at: https://doi.org/10.3389/fnhum.2014.01075.
3. Atan, T. (2013) "EFFECT OF MUSIC ON ANAEROBIC EXERCISE PERFORMANCE," Biology of Sport, 30(1), pp. 35–39. Available at: https://doi.org/10.5604/20831862.1029819.
4. Beam, W.C. and Adams, G.M. (2023) Exercise physiology: Laboratory manual. New York: McGraw Hill.
5. Benjamini, Y. and Hochberg, Y. (1995) "Controlling the false discovery rate: A practical and powerful approach to multiple testing," Journal of the Royal Statistical Society: Series B (Methodological), 57(1), pp. 289–300. Available at: https://doi.org/10.1111/j.2517-6161.1995.tb02031.x.
6. Bosco, C., Luhtanen, P. and Komi, P.V. (1983) "A simple method for measurement of mechanical power in jumping," European Journal of Applied Physiology and Occupational Physiology, 50(2), pp. 273–282. Available at: https://doi.org/10.1007/bf00422166.
7. Cetin, N. et al. (2008) "Effects of lower-extremity and

trunk muscle fatigue on balance," The Open Sports Medicine Journal, 2(1), pp. 16–22. Available at: https://doi.org/10.2174/1874387000802010016.
8. Cunnningham, D. and Faulkner, J. (1969) "The effect of training on aerobic and anaerobic metabolism during a short exhaustive run," Medicine & Science in Sports & Exercise, 1(2). Available at: https://doi.org/10.1249/00005768-196906000-00002.
9. Davlin, C.D. (2004) "Dynamic balance in high level athletes," Perceptual and Motor Skills, 98(3), pp. 1171–1176. Available at: https://doi.org/10.2466/pms.98.3.1171-1176.
10. Fry, A.C. et al. (2014) "Kansas Squat Test," Journal of Strength and Conditioning Research, 28(3), pp. 630–635. Available at: https://doi.org/10.1519/jsc.0b013e3182a0cb23.
11. Haff, G. and Triplett, T. (eds) (2016) Essentials of strength training and conditioning. 4th edn. Champaign, IL : Human Kinetics.
12. Hamner, S.R., Seth, A. and Delp, S.L. (2010) "Muscle contributions to propulsion and support during running," Journal of Biomechanics, 43(14), pp. 2709–2716. Available at: https://doi.org/10.1016/j.jbiomech.2010.06.025.
13. Hinrichs, R.N., Cavanagh, P.R. and Williams, K.R. (1987) "Upper Extremity function in running. I: Center of mass and propulsion considerations," International Journal of Sport Biomechanics, 3(3), pp. 222–241. Available at: https://doi.org/10.1123/ijsb.3.3.222.
14. Hinrichs, R.N. (1987) "Upper Extremity function in running. II: Angular momentum considerations," International Journal of Sport Biomechanics, 3(3), pp. 242–263. Available at: https://doi.org/10.1123/ijsb.3.3.242.
15. Hrysomallis, C. (2011) "Balance ability and athletic performance," Sports Medicine, 41(3), pp. 221–232. Available at: https://doi.org/10.2165/11538560-000000000-00000.
16. Hrysomallis, C. (2007) "Relationship between balance ability, training and sports injury risk," Sports Medicine, 37(6), pp. 547–556. Available at: https://doi.org/10.2165/00007256-200737060-00007.
17. Inbar, O., Bar-Or, O. and Skinner, J.S. (1996) The Wingate Anaerobic Test. Champaign, IL: Human Kinetics.
18. Inoue, K. et al. (2013) "Influence of lower limb muscle fatigue on balance function," Journal of Physical Therapy Science, 25(3), pp. 331–335. Available at: https://doi.org/10.1589/jpts.25.331.
19. Kellmann, M. and Kallus, K.W. (2001) Recovery-stress questionnaire for athletes: User Manual. Champaign, IL: Human Kinetics.
20. Lagally, K.M. and Robertson, R.J. (2006) "Construct validity of the Omni Resistance Exercise Scale," The Journal of Strength and Conditioning Research, 20(2), pp. 252–256. Available at: https://doi.org/10.1519/r-17224.1.
21. Luebbers, P.E. and Fry, A.C. (2015) "The Kansas squat test," Journal of Strength and Conditioning Research, 29(10), pp. 2716–2722. Available at: https://doi.org/10.1519/jsc.0000000000000929.
22. Navalta, J., Stone, W. and Lions, T.S. (2020) "Ethical Issues Relating to Scientific Discovery in Exercise Science," International Journal of Exercise Science, 12(1), pp. 1–8.
23. Payne, K., Berg, K. and Latin, R. (1997) "Ankle Injuries and Ankle Strength, Flexibility, and Proprioception in College Basketball Players," Journal of Athletic Training, 32(3), pp. 221–225.
24. Pontzer, H. et al. (2009) "Control and function of arm swing in human walking and running," Journal of Experimental Biology, 212(6), pp. 523–534. Available at: https://doi.org/10.1242/jeb.030478.
25. Potteiger, J.A. (2011) ACSM's introduction to exercise science. Wolters Kluwer.
26. Powers, S.K., Howley, E.T. and Quindry, J. (2011) Exercise physiology: Theory and application to fitness and performance. New York, NY: McGraw Hill.
27. Proske, U. and Gandevia, S.C. (2012) "The proprioceptive senses: Their roles in signaling body shape, body position and movement, and Muscle Force," Physiological Reviews, 92(4), pp. 1651–1697. Available at: https://doi.org/10.1152/physrev.00048.2011.
28. Ricotti, L. (2011) "Static and dynamic balance in young athletes", Journal of Human Sport and Exercise, 6(4), pp. 616–628. doi: 10.4100/jhse.2011.64.05.
29. Robertson, R.J. et al. (2003) "Concurrent validation of the OMNI perceived exertion scale for resistance exercise," Medicine & Science in Sports & Exercise, 35(2), pp. 333–341. Available at: https://doi.org/10.1249/01.mss.0000048831.15016.2a.
30. Tabata, I. et al. (1996) "Effects of moderate-intensity endurance and high-intensity intermittent training on anaerobic capacity and ??vo2max," Medicine & Science in Sports & Exercise, 28(10), pp. 1327–1330. Available at: https://doi.org/10.1097/00005768-199610000-00018.
31. Terry, P.C., Lane, A.M. and Fogarty, G.J. (2003) "Construct validity of the profile of mood states — adolescents for use with adults," Psychology of Sport and Exercise, 4(2), pp. 125–139. Available at: https://doi.org/10.1016/s1469-0292(01)00035-8.
32. Yaggie, J.A. and Campbell, B.M. (2006) "Effects of balance training on selected skills," The Journal of Strength and Conditioning Research, 20(2), p. 422. Available at: https://doi.org/10.1519/r-17294.1.