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The Prevalence and Efficacy of Cross-training in a Professional Ballet Environment: A Literature Review

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Abstract

Fear of ruining the aesthetic integrity of the ideal "ballet body" once barred many dancers from cross-training for endurance and strength, but evidence suggests that these concerns are largely unsubstantiated, and several major dance companies have started integrating supplementary training into their class and rehearsal regimens. Ballet-specific risk factors, busy performance schedules, and the disparity between class and performance demands all limit the extent to which fitness training can be incorporated into professional environments. In addition, the applicability of objective technique analysis in subjective sports and a lack of reliable research within the population of interest have constrained the development of coordinated systems of care amongst medical and artistic professionals. However, other sports set the standard for the future of a field which is progressing in the hands of pioneering experts across the globe.

In this thesis, I will use a detailed literature review to outline the anticipated effects of a multifaceted cross-training program on the strength and endurance of professional ballet dancers and make suggestions for further research as it relates to the prevention of overuse injuries, the unique demands of ballet, and the periodization of training. These recommendations will be based upon the standards set by other sports as well as the opinions of current professionals who work within the confines of an emerging field.

Table of Contents

Introduction

In the early 1400s, ballet was conceptualized as a form of theatrical entertainment for Italian and French nobility. What is now celebrated as a fusion of intense athleticism and art was lauded as a storytelling medium through which men in elaborate costumes reenacted borrowed tales of ancient mythology as guests of the rich. It wasn't until the middle of the 17th century, when opera houses and theatres gained prominence in Europe, that ballet expanded beyond the confines of imperial ballrooms and challenged both the physical and thematic expectations from which it began. Along with the advent of pointe shoes and increasing visibility of female dancers during social upheavals of the French Revolution, this shift from palaces to the stage redefined antiquated conceptions of ballet[1] which ultimately grew into a more physical form of expression. Because public theatres were not as intimate as the royal courts of King Louis XIV, dancers adapted their choreography to be more well received by larger audiences. They jumped higher, turned out through wider ranges of motion, performed more consecutive turns, and attempted more demanding partner lifts. This increase in the physicality of performance necessitated a greater emphasis on physical fitness overall[2] and ultimately catalyzed the birth of dance medicine.

A far cry from its earliest days, modern dance science is a field that comprises talented medical and artistic professionals who collaborate to provide quality health services aimed specifically at dancers. It is a relatively young and niche profession, only receiving public recognition in 1990 when its pioneering agency, the International Association for Dance Medicine and Science (IADMS), was founded. Since then, IADMS has grown to include more than 900 members, and its influence has spread to nearly forty countries. Committed to "enhanc[ing] the health, well-being, training, and performance of dancers by cultivating medical, scientific, and educational excellence"[3], the group serves as a precedent for future agencies dedicated to understanding and treating the unique injury risk factors associated with dance.

For as long as medical professionals have worked with ballet dancers, they have recognized the need for tailored research. Though ballet has traditionally received far less attention than more common methods of exercise, it is gaining more traction in sports physiotherapy and related fields. While regularly scheduled classes and rehearsals were once considered sufficient enough to promote optimal performance, recent data have warranted a closer look at the credibility of such assumptions, suggesting that cross-training plays an integral role in both injury prevention and performance enhancement. The cost of time off due to injury in terms of both financial and human capital, disparity between the physicality of class and performance, and distinct technical standards associated with ballet justify the need for specialized training. In this thesis, I will use a detailed literature review to outline the anticipated effects of a multifaceted cross-training program on the strength and endurance of professional ballet dancers and make suggestions for further research as it relates to the prevention of overuse injuries, the unique demands of ballet, and the periodization of training. These recommendations will be based upon the standards set by other sports as well as the opinions of current professionals who work within the confines of an emerging field.

Aesthetics

Nico Kolokythas, ASCC, PhD, acting performance enhancement coach for the Elmhurst Ballet School and strength consultant for the associated Birmingham Royal Ballet, is a current leader in dance science research. He encapsulated the need for supplementary training in a personal interview when he emphasized that dancers must focus on conditioning their bodies for what they do rather than using what they do to condition their bodies. In doing so, Dr. Kolokythas alluded to a pervasive misconception in the dance community that resistance training induces muscular hypertrophy and ruins the aesthetic integrity of the "ideal ballet body". The desire to maintain a lean physique at the expense of gaining strength is one consequence of the subjective nature of ballet and one of many factors that contributes to the acceptance- or lack thereof- of cross-training today. However, a growing emphasis on functionality has helped curtail this fear. According to lead physiotherapist of the Australian Ballet, Susan Mayes, AM, PT, PhD, the marketing departments of major companies like hers are beginning to promote strong, athletic body types, and the Birmingham Royal Ballet, Australian Ballet, and Alvin Ailey company are among those who are beginning to incorporate cross-training into their regimens.

While these changes are necessary and welcomed, the tradeoff between appearance and functionality might not be as drastic as we think. Twenty-four professional and vocational contemporary dancers participated in a 6-week exercise intervention study in which the experimental group completed two 1-hour circuit training sessions per week. The circuit consisted of a succession of 9-12 workouts performed for 15-45 seconds with 0-30 seconds of rest in between. Exercises included "jumps with feet in parallel position (using a jumping rope), press-ups, bicep curls, triceps extension (with free weights of 0.5 kg each), single leg squat, squats-jumps, heel-rises in dance first position, deep squats in dance second position, chest press exercises (with free weights of 0.5 kg each), and planks"[4], in addition to whole-body vibration training. While it may come as no surprise that dancers in the experimental group gained lower body muscular power, upper body muscular endurance, aerobic fitness, and aesthetic competence, it was particularly interesting to note that dancers in the control group actually reported lower "aesthetic competency" scores than those who engaged in cross-training[4]. Though admittedly preliminary and lacking in scientific validation, these results tentatively suggest that supplementary training protects aesthetics more than it threatens them. While this study did not address my specific population of interest, its implications can still encourage the implementation of cross-training and guide exercise intervention design in terms of both the specific movements used and the structure of the workout as a whole.

In another study conducted in 2009, Angioi et al. compared the results of physical fitness tests with aesthetic competence assessments commonly cited by contemporary dance companies as factors in hiring decisions[5]. Seven of the most common auditioning criteria for companies in the United States, United Kingdom, and Australia were evaluated on 10-digit Likert scales for a total aesthetic competence score of 70. Two dance teachers were recruited to judge six professional contemporary dancers who had 20 minutes to learn and five minutes to practice a 60-second piece of choreography. Performances were videotaped and copied so that both judges watched all six dancers three separate times for a total of 18 trials. Showing blinded copies of the same videos ensured intra-test-retest reliability while comparing the scores of both judges addressed issues of inter-rater reliability. After the precedent was set, 17 dancers were recruited for the association study in which they were graded on several fitness parameters defined by the British Association for Sport and Exercise Sciences and the American College of Sport Medicine. Anthropometric measures like height and total body mass were measured along with flexibility, muscular power, muscular endurance, and aerobic capacity through a mix of dance-specific (développé à la seconde for active range of motion versus flexibility in the hip) and generalized (maximum push-up count and plank hold for muscular endurance) fitness tests.

Then, each dancer in the experimental group completed an aesthetic competence test similar to the one administered to the six initial dancers. All 17 participants learned a 90-second piece of choreography that was judged by one professional. Statistical analysis revealed that the aesthetic competence test developed in the initial phase of the study is reliable and that upper body muscular endurance and lower body muscular power (as determined by the push-up test and jump ability test respectively) were both predictive of aesthetic competence. While Angioi et al. admit that, "contemporary dance is characterized by a greater variety of technical demands imposed by choreographers during performance"[5] than classical ballet, the study still sets a precedent for the way we might rate performance and test performance enhancement in the future.

Risk factors

Studies that exemplify the way in which we might make subjective measures of dance more quantifiable are constrained by the complex nature of ballet. Dr. Adrian Lees, professor of sport biomechanics at Józef Piłsudski University of Physical Education in Warsaw, warns that performance quality is multifactorial and should not be attributed solely to technique, regardless of the sport[6]. Campbell et al. address this idea specifically as it relates to dance when they cite hypermobility, degree of turnout, neuromuscular dysfunction, weakness of core and lower extremity muscles, range of motion in the lower extremities, fatigue, and overuse as intrinsic modifiable injury risk factors unique to ballet dancers[7]. General joint hypermobility (GJH) can be hereditary or acquired and is seen in 66% of dancers as opposed to 29% of non-dancers. GJH leads to unequal force distribution and "laxity of structures"[7] within the joints that induces chronic ankle instability, anterior cruciate ligament (ACL) injuries, tendinopathies, general joint degeneration, and hip instability. Defined as the degree of external rotation in the hips, knees, and ankles, turnout is an integral component of ballet. Dancers are more susceptible to lower extremity injuries when they overtax their natural, anatomical turnout with repetitive stretching and stress. Campbell et al. refer back to the aesthetic demands of ballet, admitting that, "while the ability to have extensive external rotation is an essential component to the aesthetics of ballet dance, forcing the range of this motion stretches the capsular structures that can lead to painful injuries within the hip"[7]. Excessive turnout induces pelvis tilting (a postural fault that Dr. Mayes has specifically addressed at the Australian Ballet, though she actually endorses a slight anterior tilt). In addition, dancers often attempt to overcome turnout limitations by contorting the angles in their knees, heels, feet, and spine. Dancers who compensate in these ways are 9% more likely to get injured[7].

When it comes to fatigue, compensation also alters neuromuscular functioning. Deficits in proprioception, balance, strength, and overall movement affect landing and twisting mechanics and induce injuries while jumping and turning. Neuromuscular dysfunction is exacerbated by weakness, especially in the lower extremity and core, and often plays a role in range of motion discrepancies. Finally, the "rigor, volume, and demands of practice and performance"[7] for dancers leads to fatigue and overuse. In fact, over the course of an average 9-hour workday, 90% of female ballet dancers received less than 60 minutes of rest (defined as exertion below 1.5 metabolic equivalents (METS)), and one third of them received less than 20 consecutive minutes[7]. Most professionals have technique classes and several hours of rehearsals or performances each day, "rendering them more liable to suffer from injuries and even permanent disabilities than most sport competitors"[8].

Regardless of intensity, professionals work at a high volume, often dancing between six and eight hours a day in rehearsal periods and up to ten hours a day in performance periods. Typical performance schedules comprise eight performances a week for four to eight weeks in addition to daily classes and rehearsals[9]. Dancers in a 2005 injury intervention study performed 145 times in 15 different shows in year one, 143 times in 18 different shows in year two, and 142 times in 20 different shows in year three[10]. While the number of annual performances plays an obvious role in short-term fatigue, Vice President of IADMS, Cofounder and Medical Director of SeaPAM Performing Arts Monthly Clinic, and Consulting Physician with Pacific Northwest Ballet (PNB), orthopedic surgeon, Nancy Kadel, MD, pointed out the long-term impact of preparing for and performing multiple different shows throughout the season in a personal interview. For example, while a company is performing the Nutcracker in the winter, they are also rehearsing for a modern piece that debuts in the spring. The disparate demands of two different styles of dance and the increasing complexity of choreography as a whole both increase the likelihood of injury.

Much like neuromuscular dysfunction[7], this kind of fatigue interferes with proper landing mechanics which explains the disproportionate number of lower extremity injuries that occur later in the day or later in the season. Regardless of when they occur, research has shown that 75% of ballet injuries are related to overuse compared to just 21.7% of injuries in other elite sports[7], but Allen et al. specifically cite injuries occurring at the end of rehearsals to justify strength and endurance conditioning[10]. Because of the influence of fatigue on injury incidence, a focus on physical fitness will only be beneficial if it can be implemented within a periodized framework.

Periodization

Athletic periodization is the segmentation of yearly training schedules into several smaller, more easily managed phases which can be categorized as preparatory, competitive, or off-season. The methodology has played an important role in the highest level of sport and can be traced back to the ancient Greek Olympians. It was conceptualized by two Soviet physicians, Mateev and Ozolin, who defined it as a means of "reach[ing] a high level of performance and 'athletic shape' at a given time"[9], so that the athlete peaks during competition or performance. Periodization attempts to coordinate multiple facets of training including adaptation, skill development, and climate so as to promote peak performance when it matters most. The preparatory phase should consist of a training program that maximizes neuromuscular and cardiorespiratory adaptation, strength, speed, endurance, and technical skill. In the first third of the phase, non-specific training is emphasized. In the latter two-thirds of the phase, sport-specific training is implemented. Because athletes are not faced with the stress of competition, this phase of intense work provides the foundation for competitive peaks when fatigue is more of a risk factor. Resistance against fatigue protects against injury and promotes psychological health, as physical exhaustion "affects [an athlete's] visualization, concentration capabilities, focusing, and motivation"[11]. Intensity of training is directly correlated with stress, so longer, less demanding pre-competition periods are more effective than more demanding ones.

The first periodization model was based upon the cyclic timeline of the Olympic Games and allowed for one competition phase, but modern renditions are more nuanced and apply the same concepts to more complex competition schedules. Track and field athletes employ a bi-cyclic, or double-peaking, plan to accommodate both indoor and outdoor seasons. Swimmers follow similar patterns for short and long course training, while wrestlers, boxers, and martial artists often use tri-cyclic plans. It is harder to periodize for sports that require multiple peaks each year[11], which is often the case with individual sports like ballet. Bompa suggests that overtraining and associated overuse injuries can be avoided by prioritizing the planned peaks that correlate with championships. At the very least, dancers can avoid challenging workouts directly following taxing performances, relax for at least two weeks after performance phases, and structure micro-cycles with principles of step loading methodology which suggests a chronological progression of low, medium, high, and low intensity training sessions over the course of the week[11].

The degree to which these recommendations can be implemented in a professional ballet environment is constrained by the performance schedules of companies. But periodization should be used because of these risk factors, not in spite of them. Wyon notes that it is a necessary consideration for dancers in light of the increasing complexity of both choreography and performance schedules and that it promotes physiological, psychological, and biomechanical health in addition to skill[9]. Because of the busy schedules of most professional ballet dancers, Wyon specifically suggests the method of block periodization, which was proposed by Yuri Verkhoshansky, a well-known sports scientist whose work has been applied to Olympic training cycles. In the first “block”, athletes work at a high volume, low work power ratio to improve motor potential and functional specialization. In “blocks” B and C, athletes increase their work power at the expense of training volume[12] (Appendix A). Nonspecific periodization models have been validated through several studies which determined that periodized athletes performed better than those who did not coordinate their training and competition schedules. Mateev and Ozolin suggest that a 3%-6% increase in training load followed by a period of tapering right before performance or competition is necessary to induce “supercompensation of the energy stores, neural and cellular recovery of the musculoskeletal systems, and an increase in strength and power”[9].

In an effort to accommodate these recommendations, Wyon suggests that if performances start on Saturday, Wednesday would be the last day of normal rehearsals with high intensity and moderate volume. On Thursday, Friday, and Saturday, intensity would increase while volume significantly decreased. Thursday and Friday mornings would consist of a short technique class, dress rehearsal, and film review with short rehearsals of any specific problem areas determined through video assessment. Imagery is a powerful tool to use, especially when closer to performance, as it increases performance quality without an associated increase in training quantity. In general, supplemental training can be justified up until the last two weeks before a performance in which it should decline in volume, before stopping completely one week out so as to compensate for increased rehearsal time. As the volume of cross-training decreases, intensity can either remain the same or increase. Tapering methods similar to those proposed by Wyon benefited dancers’ physiological performance and decreased mood disturbances in one dance company by 50%[9], though the potential for tapering to induce boredom and a fear of losing one’s place within the company are two potential externalities that deserve further investigation.

While periodization should factor into weekly scheduling, it can also be applied to performance days which should be treated as microcosms of the performance season as a whole. For a show that starts at 8:00 pm, an hour-long warm-up class from 10:00 to 11:00 am would be followed by rehearsals from 11:30 to 3:00 pm, a meal at 4:00 or 5:00 pm, and a 20-minute warm-up just prior to performance[9].

Wyon is careful to warn that while Verkhoshansky's model promotes aerobic, anaerobic, strength, power, and flexibility gains simultaneously, companies should specifically emphasize those factors which are most relevant to the performance in question. He also stipulates that dancer fitness and company rank should be considered when formulating a periodization schedule for individual dancers that fits within the general plan of the company. These unique factors, which set dance apart from other sports that take advantage of periodization techniques, will also serve as barriers to the proper and effective application of such principles in a real-world context. In fact, Wyon admits that his advice is based off of experience and theory as "only a few dance companies have implemented this methodology into their planning and scheduling"[9], providing yet another reason to heed the advice of Dr. Mayes, Dr. Kolokythas, and Dr. Kadel who stress the need for more randomized controlled trials within professional environments.

Energy expenditure

While the evidence to support specific recommendations is lacking, it is clear that dancers rarely maximize their physiological exertion during performances- in part because it is noncompetitive, and exercise intensity is determined by choreographers instead of the athletes themselves[13]. In addition, many studies have suggested that technique classes, rehearsals, and performances do not stimulate cardiovascular endurance in a significant way, comparing the aerobic fitness of dancers to that of non-endurance athletes. In fact, research suggests that dancers more closely resemble athletes in "power-based sports where there is a predominant anaerobic component"[13]. Some data have alluded to a thickening of the left ventricular wall of the heart in dancers compared to a control group, but there was no associated increase in ventricular volume that would be indicative of increased aerobic fitness. Authors suggest that this is a product of the dual isometric-isotonic demands of ballet[13]. This sentiment is shared by Twitchett, Koutedakis, and Wyon who compared the physical demands of ballet class, ballet performance, and other athletic events in order to argue that dancers are actually less physically fit than most other athletes, relying on skill instead of strength to carry them through intense training and performance schedules[2]. Wyon and Moita et al. both concur, warning that professional dancers often exhibit fitness levels comparable to sedentary adults of similar ages[9,14]."The repetitive nature of dance movement patterns in classes and rehearsals"[14] without adequate rest in between[7] leads to fatigue which promotes a lack of proper alignment as skill is undermined[14]. This issue is exacerbated by intense choreography and performance schedules that are only supplemented with more dance. Like rhythmic gymnastics, dance views physical strength as a means to the successful demonstration of sophisticated skill patterns rather than as an end within itself. Both classical ballet and contemporary dance use rehearsals to prepare for performance, despite the disparity between the physical stresses of rehearsal and those of performance which stimulate fast glycolytic and aerobic systems to a much greater degree. This disparity is demonstrated by proven increases in aerobic fitness during performance seasons as compared to preparatory periods[15].

Cohen et al. recorded the VO2 max of fifteen American Ballet Theatre dancers (seven men and eight women between the ages of 20 and 30) during treadmill running and a typical 1-hour ballet class consisting of 28 minutes of barre exercises and 32 minutes of center floor exercises. Measured in beats/min (bpm), heart rate (HR) data from eight of the dancers who underwent maximal treadmill running tests revealed that the average VO2 max reached was 48.2 ml/kg/min for men and 43.7 ml/kg/min for women. HR data from ten of the dancers who took the standard ballet class showed that the average VO2 reached during barre was only 38% of VO2 max as measured by the treadmill test (18.5 ml/kg/min for men and 16.5 ml/kg/min for women). Not surprisingly, VO2 averages for center exercises were higher in both genders (26.3 ml/kg/min for men and 20.1 ml/kg/min for women). However, these values were only 55% and 46% of max VO2 for men and women respectively. The training sensitive zone is the HR range which induces increased aerobic fitness and is commonly considered to be 70% of max HR within the wellness community. Cohen et al.'s data indicate that dancers' HR did not meet or exceed this benchmark for any significant period of time during barre. While men reached a peak HR of 178 bpm (92% of HR max) and women peaked at 158 bpm (85% of HR max), these elevated states were only maintained for brief periods of time[16]. Thus, the commonly cited caveat that longer exercise duration might compensate for lower maximal HR does not apply.

Barre is comprised of consecutive 4 to 5-minute periods of low-intensity exercise that stimulate the aerobic system with average HR between 117 and 134 bpm, while center is comprised of alternating periods of intense work (10-40 seconds) and rest (2-5 minutes) which stimulate the anaerobic system to a greater degree in between periods of complete recovery. Performances mirror the intensity of center with the duration of barre (1-4 minutes), recruiting both the glycolytic (aerobic) and glycogenolytic (anaerobic) respiratory systems. While both pathways are normally in use, the intensity of work and muscular demand for ATP determines the ratio of energy production. Two minutes of maximal exercise is generally considered the point at which both pathways contribute 50% of the energy. Beyond that, there is a direct relationship between the duration of exercise and the contribution of the aerobic pathway. Even so, increased aerobic capacity can enhance anaerobic functionality by maximizing rest period recovery. In fact, Wyon suggests that dancers should develop their fast twitch muscle fibers (typically recruited during high-intensity training) and aerobic capacity before rehearsal periods in which they can allow performance preparation to induce cardiovascular gains organically. This training structure demands the implementation of periodization within a three-tier process in which "the first stage develops an aerobic foundation, the second stage facilitates maximal aerobic power, and the third stage develops the fast-glycolytic system"[15].

Wyon emphasizes the aerobic foundation period for its promotion of overall conditioning and ensures that benefits can be gained regardless of whether the training is dance-specific or more generalized as long as intensity remains within 60%-85% of VO2 max and 70%-90% of HR max throughout 20-40-minute sessions. In the second phase, the aerobic power phase, Wyon stresses the importance of raising a dancer's VO2 max threshold as a preventative measure against fatigue-related injury. In this stage, dancers should work within a 1:1 exercise to rest ratio, with each interval lasting between 3-6 minutes and operating within 90%-95% of either VO2 max or HR max. It should be noted that rest periods are periods of low intensity work rather than the cessation of exercise. In the final stage of Wyon's model, dancers should work at supramaximal intensity within an exercise to rest ratio between 1:3 and 1:5, each interval lasting 15-30 seconds[15].

As Wyon has noted; however, a typical dance class or rehearsal does not elicit sufficient stimulation for significant physical adaptations, particularly in terms of muscular strength[14], or aerobic and anaerobic endurance that become necessary during performances[9]. If the first priority of professional dance companies is to adequately prepare every dancer for opening night and maintain that level of readiness throughout the season[9], diversified training programs are an essential component of this bottom line. Angioi et al. demonstrated that dancers who participated in two hours of supplementary training each week did not see a decline in skill or physiological measures as compared to the control group who participated in two hours of technique class instead. In fact, the experimental group saw better outcomes than those who trained exclusively with dance[4]. In making his recommendations, Wyon cites the busy schedules of professional dancers and warns of the potential for overtraining and increased incidence of the very overuse injuries which he is trying to prevent. Thus, he posits that professionals substitute “one or two dance classes a week with physical conditioning as this would have a beneficial effect on the dancers’ underlying physical fitness without interfering or causing a deterioration of skill”[15]. He claims that there would be no loss in skill if dancers maintained a schedule of three classes per week in addition to rehearsal and performance but admits to a lack of evidence to support this claim. In addition, Wyon concedes that three or four weekly sessions might be reduced to one or two weekly sessions when rehearsals or performance are particularly taxing[15], but gives no distinction between regular and intense rehearsal from which the line might be drawn.

Twitchett et al. agree that substituting two or three weekly technique classes with physical conditioning would benefit professionals’ fitness without compromising skill[17]. In order to maximize aerobic and strength gains within the strict limitations imposed by professional ballet schedules, both Rodrigues-Krause et al.[2] and Twitchett et al.[17] recommend high-intensity interval training (HIIT). HIIT closely resembles modern choreography and has the ability to enhance muscle power reserve, muscular endurance, and cardiorespiratory endurance for explosive jumps, allegros, and grand adage respectively[2]. Because HIIT mirrors the demands of modern choreography in which periods of high intensity activity are interspersed with shorter rest periods, training in short bursts of acute activity enhances oxidative metabolic pathways and delays the onset of fatigue[2]. Rodrigues-Krause et al. specifically suggest that a HIIT program “with exercise-rest ratio 1:1, exercise time 3 to 6 min, [at] 90 to 95% of VO2 max, RPE 16 to 17, and active recovery at low aerobic intensity”[2] might be used to reconcile the difference between class and performance.

Company rank

Although researchers rationalize the need for supplementary training by contrasting the disparity between rehearsal and performance as well as the physical deficits of dancers to those of other elite athletes, even dancers of different ranks within the same company exhibit obvious differences in physical fitness[13]. Unlike most other team sport athletes who demonstrate similar cardiovascular endurance to their teammates regardless of playing position; principals, soloists, first artists, and corps dancers display definitive differences in their cardiovascular markers. Forty-nine dancers in a professional touring ballet company participated in a study that demonstrated these disparities. In order to test peak VO2, dancers wore a telemetric gas analyzer while running on a treadmill which increased in speed by 0.5 km/hour every 30 seconds. Each participant started at a predetermined speed (typically between 6 and 8 km/hour) at which their HR reached 120 bpm. Each participant stopped when their oxygen consumption plateaued or when their HR reached a standardized, age-related value. Principal dancers had higher VO2 max values (49.84 ± 4.03 ml/kg/min for men; 47.03 ± 1.65 ml/kg/min for women) than their corps counterparts (49.79 ± 3.59 ml/kg/min for men; 44.57 ±4.19 ml/kg/min for women) when sorted by gender. However, corps dancers had higher VO2 max values than both soloists (47.15 ± 4.15 ml/kg/min for men; 40.50 ± 6.72 ml/kg/min for women) and first artists (46.39 ± 4.97 ml/kg/min for men; 39.04 ±4.72 ml/kg/min for women)[13]. As a means of measuring jump height, participants jumped straight up from a first position plié with both arms at their sides. They repeated the exercise three times from both legs as well as from the left leg only and right leg only and recorded the highest of three jumps for each scenario. As with the cardiovascular data, principal and corps dancers could be grouped by their average jump heights which were noticeably different from those recorded by soloists and first artists. However, principals (50.5 ± 3.79 cm for men; 33.0 ± 1.41 cm for women) and corps (50.8 ± 7.94 cm for men; 37.3 ± 5.63 cm for women) showed lower values than soloists (55.3 ± 4.99 cm for men; 39.2 ± 5.74 cm for women) and first artists (56.0 ± 9.76 cm for men; 39.0 ± 2.82 cm for women). Because self-reported supplemental training was not predictive of either factor, Wyon et al. concluded that VO2 max and vertical jump height are more closely associated with the everyday demands of company rank[13] than with cross training. For example, corps dancers performed more regularly than principals, soloists, and first artists and thus had the highest workload. This was reflected in their increased VO2 max.

Though principals have a lower workload than any of the other three company ranks, their increased VO2 max values are not as contradictory as one might think. Wyon et al. cite the results of another analysis when they suggest that the higher intensity of most principal performances makes up for their lower workload when it comes to cardiovascular training. This finding specifically supports the use of HIIT as a means of increasing aerobic capacity when training volume is constrained by performance schedules, but Wyon et al. note that their study verified both uninterrupted low to moderate intensity exercise (reminiscent of corps choreography) and discontinuous high-intensity exercise (similar to principal choreography) as methods of enhancing aerobic power[13]. In a personal interview, Dr. Mayes promoted the integration of individual training programs for each dancer in her company, suggesting that different modalities are not mutually exclusive.

Although Wyon et al. stipulate that VO2 max and vertical jump height are independent of self-reported supplemental training, both the direct relationship between muscle circumference and leg strength and the correlation between leg strength and jump height suggest otherwise. In fact, Wyon et al. conclude their findings by admitting that supplementary training did not necessarily benefit dancer fitness in this specific study but that “these data can help guide strength and conditioning intervention strategies that need to take into account the nuances of the different seniority levels within a dance company”[13]. Studies have suggested that VO2 is a better measure of dance exercise intensity than HR, but Rodrigues-Kraus et al. warn that inconsistencies between testing methods and movement patterns typically executed by dancers might lead to an underestimation of critical metrics, and lower than expected aerobic capacity might be more indicative of unfamiliar testing modalities than of deficits in fitness[2]. Maximum effort exercise tests like those performed on treadmills or workout bicycles cause “dancers to be biomechanically inefficient, since their particular physical characteristics [such as extreme turn out] may produce pain and discomfort while working to volitional exhaustion, which they are not used to”[2]. While a focus on technical development over progressions in volume and intensity means that dancers typically have lower aerobic capacity and strength than other athletes, “it is widely acknowledged that testing anyone’s cardiorespiratory fitness on a modality with which they are unfamiliar will always produce lower VO2 peak/ VO2 max values”[2]. Twitchett and others have proposed an incremental VO2 max test more appropriate for dancers in which participants perform five stages of sixteen 4-minute tempo dance routines. The first stage would only induce VO2 values similar to those reached in class (22 to 25 ml·kg-1·min-1; 50% of VO2 max). Progressions would work through rehearsal and performance intensity (38 to 43 ml·kg-1·min-1; 85% of VO2 max) and perhaps even further[2].

Perhaps the underestimation of data as a result of problematic measurement techniques suggests that testing protocols ought to be as dance-specific as the interventions they vindicate. Even within dance-specific tests; however, the quality of movement can have a spurious effect on data. In a study done by Tiemens et al., dancers performed the Dance-Specific Aerobic Fitness Test (DAFT) twice, once "as if they were performing [and once with specific instructions to] reduce the quality of movement"[18]. Dancers wore a Polar HR monitor that measured heart rate at each of five DAFT stages as well as one and two minutes after completion. Tiemens et al. found that both perceived and measured exertion were higher during the performance quality trial, suggesting that even dance-specific metrics can deliver disparate results if not implemented carefully. Regardless of the nature of the test, specific instructions are integral to valid findings, lest a lack of effort be perceived as good aerobic fitness. Indeed, while data suggest that muscular strength and power correlate directly with jump ability and overall performance, the credibility of these findings is limited by the aesthetic assessment tools used without prior validity and reliability valuation[4]. An aesthetic competence test used by Angioi et al. consisted of 90 seconds of contemporary choreography performed and filmed before and after an exercise intervention. A dance teacher graded each performance on seven criteria established by the authors with no previous knowledge of control versus experimental group or pre versus post-intervention group[4]. While the findings of the study would be an interesting look at the effect of cross-training on performance enhancement, it would first be critical to assess the parameters by which Angioi et al. determined their intervention to be "dance-specific" or their findings to be valid.

Technique analysis

Dr. Adrian Lees recognizes that studies like these might stake their misleading findings on skill over fitness when he addresses the unique challenges of analyzing technique in subjective sports[6]. When it first showed up in the scientific literature nearly 50 years ago, technique analysis was a qualitative analysis tool for coaches who had little means of objective measurement. Technological advances now permit the collection of kinematic and temporal data with more quantitative methods, though these have been more well received in clinical settings than in applied settings where "the focus is still on the whole movement"[6]. Lees identifies several different means of observation when it comes to measuring technical success. Temporal analysis breaks skills down into their sequential phases and includes the concept of rhythm, an integral component of dance technique. However, both rhythm and dance in general "receive little attention in most sports biomechanics texts"[6]. But, technique analysis is poorly applied in many other sports settings as well. Visual templates of experts performing a specific skill have been used to demonstrate specific movements, but this approach places too much emphasis on technical skill which is not necessarily indicative of correct technique. Several researchers have suggested that biomechanical principles of movement should guide technique analysis, but "there is little detailed agreement as to how [the principles] should be categorized […and] no agreement about what each principle is fundamentally based on"[6], which has complicated any practical applications. Proposed systematic models fall apart when they identify performance factors instead of technique, but statistical models may have more merit, as they allow for the measurement and consideration of joint angle, velocity, and other quantifiable kinematic variables. This kind of analysis sets benchmarks which can be used to measure improvements over time. For example, golfers use hip-shoulder separation and soccer players use pelvic rotation to assess form. Overall, although Lees admits that these variables were selected based upon general principles of movement which have not necessarily been identified as valid inclusion criteria, they serve as an example of what future biomechanical techniques might look like. He also suggests that artificial neural networks and inter/intra-limb coordination might shape the future of quantitative biomechanical analysis[6].

Koutedakis et al. attempted to answer the question of whether the subjective nature of dance can be quantified so as to measure performance enhancement comparatively[19]. They employed a test in which dancers performed parallel sideways jumps, landing on one leg, travelling away from and back towards the center of two concentric circles drawn on the floor spaced 60 and 70 cm and 55 and 65 cm apart for boys and girls respectively. The dancers were instructed to continue jumping in alternate directions until they felt their technique begin to decline with fatigue. Dancers were scored based off of both the number of jump repetitions as well as "artistic competence […] which took into consideration posture and alignment, use and articulation of upper body and arms, lower body and feet, total body coordination, and presentation of movement"[19]. In addition, spatial accuracy was factored into the scores. If dancers returned to the inner concentric circle, one point was deducted, and if they returned to the outer concentric circle, two points were deducted. Of course, the concept of artistic competence itself is controversial in its interpretations, and the reliance on self-perception of technical decline is problematic.

These deficiencies are also exemplified by the criteria with which ballet teachers determine pointe-readiness. Length of dance training and ankle plantar flexion range of motion have long been considered the only major considerations other than a chronological age of at least 12 years. However, Richardson et al. hypothesized that dynamic motion tests are a better means of assessment[20]. To evaluate this theory, Richardson et al. performed nine different tests on thirty-seven New York-based pre-pointe ballet students from 9-17 years old and compared results with subjective teacher ratings of perceived pointe-readiness. The "Pencil Test" and Double-Leg Lower Test measured plantar flexion and core stability. A modified "Romberg" test measured the ability to balance in a flat-footed passé-relevé foot for more than 30 seconds with both eyes closed and exemplified how we might adapt general functional exams to be more dance-specific. Only three tests showed clear association with subjective teacher ratings, and Richardson et al. suggest that these should be implemented in the determination of pointe-readiness. The "Topple" Test, which assessed form during single pirouettes en dehors, was also dance-specific. The "Airplane" Test assessed neuromuscular control of the lower extremity and ability to plié without pelvic drop, hip adduction, hip internal rotation, knee valgus, or foot pronation. The Single-Leg Sauté Test was another dance-specific measure of dynamic trunk control and lower extremity alignment during consecutive single-leg jumps. Interestingly, the Single-Leg Heel Rise Test (which resembles that used by Dr. Mayes to justify dancers performing at least 25 single leg heel raises every day) was not closely associated with subjective teacher appraisal. Richardson et al. claim that "tests that require dance specific postures and tasks allow the examiner to test integration of strength, control and alignment that express technical accuracy specific to the classical dance artform"[20]. This conclusion suggests that both generalized and dance-specific tests might be useful in measuring dancer fitness which only strengthens the argument for the development of valid and reliable metrics.

Sport specificity

While the guidelines used to assess the efficacy of exercise interventions should be somewhat dance-specific, the consensus among most professionals is that the exercises themselves are most effective when they include both balletic and general movements. When asked about whether dancers should train muscles they will use during performance (such as hip adductors for turn out) or muscles that are not typically activated in ballet technique, Dr. Kolokythas answered that both are necessary. Because most dancers decide what they want to do at a very young age and dedicate themselves to a single discipline at the expense of all else, dancers do not get a sufficient amount of muscular adaptation. Specialization makes dancers “ballet strong” but risks the development of major imbalances in hip internal and external rotation and other binary systems which can undermine technique as the negative effects accumulate in broader movements. Training opposite muscle groups from a young age can protect against such imbalances and promote accurate muscle recruitment. Dr. Kolokythas notes that training ratios do not need to be 1:1, that dancers do not need to be as strong in the “turn in” direction as the “turn out” direction, but that some degree of parallel training is necessary. He exemplifies the importance of diversity in building a strong athletic foundation by explaining that track athletes who only compete in the forward direction can improve their linear speed with lateral agility training. When it comes to workout design, more repetitions (at least 12-15) with low load (less than the weight of the athlete) promote muscular endurance, while fewer repetitions with higher weight enhance strength. Dancers can also increase their muscular power with jump training, especially if they do not wish to employ heavy weights.

Dr. Kolokythas regrets the limited body of evidence available to support his recommendations and the low quality of that which does exist. Even so, there is more research about aerobic training than there is about strength training. Though this is likely due to the rejection of potential muscular hypertrophy, data that discount bulking up should assuage any hesitation. He ultimately reaffirms that the dance community would benefit from more systematic reviews, citing hip intervention work at the Australian Ballet as model research to guide future studies.

Dr. Susan Mayes, lead physiotherapist for the company, has been conducting this research since she noticed that hip injuries, most of which require surgery and a year-long rehabilitation process, comprised 7% of the Australian Ballet’s injuries. In 2006, Dr. Mayes taught her dancers several different exercises that target and strengthen muscles surrounding the hip. Ballet dancers, specifically, tend to compensate for weak adductors and weak deep external rotators with bulky upper glute quadrants and underutilized lower quadrants, imbalances that are exacerbated by excessive stretching. In fact, injury incidence data led Dr. Mayes to discourage company members from stretching at all- advice that contradicts centuries of traditional theory but that has greatly enhanced the health of the company. Since the implementation of the hip intervention in 2006, there have been no hip arthroscopies or hip surgeries, and no dancers have gone off for hip-related pain since 2012.

Dr. Mayes has been implementing cross-training measures into dancer regimens for as long as she has been with the company, allowing annual injury trends to direct her interventions. Each year she targets the muscle group with the highest rate of injury from the previous season. After 25 years, the dancers now participate in high resistance training for all muscles, focusing on both strength and endurance. The exercises Dr. Mayes prescribes are not necessarily dance-specific. But, through trial and error, she has found that some prove more advantageous when performed in ballet positions. Most exercises are executed in a series of iterations that progress from general to sport-specific movements. For example, to strengthen their hamstrings, dancers might begin by lying on their back and performing several repetitions of a weighted bridge hip raise before progressing to a single-leg Russian deadlift in parallel. Eventually dancers would advance to the same movement in an arabesque position, with the working and standing legs externally rotated and the chest lifted. Adding a weighted plate held close to the chest and pushing the working leg extension can imitate panché position and strengthen related muscle groups. In teaching these progressions, Dr. Mayes is adamant about educating her dancers on the correlation between basic movements and performance enhancement. For example, a seated leg press can be directly linked to more powerful sautés. Framing exercises this way allows dancers to conceptualize the direct benefits of cross-training which increases participant follow-through and self-efficacy.

All too often, people skip straight to the sport-specific version of an exercise before they have gained adequate strength in neutral positions. For this reason, Dr. Mayes supports the implementation of Pilates (which often imitates balletic movements) into cross-training regimens, though the method's efficacy has long been disputed. As of 2007, fitness interventions in professional settings often consisted of, "gentle or corrective exercise formats such as Pilates and gyrotonics"[13]. While Twitchett et al. warn that cross-training methods like Pilates, Feldenkrais, and the Alexander Technique are gaining recognition despite the fact that "they have generally received little scientific validation"[17], more recent research suggests otherwise. One study measured the duration and height of front, side, and back développés at the barre for 15 dancers. For the next 11 weeks, dancers in the experimental group performed three sets of 12 repetitions of mat-based Pilates exercises twice a week while the control group maintained their normal technique class schedules. After 11 weeks, both the experimental and control groups underwent identical testing. The control group showed no signs of increased strength or flexibility, but every participant within the experimental group demonstrated growth in both areas, gaining an average of nine seconds and four to ten degrees in their développé holds. Amorim and Wyon attribute core strengthening within the Pilates group to increased use of the abdominal and gluteus muscles as well as continuous engagement of the hip flexors, and they associate increased range of hip movement with increased strength rather than heightened flexibility[21]. Thus, Amorim and Wyon recommend that dancers take advantage of Pilates technique when conditioning outside of class, because it, "develops capacities crucial for performance without neglecting the artistic component"[21]. Even so, Dr. Kolokythas maintains that if Pilates was as beneficial as these results suggest, injury incidence would be far lower.

Ultimately, functionality is an end, the means to which include basic high resistance joint strengthening and muscular hypertrophy. Of course, Pilates and other low load recommendations are made with the assumption that dancers are susceptible to fatigue, a condition exacerbated by high resistance training of any sort. Dr. Mayes proposes higher weights with fewer repetitions for any strength exercise so as to decrease the workload and protect against both physical and mental overexertion. Pilates was often paired with high repetition, low load regimens in the past, potentially contributing to the negative perception of its contribution to strength enhancement. Pre-class priming of joint mobilization exercises and the addition of two or three strength training sessions per week at the end of the day might be the best schedule through which to implement this type of training.

Because the Australian Ballet is on tour for five months out of the year, Dr. Mayes cannot rely upon heavy equipment when designing workout plans. When machines are not available, dancers use TheraBand's and free weights to mimic the effect of more traditional workout equipment. Two "vital bits of machinery" that the dancers miss while on tour are the leg press and leg extension machines which specifically target the lower gluteal muscles so infamously under-utilized and hard to isolate. This kind of adaptability was especially advantageous when the COVID-19 pandemic forced dancers out of studios for several months in early 2020. With more free time and less equipment, dancers did more running, biking, and stair climbing which induced cardiorespiratory benefits and endorphin secretion similar to what they might experience with the excitement of performing on stage. Dr. Mayes also utilized Microsoft Teams as a platform to stream exercise programs for the dancers who were each prescribed an individualized routine.

FIFA 11 precedent

Though the Australian Ballet is at the forefront of cross-training research, Dr. Mayes emphasizes the gaps in our knowledge that can only be filled by other companies who are willing to experiment with their own dancers. One barrier that has limited the development of any unified system is the lack of verified performance metrics by which we can measure success in any meaningful way. One precedent for evaluating the validity of training programs in a standardized, sport-wide context was set by authors of "The FIFA 11+ Injury Prevention Program for Soccer Players: A Systematic Review" who sought to validate the credibility of the FIFA 11+ injury prevention program (developed for soccer players by the Fédération Internationale de Football Association (FIFA) Medical Assessment and Research Centre, Oslo Sports Trauma Research Center, and Santa Monica Orthopaedic and Sports Medicine Center in 2006) (Appendix B) by reviewing randomized clinical trials on the subject. Strict inclusion criteria limited the review to six trials performed in Europe, North America, and Africa, but its intent and breadth (6,344 players total) ought to be modeled in similar reviews amongst the ballet dancer population. Though inconsistent results called the efficacy of the FIFA 11+ program into question, Sadigursky et al. determined that it is effective in reducing injury incidence, "as its use led to a 30% reduction in injury occurrences, with an estimate RR of 0.70 (95% confidence interval [CI], 0.52-0.93; p = 0.01"[22]. They also noted that heterogeneity might be attributable to "clinical factors inherent to the sample, such as sex, age, body mass index (BMI), […] clinical characteristics of the injuries […] type of warm- up adopted by the [control group], non-blinded trainers, differences in capacity among training teams, and technical managers, as well as study frequency and duration"[22].There is a similar need for scientific validation of proposed exercise interventions for dancers; however, more trials must be performed before a meta-analysis could even be considered significant. In fact, Sadigursky et al. concede that even the FIFA 11+ program is limited by the lack of literature to support it as well as its relative newness, stressing the importance of continued research within the specific population of interest[22].

Nawed et al. discuss the benefits of the FIFA 11+ program in terms of decreased rates of injury but admit that any preventative program ought to improve performance as well, in order to promote coach and player participation and follow through[23]. The distinction between injury prevention and performance enhancement as documented by Lees[6] seems to support this stance. In 2018, Nawed et al. attempted to rectify the disparity between both measures by conducting a study on 57 amateur male soccer players from Jamia Hamdard University. Over the course of 12 weeks, half of the men completed a standard 20-25 minute warm up while the other half performed the 20-25-minute FIFA 11+ program. A vertical jump test, 20-meter sprint run test, t-test, and Illinois agility run test were conducted both before and after the intervention period to assess leg power, speed, and agility. Results indicated that the FIFA 11+ program is effective at increasing leg power and sprint speed (as indicated by vertical jump and 20-meter sprint scores) but not necessarily agility (as measured by both the t-test and Illinois agility test). The authors link these data to increased performance amongst experimental group players, suggesting that because “the ability to jump higher to head the ball, run faster with or to the ball, and change direction are critical in scoring and defending the goal in soccer […] interventions that improve these measures can enhance the players’ performance during competitions”[23]. Though their study was predicated upon the difference between enhanced performance and injury reduction, any distinction they attempt to make between the terms is convoluted at best by undifferentiated results that seem to support both. Another meta-analysis performed by Gomes Neto et al. examined the effects of FIFA 11 (a primitive version of the FIFA 11+ program) on 4700 football players in 11 different trials[24]. Results indicated that FIFA 11 improved balance and agility, but that any improvements in jump height and running sprint speed were not statistically significant. They ultimately determined that FIFA 11 can be used to reduce injury incidence[24] but did not cite it as a means of improving power or speed. These interpretations suggest that balance and agility correlate with injury prevention specifically, thus implying that jump height and sprint speed correlate with performance enhancement alone.

Confounding results question both the validity of conclusions made by Nawed et al. and Gomes Neto et al. as well as the definitions of performance enhancement and injury prevention that guide our current research. Gomes Neto et al. cite the relative lack of football-related studies as a potential limitation to their conclusions and warn that, “caution is warranted when interpreting [their] results”[24]. The abstract nature of such research seems to suggest that injury prevention is much more easily documented than any improvement in performance parameters. For example, Sadigursky et al. discuss injuries in terms of their incidence and bodily location amongst soccer and ballet athletes[22], and Nawed et al. judged the FIFA 11+ program by its ability to promote those activities necessary for scoring[23]. But, there are no comparable, quantifiable goals within dance, and neither group offered similar metrics for the comparison of performance enhancement. And even if performance quality was a more objective concept in general, the unique nature of dance (as discussed by Tiemens et al.[18]) in contrast to most other goal-oriented sports suggests that judging ballet performance provides a unique challenge irrespective of those posed by abstract definitions. These shortcomings provide further incentives for additional, sport-specific research that differentiates between two different potential benefits of cross training.

11+ Dance

Dr. Kolokythas is one professional who has lamented these deficiencies. Modeled after the FIFA 11+ program, his *11+ Dance* regimen (Table C1) addresses part of the gap, particularly in terms of injury prevention as opposed to performance enhancement. FIFA 11+ was originally designed to address the disproportionate percentage of soccer player injuries that occur within the first and last 15 minutes of competitive play[22]. This temporal pattern of injury suggests that, much like injuries recorded in dancer populations, the most common injuries amongst soccer players are those associated with fatigue, inadequate warm-up, and muscular imbalance, especially of the lower limbs. These similarities suggest that dance and soccer are not as disparate as they seem and might allow relevant comparisons to be made between injury prevention methods. Although it was intended to benefit soccer players, "several studies demonstrated [FIFA 11+'s] effectiveness for other sports such as basketball"[22], and Dr. Kolokythas adapted it even further when he marketed similar exercises to dancers. FIFA 11+ consists of 15 exercises that enhance core stability, eccentric thigh muscle strength, proprioception, and plyometrics. *11+ Dance* consists of two sessions of 14 and 12 exercises respectively. Both programs are approximately 20 minutes in duration and intended to be performed at least twice a week (Table C2). Dr. Kolokythas promotes the use of sport-specific training for dancers of all levels with *11+ Dance* in contrast to Wyon, who suggests that the American College of Sports Medicine's generalized standards for health maintenance are adequate supplementary training guidelines for students and recreational dancers and are only insufficient when it comes to the professional demographic[15].

In a personal interview, Dr. Kolokythas suggested that rather than performing research as an end in itself, dance medicine professionals ought to explore those issues that would most enhance the lives of dancers when resolved- research as a means to an end. And, the more "methodologically robust" that research is, the more likely practitioners are to implement conclusions into their recommendations and treatment plans. Dr. Kolokythas specifically mentions studies being done at his own company, the Birmingham Royal Ballet, as well as the aforementioned work of Dr. Susan Mayes with the Australian Ballet as potential sources for credible data, maintaining that the most useful information for professional dancers will come from professional companies themselves.

USFS & USAG standards

While Dr. Kolokythas derived his recommendations from those originally intended to benefit soccer players, Liederbach and others have demonstrated distinct differences in these populations[25]. Dancers suffer far fewer ACL injuries than athletes in team ball sports like soccer and basketball. Because ballet might actually protect against ACL injuries, supplementary training for ballet may not need to target balance and landing mechanics as much as training for other sports[25]. So, while FIFA 11+ provides a basis from which recommendations might be made, discontinuities amongst target populations might limit the effectiveness of associated interventions. Gymnastics and figure skating are two aesthetic sports perhaps more comparable to ballet that have their own set of fitness recommendations. Nationally standardized intervention plans put forth by the governing bodies of both sports serve as examples of how programs like *11+ Dance* might be incorporated into a consistent, regulated national standard. U. S. Figure Skating (USFS) is recognized by the United States Olympic Committee as America's national governing body for the sport of figure skating. The USFS website includes standardized information on injury prevention, overtraining and recovery, and nutrition that is readily available to the public. Their Standardized Testing of Athleticism to Recognize Skaters (S.T.A.R.S.) program consists of fourteen tests that measure agility, balance, coordination, strength, power, and flexibility off the ice (Appendix D). The U.S. Figure Skating YouTube channel also has three "Off-Ice Training" videos that guide participants through a series of exercises for core, foot and ankle, and shoulder stability (Video F1). In addition, USFS employs the High-Performance Movement Screen (HPMS) in injury prevention efforts which assesses mobility, stability, and symmetry with the y-balance test, single leg squat test, rotary stability test, shoulder mobility test, hip mobility test, and balance error scoring system (Appendix E). Any USFS skater can receive an individual screening with a physician, physical therapist, or certified athletic trainer to identify potentially injury-inducing weaknesses[26].

Much like the USFS, USA Gymnastics (USAG) offers the USAG Fitness Program as a means of enhancing athlete fitness and overall health (Appendix G). The handbook discusses basic gymnastics skills and the fitness fundamentals they are built upon, namely aerobic exercise, movement, strength training, flexibility and nutrition. While dance professionals address a lack of verified fitness metrics and baseline measurements within their community, USAG specifically discusses ways to determine fitness levels and set fitness goals before starting the program which itself offers a series of cardiovascular games; movement exercises for sprint mechanics, lateral movements, and plyometrics; strength training exercise progressions for the core, glutes, squats, lunges, push-ups, pull-ups, total body, and static flexibility; and nutrition advice. Although it is marketed towards 3-16-year-old recreational, club, and team gymnasts instead of professionals, the program still exemplifies a concerted effort to promote athlete wellbeing by a governing body. Ballet lacks any similar regulation regarding standardized resources for athlete wellness.

Injury incidence

Creating a widely accepted standard for fitness amongst dancers would facilitate coordination amongst professional companies and medical teams and provide guidelines from which future recommendations and research could be based. Without a means by which comparisons can be made, it will be nearly impossible to launch a concerted effort to enhance dancer wellness. Although research has demonstrated a need for supplementary training, the available evidence conveys injury prevalence and strength deficits more than it suggests how to overcome these limitations. Clanin et al. found that 159 dancers sustained 335 injuries over the course of two years[8]. Ramkumar et al.[27] and Koutedakis et al.[8] both conducted incidence studies that identified lower back and lower extremity injuries as the two most prevalent. Additionally, Stacciolini et al. stress the need for injury prevention over treatment by citing injury incidence data for both pre-professional and professional populations (0.77 to 1.55 per 1,000 dance hours and 0.60 to 0.62 per 1,000 dance hours respectively). Even then, they warn that an inconsistent definition of “injury” reduces the efficacy of data interpretation. The authors continue on to debunk several misconceptions about resistance training for dancers, namely that it is unsafe for children, induces bulky muscles, does not benefit young females, and that there is one right way to perform the exercises[25]. However, they fail to suggest possible alternatives when making this claim.

Yet another example of research that must be extended beyond tracing incidence into providing a tangible product is that of Allen et al. who employed Van Mechelen’s injury prevention model, the Functional Movement Screen (FMS), and lead author, Nick Allen M.Sc.’s, Hybrid Intervention Model (HIM) in evaluating the validity of an injury prevention program amongst professional ballet dancers[10]. Van Mechelen’s model establishes the progression of preventative measures from determining the extent and etiology of the injury to introducing preventative measures and assessing success by revisiting the incidence and severity of the injury after treatment. The FMS is a generalized assessment that measures mobility and predicts injury occurrence with seven basic exercises (Appendix H). Implemented in year one of the study, participants performed a deep squat, hurdle step, in-line lunge, trunk stability pushup, shoulder mobility stretch, active straight-leg raise, and rotary stability sequence. FMS results guided HIM-based injury prevention efforts through years two and three of the study. Conceived as a means of designing personalized strength training regimens, the HIM is applicable to both rehabilitative and maintenance-oriented conditioning programs. It addresses neuromuscular facilitation, isolated segmental deficit training, and functional integration as they relate to the injury itself, the cause of injury, and the desired outcome[10].

Fifty-eight dancers in a professional ballet company participated from 2005 to 2008. Dancers performed 145 times, 143 times, and 142 times in years one, two, and three respectively. They were all injury-free at the beginning of year one. Following HIM implementation, injury progression was audited. 355 injuries were reported in year one, decreasing to 183 in year two and 174 in year three despite an increase in overall exposure to dance (as measured by allowable dance-related activity). A Poisson distribution model confirmed the significance of rate differentials. Though injury severity (as measured by injury-related days-off of work) increased slightly each year, the incidence of recurrent injuries as a proportion of the total declined by 15%. In addition, the authors suggest that the increase in severity reflects a greater understanding of the necessary rehabilitation time for comparable injuries rather than injuries with worse prognoses[10].

Though the HIM was developed based upon “key performance attributes from elite sport and dance [and combines] the skill and ‘efficiency of movement’ characteristics noted with elite dancers, together with the fitness and strength attributes of ‘traditional’ elite sports athletes”[10], Allen et al. do not address the degree to which it is dance-specific. In fact, the authors admit that a “notable aspect of the FMS in relation to other dance screening is the absence of any dance specific testing” but reaffirm that they “chose a normal movement screening to establish the nature of movement outside of the skill and technique as a dancer to provide a more accurate indication of risk for when their skill or technique is diminished for any reason [as by fatigue]”[10]. In this case, Allen et al. cite the lack of specificity as a strength rather than a weakness. In addition to generalized measurement models, Allen et al. further claim that a broad strengthening program helps dancers “be better conditioned to withstand the rigors of modern-day elite level ballet”[10]. While the deep squat and in-line lunge tests of the FMS both helped practitioners identify sacroiliac instabilities, the authors maintain that the importance of dance-specific measures cannot be understated in the treatment of this specific population[10].

Conclusions

Dr. Nancy Kadel supports the push for company-funded research and solution-based thinking. In a personal interview, she expressed the need for professional companies with both adequate funding and sufficient buy-in from dancers and management who are willing to participate in such studies. In fact, she blames the current lack of coordinated regulation amongst companies and health professionals for perpetuating inefficiencies in the provision of quality care. In order to clarify loosely defined recommendations, Dr. Kadel reiterates the need for company-wide studies, specifically year-long interventions with control and experimental groups. In companies that are willing to invest in research like this, half of the dancers should act as the experimental group (performing a prescribed conditioning program) while the other half acts as the control group with no change to their training schedules. She specifically mentions work done by Dr. Matthew Wyon who studied the effects of one hour of conditioning class in an experimental group substituted for an additional hour of dancing in the control group. This study design should guide future research for programs who prescribe any hour-long training regimen under question to one group of dancers and compare fitness outcomes to another group who dances for an additional hour instead. In another personal interview, athletic trainer with the Harkness Center for Dance Injuries, Josh Honrado, DAT, MS, ATC, CSCS, RYT, discussed the need for more studies on pointe shoe readiness, lifting and partnering preparedness, plyometric training to promote better jumping, and the disparate effects of petite versus grande allegro movements. Much like Dr. Kolokythas, Dr. Mayes, and Dr. Kadel, Dr. Honrado recognizes that the most applicable data will come out of in-house research amongst the population of interest but admits that the Harkness Center is not currently performing this type of research, focusing more on epidemiology, jump landing biomechanics, and spinal motion instead.

Of course, Dr. Mayes is careful to stipulate that even the research done with professional companies will not be dependable until the testing methods themselves have been validated. She suggests that one way to assess the validity of a test would be to perform it on both dancer and non-dancer athletic populations and determine whether or not comparable results were obtained. Based off of the intervention already created for soccer players, Dr. Kolokythas' *11+ Dance* is one program that exemplifies how this might be done.

Alvin Ailey is one professional company that is prioritizing physical fitness as a preventative measure against injury-related losses. Data collected in an experiment conducted from 1998 to 2001 were contrasted with comparative statistics from 1996 and 1997. In both years directly preceding the intervention, Alvin Ailey dancers did not have access to on-site medical professionals when they suspected injury. They either sought treatment at an emergency department or received a referral for private practice physical therapy through an orthopedic surgeon associated with the company. In years three, four, and five, dancers had access to primary preventative measures like annual dance-specific fitness screenings, technique allowances, cross-training, and medical advice for minor ailments. Secondary preventative measures were also improved to provide more coordinated treatment and rehabilitation. Physical therapists saw patients in-house at rehearsals, backstage at performances, and on the go during the US touring season. Introduction of the intervention resulted in a drop of new worker's compensation claims from 79-81% to 17% in year five. Total injuries per 1,000 hours of dance, regardless of insurance status, declined as well, falling from 0.51 in year one to 0.18 in year five[28].

Like Alvin Ailey, other professional companies are starting to recognize the importance of research like this. In fact, although the COVID-19 pandemic forced many companies off the stage and out of the studio for several months in 2020 and 2021, it also provided a unique opportunity for companies to experiment with cross-training when they were forced to address the physical deficits that accompanied quarantine stay-at-home regulations. Dr. Kolokythas commented that his dancers focused more on strength training during quarantine than ever before, both because they did not have access to their usual facilities and because they had more energy and free time without the burden of their typical training schedules. When dancers were allowed back into the studio, teachers and health professionals worried that a quick return to normal training would result in increased injury rates. Dr. Mayes attributed this pattern in injury incidence to the fact that most dancers were careful at home and naturally more guarded on un-sprung floors but were overzealous when they returned to the more supportive marley flooring of their studios. Surprisingly,Dr. Mayes was more worried about the demands of petite allegro than those of grand allegro. While the traveling aspect of grand allegro posed an injury threat for those dancers who had been confined to approximately one square meter at home, Dr. Mayes cited the speed and accuracy required in petite movements as riskier than the height required in grand combinations. Her protocol for dancers returning to normal work was much like that of dancers rehabbing an injury: begin training allegro in place with lower pirouette complexity, fewer traveling sequences, and a fairly normal barre warmup; progress to grand allegro with a slow speed; and, eventually, add fast petite allegro. When Australian Ballet dancers first came back to work after a second wave of COVID-19 in Melbourne, they had an hour to use strength equipment in the studio, then class and rehearsal before another hour in the gym.

While increased injury rates were, in fact, observed in conjunction with loosening lockdown restrictions (regardless of professional status), heightened concern catalyzed the kind of coordinated communication that dance medicine has lacked thus far. Both the Harkness center for Dance Injuries and IADMS posted educational content on various social media platforms throughout lockdown. The Harkness Facebook page has links to several livestreams with health professionals who discuss aerobic training and mental health. Ashley Houck, PT; Rebecca Kesting, MD, PT; and Lauren McIntyre, AT discuss the risks and benefits of different cardiovascular training methods in a video posted on June 12, 2020 (Video F2). Much like Wyon et al.[13], they justify training to supplement the relatively low level of aerobic endurance developed through class alone. Similarly, IADMS created a YouTube playlist entitled “Performing Artists’ Mental Health and COVID-19” with videos discussing sleep, stress, and depression (Video F3). Another series of videos, “Safe Dance Practice Live Panels”, addresses dance education, safe dance practice during quarantine, and conditioning in the context of a global pandemic (Video F4). Dr. Kolokythas was one guest panelist along with Stevie Oakes, MFA, CSCS, and Dr. Robert Tsai, PT, DPT. The panelists discuss skill as a function of endurance, strength, function, and speed.

Although this influx of educational information is necessary and has been long-awaited in the dance community, all three IADMS panelists emphasize the importance of media literacy and context when choosing which resources to trust and which conditioning methods to adopt. Dr. Tsai endorses “purpose” and “intention” as the guiding pillars of his practice as a healthcare provider. Much like Dr. Mayes, he ensures that his dancers know why they are doing what they are doing. Oakes asks dancers to be judicious in deciding which strength coaches and teachers to trust (What are their affiliations? What other resources do I already know and trust?) and to use their intuition (How does this resonate with me? Does it make sense to me? How do I feel?) in order to be discerning about the media content they use. Dr. Kolokythas recommends that dancers ask a different set of questions (How full is the [social media] post? Is it taking me through the whole process so that I can understand why I’m seeing what I’m seeing? Is there a start and an end? Does it explain the why behind the movement?). He emphasizes that follower count is not an adequate metric when determining the credibility of fitness accounts and suggests that dancers and dance educators alike seek direct advice from medical professionals like himself instead of taking fitness into their own hands. In fact, Dr. Kolokythas posits that global lockdown during the COVID-19 pandemic “could be an opportunity for further collaborations and actually open the door to [a] multidisciplinary […] and holistic approach of dancer development” (Appendix F, Video F4).

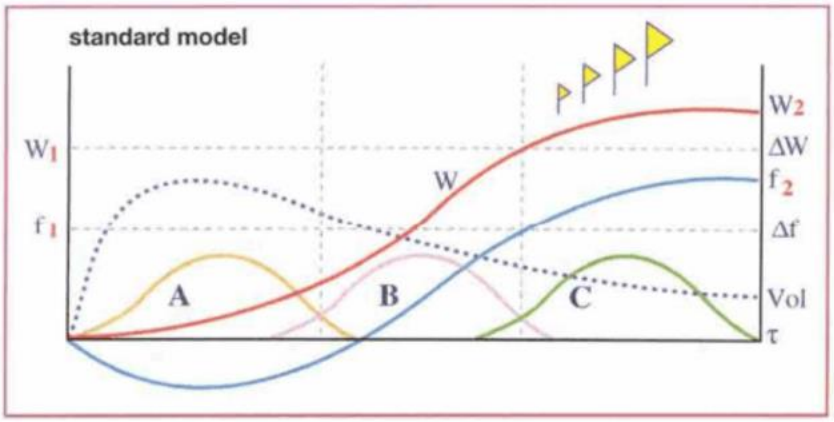
To wrap up the panel, moderator Ellie Kusner, MSc, asked, “in the face of not having to be performance ready, what can we do with this time […] how do we think strategically about fitness?”. While the current state of the world has revolutionized the ways in which we approach art, ballet has always been a dynamic reflection of society. It was conceived at a crossroads between the Renaissance and Enlightenment eras in Europe and has evolved in the context of social, cultural, and political upheavals in the centuries since. Ballet will continue to reflect the conditions in which it exists, especially in an age of enhanced access, visibility, and communication in which the resources and tools our dancers need to become stronger athletes and better performers are more accessible than ever before. In the face of not having to be performance ready, then, we can shift from the limited, dichotomic perception of dancers as either performance ready or not and begin to focus on their athleticism, strength, tenacity, and fortitude as artists and people with strong ties to our past and important implications for our future.

References

1. Sun kings and sylphs, glamour and grit: a short history of ballet. The Australian Ballet. https://australianballet.com.au/ballet-101/short-history-of-ballet
2. Rodrigues-Krause J, Krause M, Reischak-Oliveira A. Cardiorespiratory considerations in dance: from classes to performances. Journal of Dance Medicine & Science. 2015;19(3):91-102.
3. Our story. International Association for Dance Medicine & Science. https://iadms.org/our-story/
4. Angioi M, Metsios G, Twitchett E, et al. Effects of supplemental training on fitness and aesthetic competence parameters in contemporary dance: a randomized controlled trial. Medical Problems of Performing Artists. 2012;27(1):3-8.
5. Angioi M, Metsios G, Twitchett E, et al. Association between selected physical fitness parameters and aesthetic competence in contemporary dance. Journal of Dance Medicine & Science. 2009;13(4):115-123.
6. Lees A. Technique analysis in sports: a critical review. Journal of Sports Sciences. 2002;20:813-828.
7. Campbell RS, Lehr ME, Livingston A, et al. Intrinsic modifiable risk factors in ballet dancers: applying evidence-based practice principles to enhance clinical applications. Physical Therapy in Sport. 2019;38:106-114
8. Koutedakis Y, Khaloula M, Pacy PJ, et al. Thigh peak torques and lower-body injuries in dancers. Journal of Dance Medicine & Science. 1997;1(1):12-15.
9. Wyon M. Preparing to perform: periodization and dance. Journal of Dance Medicine & Science. 2010;14(2):67-72.
10. Allen N, Neville AM, Brooks JH, et al. The effect of a comprehensive injury audit program on injury incidence in ballet: a 3-year prospective study. Clinical Journal of Sports Medicine. 2013;23(5):373-378.
11. Bompa TO. Primer on periodization. Olympic Coach. 2004;16(2).
12. Miller A, Hall J, Parker J, et al. Models of periodization. On Target Publications. https://www.otpbooks.com/models-of-periodization/
13. Wyon M, Nevill M, Doherty A, et al. The cardiorespiratory, anthropometric, and performance characteristics of an international/national touring ballet company. Journal of Strength and Conditioning. 2007;21(2):56-61.
14. Moita JP, Nunes A, Esteves J, et al. The relationship between muscular strength and dance injuries. Medical Problems of Performing Artists. 2017;32(1):40-50.
15. Wyon, M. Cardiorespiratory training for dancers. Journal of Dance Medicine & Science. 2005;9(1):7-12.
16. Cohen JL, Segal KR, Witriol I, et al. Cardiorespiratory responses to ballet exercises and the VO2max of elite ballet dancers. Medicine and Science in Sports and Exercise. 1982;14(3):212-217.
17. Twitchett EA, Koutedakis Y, Wyon MA. Physiological fitness and professional classical ballet performance: a brief review. Journal of Strength and Conditioning Research. 2009;23(9):2732-2740.
18. Tiemens A, van Rijn RM, Wyon MA, et al. Influence of movement quality on heart rate while performing the dance-specific aerobic fitness test (DAFT) in preprofessional contemporary dancers. Medical Problems of Performing Artists. 2018;33(2):77-81.
19. Koutedakis Y, Hukam H, Metsios G, et al. The effects of three months of aerobic and strength training on selected performance- and fitness- related parameters in modern dance

students. Journal of Strength and Conditioning Research. 2007;21(3):808-812.
20. Richardson M, Liederbach M, Sandow E. Functional criteria for assessing pointe-readiness. Journal of Dance Medicine & Science. 2010;14(3):82-88.
21. Amorim T, Wyon M. Pilates technique for improving dancers' performance. The IADMS Bulletin for Dancers and Teachers. 2014;5(1):9.
22. Sadigursky D, Braid JA, De Lira DNL, et al. The FIFA 11+ injury prevention program for soccer players: a systematic review. BMC Sports Science, Medicine, and Rehabilitation. 2017;9(18):1-8.
23. Nawed A, Khan IA, Jalwan J, et al. Efficacy of FIFA 11+ training program on functional performance in amateur soccer players. Journal of Back and Musculoskeletal Rehabilitation. 2018;31(5):867-870.
24. Gomes Neto M, Conceição CS, de Lima Brasileiro AJA, et al. Effects of the FIFA 11 training program on injury prevention in football players. Clinical Rehabilitation. 2017;31(5):651-659.
25. Stracciolini A, F.A.A.P., F.A.C.S.M., et al. Resistance training for pediatric female dancers. Journal of Dance Medicine & Science. 2016;20(2):64-71.
26. Athletic assessments. U.S. Figure Skating. https://www.usfigureskating.org/skate/prepare-and-train/athletic-assessments
27. Ramkumar PN, Farber J, Arnouk J, et al. Injuries in a professional ballet dance company: a 10-year retrospective study. Journal of Dance Medicine & Science. 2016;20(1):30-37.
28. Bronner S, Ojofeitimi S, Rose D. Injuries in a modern dance company: effect of comprehensive management on injury incidence and time loss. The American Journal of Sports Medicine. 2003;31(3):365-373.

Appendix A. Verkhoshansky's block periodization model
Retrieved from: https://www.otpbooks.com/models-of-periodization/

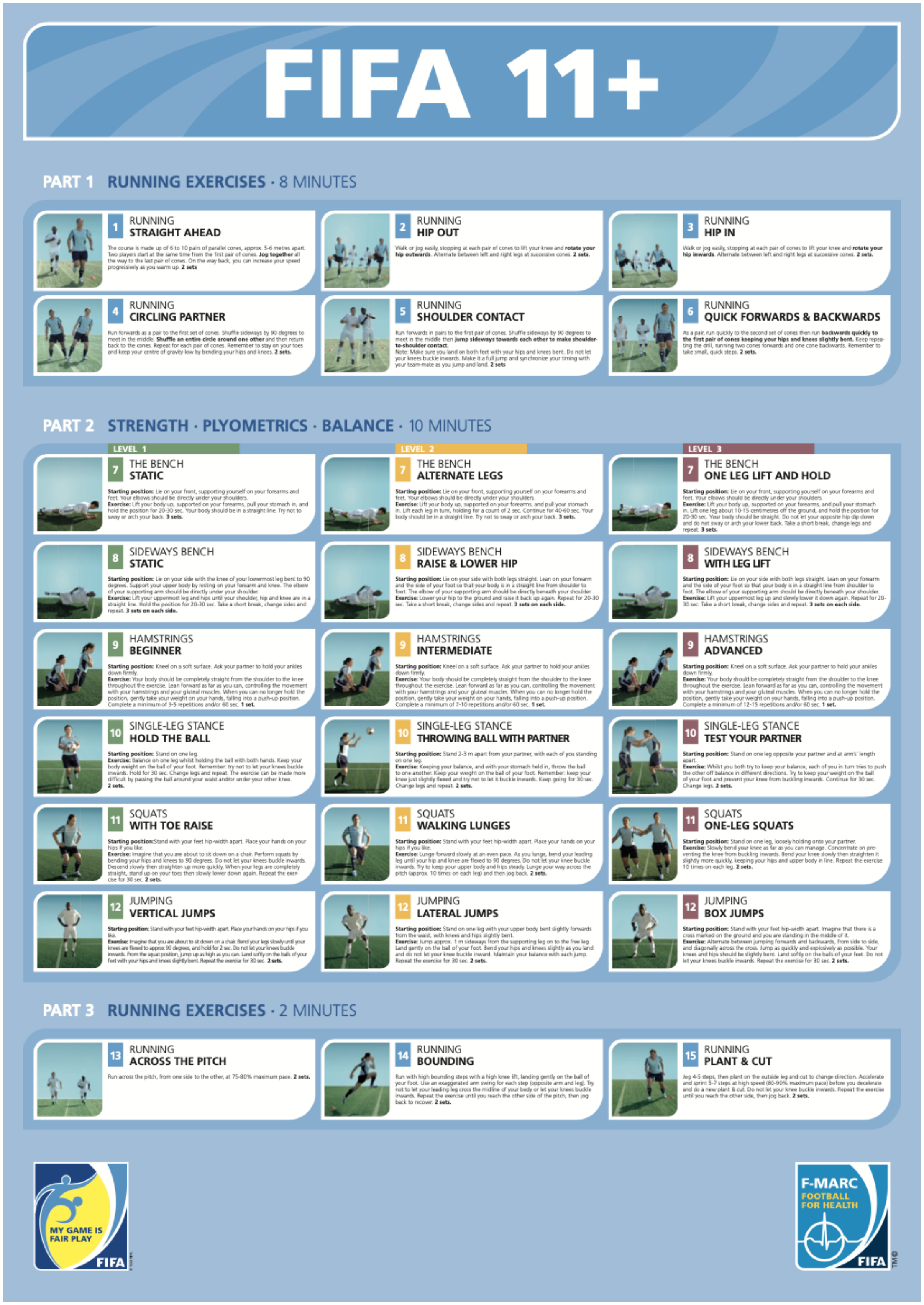


Verkhoshansky's Standard Model for the Main Adaptation Cycle[iii] Model

W = Work Power Vol = Volume f = Maximal level of functional parameters

Appendix B. FIFA 11+ injury prevention program

Retrieved from: https://kneesurgerysydney.com.au/preventing-acl-injuries-with-the-fifa-11-program/



Appendix C. *11+ Dance* description and comparison
Retrieved from: https://www.strengthmotionmind.com/11-dance

All credit to Dr. Nico Kolokythas, ASCC, PhD

Table C1. *11+ Dance* description
Session 1
*only challenge yourself with progressions if you can maintain a neutral spine and/or knee alignment in basic position

Exercise	**Description**
1. Skip	Skip for three 1-minute sessions with rest intervals of 15-20 seconds in between. Focus on landing with both feet at the same time.
Progressions:	*Alternate skips:* perform one skip on each leg, alternating every time. *Single-leg serial skips:* perform two to three consecutive skips on one leg, then switch legs.
2. Plank on Elbows	
Progressions:	*Raise opposite hand & leg* *Plank rotations:* open up shoulder and hip to face one side while keeping toes planted.
3. Side Plank with Bent Knee	Bend bottom leg at a ninety-degree angle while supporting body with elbow. Keep other hand on hip, and raise top leg to create a straight line from shoulder to ankle.
Progressions:	*Side plank with straight leg:* extend bottom leg so that both feet are planted, hold plank position. *Elbow to knee:* touch the elbow on top arm to the knee on top leg by bringing both limbs together in line with stomach.
4. Bridge	Lie with feet and head planted, knees bent, and glutes raised so that there is a straight line from shoulders to knees.
Progressions:	*Bridge with steps:* raise alternate legs with pointed toes.

	Bridge with knee extension: raise alternate legs with pointed toes, extend the knee before returning to bent position. *Bridge with knee extension & hold* (3-5 sec).
5. Hamstring Raises Progressions:	Lie down. Plant heels into the ground with flexed feet and bent knees. Raise glutes off the ground into a straight line from shoulder to knee. *Repeat with feet further away from glutes.* *Single leg:* raise one leg at a time; alternate legs.
6. Squats to Demi-Pointe Progressions:	Perform a regular squat, returning to demi-pointe relevé instead of flat-footed stance. Maintain natural turnout with feet shoulder width apart. *Slow descent with explosive intention upwards:* use four counts to reach bottom of squat. *Pause at bottom.* *Single leg demi-pointe:* perform regular squat, return to demi-pointe parallel passé, alternate legs.
7. Walking Lunges Progressions:	Maintain knee alignment with parallel hips. *Demi-pointe:* return to demi-pointe after every lunge. *Développé before lunge:* perform developpé on demi-pointe before each lunge. *Lunge rotations:* turn 360 degrees towards back leg after each lunge, landing in the alternate leg lunge.
8. Side Lunges Progressions:	Alternate legs and maintain natural turnout. *Side to cross body:* step out of lunge, and bring bent leg across to other side of body, bending both knees one over the other.
9. Single Leg Balance with Hip Rotations	Stand with both elbows behind head and one leg extended straight out from the hip with

	bent knee. Maintain body position while opening and closing knee.
Progressions:	*Upper body rotation:* maintain closed, raised knee position while rotating head and shoulders from one side to another.
10. Cross-Country Skiing	Balance on one leg with the other knee extended in line with hip. Raise opposite arm, bent at elbow. Extend raised leg back as far as possible while bending supporting leg and lowering chest so as to maintain a straight line from toe to head.
Progressions:	*Overhead reach:* perform cross-country ski, reaching arms in a straight line from toe to finger when in the extended position.
11. Hip Airplane	Extend one leg behind you in line with bowed chest while balancing on the opposite bent leg. Extend arms to either side and open up chest to alternating sides.
Progressions:	Perform the same exercise at a faster pace.
12. Forward Landings	Jump with both feet from a standing position, landing in a parallel squat.
Progressions:	*Freeze the landing:* hold the squat position upon landing before making the next jump. *One forward, one up:* perform squat jump in place; alternate with forward landing jumps.
13. Side Landings	Jump to the side with both feet remaining front-facing and parallel; land in squat position.
Progressions:	*Rotations:* land in squat facing alternate directions each time.
14. Single Leg Landings	Perform forward landing squat jump, landing in single-leg squat with opposite leg bent either in front or behind the body.
Progressions:	*One forward, one up:* perform single-leg forward jump alternating with single-leg straight jump. *Left right stick:* jump to the side, landing on outside leg with opposite leg bent in front of

	the body; alternate directions, pausing after every third jump.
15. Single Leg Side Landings Progressions:	Perform side landing jump, landing on outside leg and bending opposite leg. *One side, one up:* after landing from single-leg side landing jump, push off of landing leg into a vertical jump. *Step-cross-jump:* perform tombé pas de bourrée sequence in front of body before performing a single-leg side landing jump.

Session 2

*only challenge yourself with progressions if you can maintain a neutral spine and/or knee alignment in basic position

Exercise	**Description**
1. Plank on Hand with Elbow Taps Progressions:	Tap one elbow with the opposite hand; alternate hands. *Shoulder taps with pause:* remain in single-arm pushup position before alternating.
2. Bear Crawls Progressions:	Begin with toes and hands on the floor, lifting one hand off at a time to maintain three points of contact with the ground. *Small steps forwards and backwards:* bring one hand and the opposite leg forward before returning to neutral and alternating sides. *Repeat the same motions in the backwards direction as well.* *Crawling:* perform a bear crawl straight forward or backwards. *Travel in different directions:* maintain the bear crawl posture while traveling in multiple directions.
3. Crab Walks Progressions:	Begin in the crab walk position and alternately raise each hand and each leg. *Small steps forwards and backwards:* bring one hand and the opposite leg forward before returning to neutral and alternating sides.

	Repeat the same motions in the backwards direction as well. *Walking:* perform a crab walk straight forward or backwards. *Travel in different directions:* maintain the crab walk posture while traveling in different directions. *Faster:* continue walking at a faster pace.
4. Cook Hip Lifts	Lay on back with knees bent, as if you are about to perform a sit-up. Lift glutes off the ground in line with knees and shoulders and draw one knee into chest. Lower and raise glutes while holding knee at chest.
5. Monster Walks Progressions:	Wrap a resistance band around ankles. Step out with one leg before bringing the other to meet it. *All four directions:* step forward and backwards in a similar motion. *Soft knees:* repeat the side steps with bent knees. *Soft knees, all four directions:* repeat the forward and backward steps with bent knees. *Demi-pointe:* repeat the side steps on relevé. *Demi-pointe, all four directions:* repeat the forward and backward steps on relevé.
6. Deep Squats with Overhead Reach Progressions:	Squat beyond a ninety-degree angle. Extend your arms above your head once you reach the deepest point of your squat. *Squeeze hands together:* repeat the deep squat with hands above head throughout the entire movement, pressed together as if you were about to dive into a pool. *Push hands outward with resistance band:* repeat the deep squat with your hands above head throughout the entire movement,

	pushing outward against a resistance band looped around wrists.
7. Side Slides Progressions:	Perform a side lunge. Instead of returning to planted foot, bring extended leg to meet bent leg so that you travel to one side or the other. *Pause at bottom* *Raise leg on way up*
8. Leg Swings Progressions:	Stand on one leg while swinging the other back and forth with knee slightly bent. *Cross-body swings:* swing leg medially and laterally instead of forward and backwards.
9. Single Leg Reach	Squat with one bent leg and one extended in tendu with pointed toes to the front of the body. Repeat to the side, back, and opposite side, maintaining center of balance above bent leg.
10. Forward Landings Progressions:	Jump with both feet from a standing position, landing in a parallel squat *Freeze the landing:* hold the squat position upon landing before making the next jump. *One forward, one up:* perform squat jump in place; alternate with forward landing jumps.
11. Side Landings Progressions:	Jump to the side with both feet remaining front-facing and parallel; land in squat position. *Rotations:* land in squat facing alternate directions each time.
12. Single Leg Landings Progressions:	Perform forward landing squat jump, landing in single-leg squat with opposite leg bent either in front or behind the body. *One forward, one up:* perform single-leg forward jump alternating with single-leg straight jump. *Left right stick:* jump to the side, landing on outside leg with opposite leg bent in front of the body; alternate directions, pausing after every third jump.

13. Single Leg Side Landings Progressions:	Perform side landing jump, landing on outside leg and bending opposite leg. *One side, one up:* after landing from single-leg side landing jump, push off of landing leg into a vertical jump. *Step-cross-jump:* perform tombé pas de bourée sequence in front of body before performing a single-leg side landing jump.

Table C2. Comparison of FIFA 11+ and *11+ Dance* interventions

FIFA 11+ (20 min total) To be performed at least twice per week before regular training Retrieved from: https://kneesurgerysydney.com.au/preventing-acl-injuries-with-the-fifa-11-program/	**11+ Dance (25-30 min total)** To be performed at least twice per week Retrieved from: https://www.strengthmotionmind.com/11-dance All credit to Dr. Nico Kolokythas, ASCC, PhD
Running Exercises (8 min duration) Straight ahead (x2) Hip out (x2) Hip in (x2) Circling partner (x2) Shoulder contact (x2) Quick forwards & backwards (x2) **Strength, Plyometric, & Balance Exercises (10 min duration)** ***each exercise has three iterations depending on skill level and target performance** Bench (x3) Sideways bench (x3) Hamstrings (x1) Single-leg stance (x2) Squats (x2) Jumping (x2) **Running Exercises (2 min duration)** Run length of soccer field (x2) Bounding runs (x2) Plant & cut runs (x2)	**Muscle Activation** Skip (1 min x3) **Session 1** ***each exercise has several iterations depending on skill level and target performance** Plank on elbows Side plank Bridge Hamstring raises Squats to demi-pointe Lunges Side lunges Single-leg balance Cross-country skiing Hip airplane Forward landings Side landings Single-leg landings Single-leg side landings **Session 2**

	***each exercise has several iterations depending on skill level and target performance** Plank on hands with elbow taps Bear crawls Crab walks Cook hip lift Monster walks Deep squats with overhead reach Side slides Leg swings Single-leg reach Side landings Single-leg landings Single-leg side landings

Appendix D. U.S. Figure Skating S.T.A.R.S. Manual

U.S. FIGURE SKATING
S.T.A.R.S.
MANUAL

US FIGURE SKATING
S.T.A.R.S. Program

US FIGURE SKATING | PROFESSIONAL SKATERS ASSOCIATION | COACHING PROGRAM

U.S. FIGURE SKATING S.T.A.R.S. MANUAL

PROGRAM OVERVIEW

Welcome to the U.S. Figure Skating S.T.A.R.S. Program. S.T.A.R.S. (Standardized Testing of Athleticism to Recognize Skaters) is a comprehensive off-ice assessment that tests areas of athleticism relevant to the sport of figure skating. The program was developed in 2010 by the U.S. Figure Skating Sports Science and Medicine Committee along with the National Strength & Conditioning Association.

The S.T.A.R.S. Program hosts combines nationwide between April and August each year. Athletes register to participate through U.S. Figure Skating and the S.T.A.R.S. website (www.STARScombine.org). Coordinating and logistics of each combine are arranged by U.S. Figure Skating. Each combine location is assigned a combine anchor who oversees the execution of the event. The combine anchor is required to hold an NSCA-CSCS credential and have previous S.T.A.R.S. assessor experience and knowledge of the testing protocol. The combine consists of a staff of assessors who may hold credentials in strength and conditioning, physical therapy, athletic training, personal training and group fitness. The assessors assist the combine anchor in measuring and evaluating the athletes at each combine. All assessors are eligible for a stipend from U.S. Figure Skating for their assistance.

The S.T.A.R.S. testing protocol consists of 14 assessments in the areas of agility, balance, coordination, strength, power and flexibility. All assessments take place off the ice and require standardized equipment (supplied by U.S. Figure Skating). The assessment takes approximately 1 hour for an athlete to complete. Once an athlete completes the assessment they can evaluate their physical fitness by comparing their performance to their peers according to skating level and age/gender, and measure personal improvement over time. Data is normalized and calculated through the sports science platform, Ex3. Athletes receive a score sheet with the raw data on the day of the combine and a detailed report at the end of the season. After each season, top athletes in each age and gender category are recognized by U.S. Figure Skating through various platforms like SKATING magazine.

INTRODUCTION/OBJECTIVES

S.T.A.R.S. was developed as an initiative to promote robust, all-around fitness in young American skaters, to push and maintain the athletic ability curve ahead of the skills curve, to ensure that young figure skaters are physically prepared to handle the introduction of new, complex and more demanding skating skills, and to reduce the potential for injury typically sustained during the training of these new skills. S.T.A.R.S. is a system of athletic assessments designed to support U.S. Figure Skating's existing testing and competition progressions.

S.T.A.R.S. OBJECTIVES

1. Promote and enhance athleticism in all young figure skaters through assessment, recognition and opportunity.
2. Reduce the rate of injury across all figure skating disciplines and competitive levels.
3. Identify skaters who demonstrate exceptional aptitude for athleticism.
4. Assist coaches and parents in developing and guiding their skater's potential.
5. Connect skaters, coaches and parents with qualified strength and conditioning specialists in their region and around the country.
6. Be challenging and fun!

STRUCTURE/SYSTEMS

As a voluntary participation program, S.T.A.R.S. encourages athletic improvement through its progressive system of recognition and awards. It allowing skaters, coaches and parents to access age, gender and competitive matched fitness assessment data across the United States.

As a system, S.T.A.R.S. is also designed to establish a standard of athleticism for young figure skaters and encourage athletic development and progression by incorporating a series of achievement awards and improvement certificates. Every skater is given the opportunity to be recognized for national performance, individual achievement and personal improvement.

Participation in S.T.A.R.S. should be fun, motivating, challenging and personally rewarding.

QUALITY ASSURANCE

To establish and maintain quality within the S.T.A.R.S. assessment system, U.S. Figure Skating S.T.A.R.S. combines are overseen by a National Strength and Conditioning Association (NSCA) Certified Strength and Conditioning Specialist (CSCS). Where applicable, individual assessments have been cross-referenced with the NSCA protocol and the NSCA's Essentials of Strength and Conditioning textbook. The CSCS oversees other credentialed fitness professionals as they carry out the assessments during the combine.

A complete list of references used in the development of S.T.A.R.S. and the selection of individual assessments is provided at the end of this manual. In general, certified S.T.A.R.S. assessors are responsible for upholding the integrity of the S.T.A.R.S. assessment protocol.

In some cases, skaters, coaches and/or parents may ask an assessor for assistance with their individual report and feedback to continue performing S.T.A.R.S. assessments individually throughout the competitive season. Such requests should be greeted by assessors as business opportunities but must be handled as independent inquiries and not part of the combine season of assessment. Only assessments performed as part of an official sanctioned S.T.A.R.S. combine will be considered for official S.T.A.R.S. scoring.

COMBINE SEASON AND PARTICIPATION

In keeping with a focus on athleticism, S.T.A.R.S. assessments are conducted during a single and pre-determined combine season.

The S.T.A.R.S. combine season is established by U.S. Figure Skating to coincide with the transition from summer training into the start of the competitive season. At this point in time, skaters should be relatively well-trained and injury free. This point in the season also presents an ideal opportunity for feedback before moving into the intensity of training associated with the competitive season.

Skaters who wish to participate in a S.T.A.R.S. combine must meet the requirements listed below:

1. Skater must be healthy and free of acute physical or mental injury at the time of the assessment.
2. Skater must be a current member in good standing of U.S. Figure Skating.
3. Skater must be at least 6 years of age at the time of the combine.
4. Skater must have passed pre-preliminary moves in the field or higher by the date of the combine.
5. Skater must not have participated in another S.T.A.R.S. combine within the current calendar year.

ASSESSMENT CRITERIA

S.T.A.R.S. is an assessment system designed to support U.S. Figure Skating's existing on-ice testing and competition programs and progressions.

A single S.T.A.R.S. assessment includes 14 active assessments addressing various aspects and combinations of strength, power, flexibility, agility, balance and coordination.

Each individual assessment in the S.T.A.R.S. system was selected for its strong match to a pre-determined set of criteria. More specifically, each individual assessment is:

1. Addressing an aspect of strength, power, flexibility, agility, balance and/or coordination.
2. Easy to instruct and easily understood and preformed for children as young as age 6.
3. A field test or adaptable to a field test setting.
4. Directly or indirectly relevant to on-ice skating skills.
5. Discriminatory in the statistical sense, with the ability to distinguish certain skaters from others.
6. Not redundant, relative to other individual assessments.
7. Having high standards of test-retest reliability

ASSESSMENTS

Assessment Order

1. Hexagon Jump (agility/balance/coordination)
2. Vertical Jump (strength/power)
3. Single Leg Bound Left (strength/power)
4. Single Leg Bound Right (strength/power)
5. Timed Tuck Jumps (strength/power)
6. Push-ups (strength/power)
7. Bent Knee V-ups (strength/power)
8. Side Plank (strength/power)
9. Front Split Left (flexibility)
10. Front Split Right (flexibility)
11. Standing Spiral (flexibility)
12. Seated Reach (flexibility)
13. Lumbar Extension (flexibility)
14. Standing Spiral Balance (agility/balance/coordination)
15. Standing Spiral Balance Eyes Closed (agility/balance/coordination)
16. Anthropometric Measurements

CONTEXT AND CALCULATION

S.T.A.R.S. creates relevance and context through a combination of raw and calculated variables and factors with a strong focus on individual athlete potential

STARS/Q-Age

SP/BMI

Bounder distance per leg length (distance/leg length)

Front split: Percent of potential (distance/ (leg length x 2))

Standing Spiral: Percent of potential (distance/ (leg length x 2 + height lateral malleolus))

Calculated National Factor Scores: Percent of current highest

Calculated National Component Score: 300 ABC/700 SP/500 F

Calculated S.T.A.R.S. Score: 1500 maximum

Calculated S.T.A.R.S. Improvement score (since last combine)

Calculated Talent Identifiers: index, SP/BMI, Q-age

Although normative data does exist for many of the individual assessments in the S.T.A.R.S. system, the program does not utilize combine data in this way. S.T.A.R.S. assessments performed independently outside of the sanctioned combine season may incorporate norms for individual assessment and feedback.

EQUIPMENT AND SET-UP

S.T.A.R.S. was designed with facility flexibility in mind. All required equipment is available at most stores. Equipment includes:

- One bathroom scale (anthro)
- Two disc tape measures (anthro, lumbar extension)
- One tape measure 120" (anthro-height)
- Two yoga mats (v-ups, side plank)
- Three 12 ft. tape measures (vertical jump, splits, seated reach)
- One 24 ft. tape measure (single leg bound)
- One roll of paper (vertical jump)
- Chalk or washable ink pad (vertical jump)
- One hexagon template cut-out
- Two rulers (single leg bound, front splits)
- One metronome (Push-ups)
- Four 2" Styrofoam blocks (side plank)
- Five stopwatches (hexagon, tuck jumps, bent knee v-ups, side plank, Spiral balance)
- Two rolls of duct tape
- Two rolls of painter's tape
- Calculator

RESULTS AND REPORTS

At the end of the combine season, each participating skater will receive and/or have access to a personalized Athlete Report, including introductory feedback on category strengths, weaknesses and imbalances that can be incorporated into the current training plan. A skater's personal Athlete Report includes:

- All raw and calculated data for the four more recent assessment sets
- S.T.A.R.S. score, individual improvement score, individual component index
- Three tables of individual performance according to age/gender category

TABLE OF CONTENTS

U.S. FIGURE SKATING S.T.A.R.S. MANUAL

HEXAGON JUMP

EQUIPMENT

Hexagon template, painter's tape, stopwatch

SET-UP

Place the hexagon template flat on the floor. Using mark the outline of the hexagon shape with painter's tape. If the template is not available, use six strips of tape 24" in length. Use 120 degree angles to create a hexagon shape. The distance between parallel lines will be 41.5"

ASSESSMENT OBJECTIVE

- Recorded for time
- Record time to the nearest .01 second
- Record best time of two successful trials

ASSESSMENT PROTOCOL

1. The athlete warms up and practices performance of the test at submaximal speed.
2. The test begins with the athlete standing in the middle of the hexagon.
3. On an auditory signal, the athlete begins double-leg hopping from the center of the hexagon over each side and back to the center, starting with the side directly in front of the athlete, in a continuous clockwise sequence until all six sides are covered three times (total of 18 jumps) and the athlete is again standing at the center. The athlete remains facing the same direction throughout the test.
4. Stop the trial and re-start if any of the following occur:
   - Athlete lands on tape or inside hexagon rather than jumping outside of hexagon
   - Athlete's body changes directions or goes in wrong direction
   - Athlete falls/steps out or takes an extra step

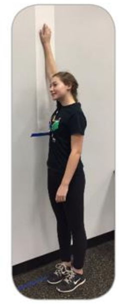
NSCA cross-referenced in "Essentials of Strength and Conditioning" textbook p.264

U.S. FIGURE SKATING S.T.A.R.S. MANUAL

VERTICAL JUMP

EQUIPMENT

Roll of paper, tape (to secure paper to wall and mark 6" line from wall), 12 ft. tape measure, chalk or washable ink



SET-UP

Secure a 6-9 ft. scroll of paper to a wall using tape. Place an additional piece of tape exactly 6" from the wall.

ASSESSMENT OBJECTIVE

- Recorded for distance (height of jump)
- Record measurement of point between standing reach mark and highest mark for vertical jump
- Record jump height to nearest .5 inch.
- Record the highest jump of three trials

ASSESSMENT PROTOCOL

1. Mark the index finger of the athlete's dominant hand with chalk or ink.
2. Have the athlete stand with the dominant shoulder 6" from the wall, and with both feet flat on the floor, athlete will reach as high as possible with the dominant hand and make a chalk/ink mark on the paper affixed to the wall.
3. The athlete then lowers the dominant hand and without a preparatory or stutter step performs a countermovement by quickly flexing the knees and hips moving the trunk forward and downward and swinging the arms backward. During the jump the dominant arm reaches upward, while the other arm moves downward relative to the body.
4. At the highest point, the athlete places a second mark on the wall with the fingertip of the dominant hand. The score of the vertical jump is the distance between the two marks (standing and jumping).
5. Record the best of three trials to the nearest 0.5 inch.

U.S. FIGURE SKATING S.T.A.R.S. MANUAL

SINGLE LEG BOUND LEFT

EQUIPMENT

24 ft. tape measure, duct tape, 12 in. ruler or clipboard

SET-UP

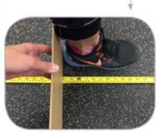
Secure a 24 ft. tape measure to the floor using duct tape. Ensure the duct tape lines up with the zero mark of the tape measure to create a starting line for the athlete's toes.

ASSESSMENT OBJECTIVE

- Recorded for distance
- Recorded to the nearest 0.5 inch
- Record measurement from the heel of the landing foot
- Record the longest distance of two successful trials

ASSESSMENT PROTOCOL

1. The athlete begins by standing on one leg with his or her toes on the starting line.
2. The athlete will perform a maximal hop for distance landing on the same leg.
3. Arms may swing freely or stay at the side, but must stay consistent with trials.
4. Landing position must be held for 2 seconds with no loss of balance or extra steps (once balanced is established athlete may rest on both feet while measurement is taking place)
5. Distance is measured from the starting line (0" mark of tape measure) to where the posterior heel lands.
6. Assessment is performed on both the left and right foot.
7. STARS score is calculated by bounding normalized by leg length (bounding distance/leg length)



U.S. FIGURE SKATING S.T.A.R.S. MANUAL

TIMED TUCK JUMPS

EQUIPMENT

48" elastic band, duct tape or painter's tape, stopwatch

Tuck jump setup

SET-UP

Using an open wall space, secure tape to wall surface according to athlete's hip height

ASSESSMENT OBJECTIVE

- Count
- Record number of successful jumps in 30 second trial
- One trial (re-test if there is an assessor or equipment error)

ASSESSMENT PROTOCOL

1. Position the athlete parallel to the wall. Have the athlete raise the leg closest to the wall so both the knee and hip are flexed at 90 degrees. At the height of the patellar tip of the flexed knee, affix the 48" elastic band or tape to the wall. Pull so the band/tape is perpendicular from the wall.
2. Remind the athlete that only proper tuck jumps where the knee reaches the same height as the band or tape will be counted.
3. Line the athlete up so they are able to execute a tuck jump approx. 12-24" away from the band/tape to provide the assessor a visual line of sight for the height of each jump. Have the athlete execute 2-3 practice jumps prior to the start of the test.
4. On the assessor's count, begin the test and time the assessment for 30 seconds. Terminate the test if the athlete rests/fails to take off immediately upon landing, or double bounces/stutter steps.
5. Record only the number of jumps where the knees have come level or above the height of the band or tape.

Incomplete jump

PUSH-UPS

EQUIPMENT

metronome set to 60 bpm, yoga mat (optional)

SET-UP

Have metronome pre-set to 60 bpm and positioned close enough that the athletes and assessor can clearly hear the beat

ASSESSMENT OBJECTIVE

- Count
- Complete as many push-ups as possible while maintaining cadence with the metronome and proper body position
- Record the number of successful repetitions

ASSESSMENT PROTOCOL

1. Have the athlete assume a prone plank position with the hands directly under the shoulders, feet together, ankles flexed and fingers facing forward.
2. Set the metronome directly in front of the athlete.
3. Athlete bends arms, lowering chest until the elbows are flexed at 90 degrees with elbows pointing 45 degrees back from torso, while maintaining flat body position and returning to straight arm position.
4. Repeat push-ups to beat of metronome, 1 second down, 1 second up rhythm.
5. Count the number of full push-ups athlete is able to complete without breaking the rhythm or body position.
6. Allow athlete to practice and demonstrate proper down and up positions prior to the start of the test.
7. Coach as needed on position and rhythm.
8. Terminate the test if the athlete is unable to maintain rhythm or form for three consecutive push-ups.

Push-up starting position

Push-up down position

Improper positions

Incomplete position

BENT KNEE V-UP

EQUIPMENT

Yoga mat, stopwatch

SET-UP

Place yoga mat in an open area so athlete has ability to have full range of motion from supine position

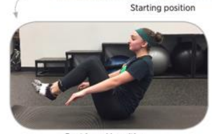
ASSESSMENT OBJECTIVE

- Count
- Complete as many repetitions as possible in 30 second trial
- Record the number of successful repetitions completed in 30 seconds
- One trial (re-test if there is an assessor or equipment error)

ASSESSMENT PROTOCOL

1. Have the athlete lay in a supine position on the mat, feet slightly apart, legs fully extended and heels gently touching the floor with the arms extended along sides of body.
2. Have athlete demonstrate the bent knee v-up position by having them simultaneously lift their legs and torso while bringing the knees towards the chest and heels towards the glutes so the athlete is balanced on the tailbone, creating a "V." The athlete then returns to a fully extended position with the heels and scapulae hitting the mat/floor between each repetition. Arms remain extended at the athlete's side.
3. On the assessor's cue, begin the timer and record the number of successful repetitions in a 30 second trial.
4. Coach the athlete on technique and emphasize the pace to be as quick as possible.

Starting position



Bent knee V position

Error - heels off floor

Error - athlete doesn't obtain V position

SIDE PLANK

EQUIPMENT

Yoga mat, stopwatch, 60" tape measure, two Styrofoam blocks, duct/painters tape

SET-UP

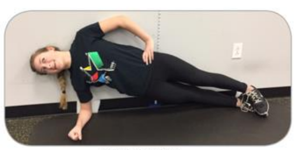
Secure 60" tape measure to a wall using either duct tape or painter's tape. Place Styrofoam blocks behind the athlete's elbow and heel.

ASSESSMENT OBJECTIVE

- To maintain plank position for maximum amount of time
- Record time to nearest .01 second
- Maximum time of 120 seconds
- Record time during one trail (re-test if there is an assessor or equipment error)

ASSESSMENT PROTOCOL

1. Have athlete lay on his/her side with dominant elbow and forearm on the floor. The side of the dominant side foot is on the floor with the other foot stacked directly on top.
2. Have athletes ASIS lined up with the vertical tape measure and place Styrofoam blocks behind the athlete's elbow and heel.
3. Have athlete demonstrate the side plank position by lifting core and bringing the body into a straight line, with supporting shoulder directly over supporting hand. Glutes and shoulders should be pressing toward the wall, feet stack and free hand placed on the hip.
4. Note the height of the athlete's hip while in the neutral position. This is the starting height for the test.
5. When the athlete is ready to begin the test, start the stopwatch once the plank position is established. Coach the athlete to hold the proper body position.
6. Terminate the test if the athlete's ASIS drops two inches from the starting point or if the athlete loses balance and touches down with the free hand or knees or moves hips and shoulders away from the wall.



Side plank position

Hip height

Elbow and shoulder position

Heel position

FRONT SPLIT

EQUIPMENT

12 ft. tape measure, ruler, duct tape, 12" ruler, calculator

SET-UP

Secure a 12 ft. tape measure to the floor using duct tape. Have ruler and calculator accessible for measurement and recording.

ASSESSMENT OBJECTIVE

- To demonstrate a split position to the best of the athlete's ability
- Distance
- Record distance to the nearest 0.5 inch
- Athlete's score is based on their recorded distance in relationship to their leg length (which predicts maximum range of motion)

ASSESSMENT PROTOCOL

1. Athlete stands parallel to the measuring tape. Using hands for balance, the athlete extends the front and back legs lowering hips toward the ground into a split position.
2. If the athlete demonstrates a full split position with feet, knees and hips on the ground, record the score as 100 percent (not necessary to measure distance).
3. If the athlete is not in full contact with the floor and uses their hands for balance, record the distance of the split. Identify the distance on the tape measure for the lateral malleolus of the right and left foot. Use the ruler to accurately line up the center of the lateral malleolus with the tape measure. Subtract the difference to identify the distance of the front split.
4. Repeat the assessment for the other leg.
5. S.T.A.R.S. score is calculated by the following equation: split distance / (leg length x 2)

Full split position

Split measurement

STANDING SPIRAL

EQUIPMENT

120" tape measure (with duct tape flap)

SET-UP

Place the athlete proximal to a wall or railing (to be used for balance) and place the duct tape flap underneath the heel of the athlete's standing foot.

ASSESSMENT OBJECTIVE

- To measure the distance of the athlete's spiral position
- Record distance to the nearest 0.5 inch
- Athlete's score is based on their recorded distance in relationship to their leg length

ASSESSMENT PROTOCOL

1. Athlete places duct tape flap under the heel of the preferred standing leg.
2. Using their own balance, the athlete will extend their free leg and assume a full spiral position.
3. The athlete may use a chair, railing or wall for balance while the measurement is being taken. Take note the athlete is not to lean their body weight into the arm, but only use the wall, chair or railing for balance.
4. When the athlete has assumed a spiral position, record the distance from the athlete's heel to the lateral malleolus of the free leg.
5. Record the distance on the score sheet
6. STARS score is calculated by the following equation: spiral distance / (leg length x 2 + height of lateral malleolus)


Spiral with full split


Spiral leaning against wall


Spiral measurement

SEATED REACH

EQUIPMENT

12 ft. tape measure, painter's tape

SET-UP

Secure the 12 ft. tape measure to the floor, place a piece of painter's tape 12" in length across the 15" mark on the 12 ft. tape measure.

ASSESSMENT OBJECTIVE

- To reach the hands as far as possible from a seated position
- Distance
- Record distance to the nearest 0.5"
- Record the greatest distance of three measured trials

ASSESSMENT PROTOCOL

1. Have the athlete sit shoeless with the 12 ft. measuring tape between the legs and the feet 12" apart, lined up with the piece of painter's tape. The athlete's feet are flexed and the heels are touching the ends of the tape.
2. The angle between the thigh and pelvis should be 90 degrees. If the thigh to pelvis angle is greater than 90 degrees, the athlete receives a zero as they are unable to achieve the correct start position.
3. Have the athlete slowly reach forward with both hands as far as possible on the measuring tape, holding the extended position momentarily. To get the best stretch, the athlete should exhale and drop the head between the arms when reaching.
4. Be sure the athlete keeps the hands adjacent and does not lead with one hand. Fingertips should remain in contact with the tape measure.
5. Ensure the athlete is not bending their knees during the trial.


Starting position


Seated reach


Feet position


Hand position


Error - bent knees on reach

LUMBAR EXTENSION

EQUIPMENT

Tape measure

SET-UP

No set-up necessary for equipment

ASSESSMENT OBJECTIVE

- Achieve the greatest degree of flexibility in the spine
- Distance
- Record distance to the nearest 0.5 inch
- Record the smallest distance of two measured trials

ASSESSMENT PROTOCOL

1. Have the athlete warm-up their back flexibility by completing a few repetitions of down dog and up dog/cobra.
2. The athlete will begin in a prone position. They will then place their wrists directly under the shoulders to pull their chest up.
3. The athlete will arch their back, extending the spine and pull the feet toward the head.
4. Once the athlete has completed the greatest range of motion, measure the distance from the crown of the head to the toe closest to the head.
5. Record the smallest distance of two trials.
6. If athlete touches their toes to their head, record a distance of zero.


Starting position


Full lumbar extension

SPIRAL BALANCE

EQUIPMENT

6" strip of duct tape/painters tape, stopwatch

SET-UP

In an open area, secure tape to the floor allowing for plenty of space for athlete to achieve a spiral position

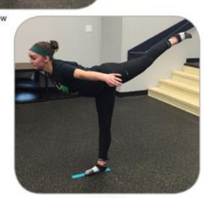
ASSESSMENT OBJECTIVE

- To balance in a spiral position for maximal amount of time
- Time
- Record time to the nearest .01 second
- Maximum time of 120 seconds
- One trial for open eye assessment, two trials for closed eye assessment

ASSESSMENT PROTOCOL

1. Have the athlete stand on the dominant leg so it is lined up on the tape secured to the floor.
2. Ensure the test is not being performed in front of a mirror or glass surface where the athlete has an advantage of using visual focal points.
3. Have the athlete demonstrate a spiral position where they hinge at the hips and elevate the free leg to the height of the hip or higher (hip may be externally rotated).
4. Athlete may extend arms to assist with balance.
5. Once the position is established, the assessor will begin the stopwatch.
6. Terminate the test if the athlete's free leg drops below hip height, if the athlete touches down with their hands or if the standing leg moves off the established position on the duct tape.
7. Repeat the test with the eyes closed.
8. For closed eye assessment, allow the athlete to rest a minimum of 60 seconds between open eye and closed eye trials. Once the athlete establishes the position, the assessor will count down, instruct the closing of eyes and begin timing the trial. Repeat a second trial for the closed eye portion.


Front view


Side view


Terminate test if athlete loses balance

ANTHROPOMETRIC MEASUREMENTS

Instruct athlete to remove shoes for the duration of all anthropometric measurements.

Record distances to the nearest 0.25 inch.

Record weight to the nearest 0.5 pound.

BODY WEIGHT

1. Ensure scale is level on solid floor.
2. Athlete stands on scale for body weight measurement.
3. Use utmost sensitivity in the weighing of athlete.

HEIGHT OF HEAD

1. Instruct athlete to stand up straight with back and heels against vertical measurement tape attached to wall.
2. Use a straight edge on top of athlete's head to meet tape measure at height measurement.

LEG LENGTH

1. Instruct athlete to put his/her weight on spiral skating leg; use other foot for balance as necessary.
2. Verbally inform athlete that you are about to touch the upper outer part of the leg.
3. Palpate ASIS and use thumb or forefinger to anchor disc tape measure zero mark. Pull tape measure down to the center of the lateral malleolus to record leg length measurement.

HEIGHT OF LATERAL MALLEOLUS

1. Athlete stands on both feet with feet hip width apart.
2. Anchor zero point of disc tape measure at the center of lateral malleolus of spiral free leg.
3. Measure distance from lateral malleolus to floor.

THIGH CIRCUMFERENCE

1. Athlete stands on both feet with feet hip width apart.
2. Verbally indicate to athlete that you are going to "wrap tape measure around upper leg."
3. Using disc tape measure, encircle leg and raise/lower tape measure to find greatest circumference of the thigh.

HIP WIDTH

1. Instruct athlete to stand on two feet with feet together.
2. Verbally indicate you are "about to touch your hips."
3. Palpate widest point of posterior iliac crest bilaterally.
4. Anchor zero point of disc tape measure at widest point on one side.
5. Measure distance from widest point to widest point of iliac crest.

SHOULDER WIDTH

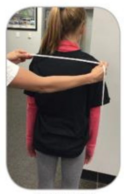
1. Verbally indicate to athlete "about to touch outsides of shoulders."
2. Palpate most lateral points of left and right shoulders at greater tuberosity of each humerus, respectfully.
3. Anchor zero point of disc tape measure at outermost point on one arm.
4. Measure distance from widest point to widest point.

Leg length

Hip width

Height of lateral malleolus

Thigh circumference



Shoulder width

REFERENCES

1. Barber-Westin, Noyes, Galloway Am J Sports Med 2006 Mar 34(3):375-84 Jump-land characteristics and muscle strength development in young athletes: a gender comparison of 1140 athletes 9 to 17 years of age.
2. Bradley Curr Sports Med Rep 2006 Sep 5(5):258-61 Prevention and treatment of foot and ankle injuries in figure skaters.
3. Bruening, Richards J App Biomech2006 Nov 22(4):285-95 The effects of articulated figure skates on jump landing forces.
4. Butcher, Crave, Chilibeck, Spink, Grona, Springings J Orthop Sports Phys Ther 2007 May 37(5):223-31 The effect of trunk stability training on vertical takeoff velocity.
5. Dubravcic-Simunjak, Pecina, Kuipers, Moran, Haspl Am J Sports Med 2003 Jul-Aug 31(4):511-7 The incidence of injuries in elite junior figure skaters.
6. Haguenauer, Legreneur, Monteil2006 J Biomech 39(4):699-707 Influence of figure skating skates on vertical jumping performance.
7. King Can J Appl Physiol2005 Dec 30(6):743-53 Performance triple and quadruple figure skating jumps: implications for training.
8. Kjaer, Larsson J Sports Sci 1992 Feb 19(1):29-36 Physiological profile and incidence of injuries among elite figure skaters.
9. Kovacs, Birmingham, Forwell, Litchfield ClinJ Sport Med 2004 Jul 14(4):215-24 Effect of training on postural control in figure skaters: a randomized controlled trial of neuromuscular versus basic office training program.
10. Leone, Mariviere, Comtois J Sports Sci2002 Jun 29(6):443-9 Discriminant analysis of anthropometric and biomotorvariables among elite adolescent female athletes in four sports
11. Lipetz, Kruse Clin Sports Med 2000 Apr 19(2):369-80 Injuries and special concerns of female figure skaters.
12. Lockwood, Gervais, Mccreary Sports Miomech 2006 Jul 5(2):231-41 Landing for success: a biomechanical and perceptual analysis of on-ice jumps in figure skating.
13. Mannix, Healy, Farber J Sports Med Phys Fitness 1996 Sep 36(3):161-8 Aerobic power and supramaximal endurance of competitive figure skaters.
14. Monsma, Malina J Sports Med Phys Fitness 2005 Dec 45(4):491-500 Anthropometry and somatotypeof competitive female figure skaters 11-22 years. Variation by competitive level and discipline.
15. Nadler, Malanga, Feinberg, Prybicien, Stitik, DePrince Am J Phys Med Rahabil 2001 Aug 80(8):57207 Relationship between hip muscle imbalance and occurrence of low back pain in collegiate athletes: a prospective study.
16. Omey, Micheli, Gerbino Clin Orthop RelatRes 2000 Mar (372):74-84 Idiopathic scoliosis and spondylolysisin the female athlete. Tips for treatment.
17. Pauole,Madole, Garhammer, Lacourse, RozenekJ Strength CondRes 2000 14:443-450 Reliability and validity of the T-test as a measure of agility, leg power and leg speed in college age males and femailes.
18. Podolsky, Kaufman, Cahalan, Aleshinsky, Chao Am J Sports Med 1990 Jul-Aug 18(4):400-5 The relationship of strength and jump height in figure skaters.
19. Semenicj NSCAJ 1990 12(1):36-37 Tools and measurement: The T-test.
20. Smith ClinSports Med 2000 Oct 19(4):741-55 The Young Skater.
21. Smith, Norris, Hogg Sports Med 2002 32(9):539-54 Performance evaluation of swimmers: scientific tools.
22. Smith, Stroud, McQueen J Pediatr Orthop1991 Jan-Feb 11(1):77-82 Flexibility and anterior knee pain in adolescent elite figure skaters.
23. Ugarkovic, Matavulj, Kukolj, Jaric J Strength Cond Res 2002 May 16(2):227-30 Standard anthropometric, body composition, and strength variables as predictors of jumping performance in elite junior athletes.
24. Wilkerson, Colston, Short, Neal, Hoewischer, Pixey J AthlTrain 2004 Mar 39(1):17-23 Neuromuscular changes in female collegiate athletes resulting from a plyometric jump-training program.

Appendix E. High Performance Movement Screen

HPMS INTRODUCTION

The purpose of the movement screen designed by the United States Figure Skating High Performance Department, is to assess movement patterns in figure skaters to identify and treat mechanics that may prohibit optimal performance. Figure skaters have the highest risk of overuse injury in the lower extremity as well as an elevated risk of concussion and the tests included in the high performance movement screen are valid and reliable tests to assess mobility and stability in the lower extremity as well as baseline test for concussion. These tests include the y-balance test, single leg squat, rotary stability, shoulder mobility, hip mobility, and the balance error scoring system. It is important to note that the goal of the movement screen is not to predict injury. Rather, the goal is to minimize risk of injury and maximize performance.

HIGH PERFORMANCE MOVEMENT SCREEN OBJECTIVES

1. Evaluate stability, mobility and symmetry through evidence based assessments
2. Score the athletes according to color coded flags to properly recommend training progressions and corrective exercises to increase mobility, stability and symmetry
3. Connect athletes, parents and coaches to a network of professionals with experience in movement screens and exercise prescription
4. Provide a baseline concussion assessment

STRUCTURE/SET-UP

The High Performance movement screen is administered by a physician, physical therapist or certified athletic trainer that has experience in movement screens and also been trained by the U.S. Figure Skating Sports Science and Medicine staff. The screen is a one-on-one evaluation that takes approximately 30 min. to complete. The assessor moves through the evaluations with the skater recording the scores, measurements and any notes/feedback on the athlete's score sheet.

The assessment requires a small open space, with a solid floor surface and the following pieces of equipment:

1. Y Balance Apparatus
2. Athletic training table, or bench/bleacher
3. Tape measure
4. Yoga mat with two parallel pieces of painters tape exactly 6 in. apart
5. Airex mat
6. Stopwatch
7. Clipboard

ATHLETE SCORING AND FEEDBACK

The skater will receive feedback in the categories of balance, mobility, stability and movement. Each assessment will correspond with a colored flag: green, yellow, and red. A green flag indicates that the athlete completed the movement similar on both the right and left sides. The yellow flag indicates that the athlete demonstrated some asymmetry in the movement and may benefit from some exercises to assist with asymmetry. A red flag indicates that either a movement was completed with large asymmetry between limbs or the athlete demonstrated a movement pattern that has been associated with increased risk of injury. All asymmetry measures used to assign flags are evidence-based. Dependent on the assigned color of the flag, the athlete will then be guided to a specific protocol of corrective exercises or continued training progressions for that category. These exercises will be accessed through an online link specific for that athlete. Assessors will also have the opportunity to provide additional feedback or recommendations for the participating athletes.

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Y BALANCE ASSESSMENT

EQUIPMENT

Y-Balance Apparatus

SET-UP

The skater will be barefoot for the assessment. They will have an opportunity to practice three trials in each direction prior to the assessment.

ASSESSMENT

- The skater will begin standing barefoot with their big toe lined up with the line on the Y-balance apparatus.
- The skater will complete the assessment with both hands placed on the hips.
- While maintaining a single leg stance, the skater reaches with the free limb in the anterior, posteromedial and posterolateral directions in relation to the stance foot by pushing the indicator box as far as possible.
- The skater will complete three consecutive trials, then alternate limbs for each direction.
- Attempts will be discarded if the skater fails to maintain a unilateral stance, fails to maintain reach foot contact with the indicator while the reach indicator is in motion, uses the reach indicator for support or fails to return the reach foot to the starting position under control.
- Record athlete's leg length by measuring from the ASIS to the medial malleolus of the dominant leg"

MEASUREMENT AND SCORING

- Each trial will be recorded on the score sheet.
- Numbers will be recorded to the nearest whole number. If you do not see the line, the last number that you see the line will be recorded.
- The average of each direction will be calculated in the athlete report.

THOMAS TEST

EQUIPMENT

A flat table or bench, a tape measure

ASSESSMENT

- Skater lies supine.
- Skater brings one knee up to the chest.
- Assessor will place hand under lumbar spine to ensure the back remains flat during the test.
- Assessor will ensure that the extended leg is relaxed and that the hip flexion is a passive range of motion.
- If the leg is not flat on the table or the back is arched, it is considered a positive test.

MEASUREMENT AND SCORING

- If the test is positive (there is space between the knee joint and table), record the distance of the gap from the joint line to the table.
- Record the test as positive or negative on the athlete score sheet.
- Record distance (if any) for each leg on athlete scoresheet.

SINGLE LEG SQUAT

EQUIPMENT

No equipment necessary

SET-UP

Skater will stand with hands on hips and eyes focused on an object straight ahead. Foot will be pointed straight ahead with standing foot, ankle, knee and lumbo-pelvic hip complex (LPHC) in a neutral position and free leg parallel to the standing leg.

Skater will be barefoot for the assessment.

ASSESSMENT

- Have the skater squat to a comfortable level and return to the starting position.
- The skater will perform five consecutive squats. The free leg will remain parallel to the standing leg (and will not tuck behind the standing foot).
- Observe the athlete's knee. Does the knee move inward (adduct and internally rotate)?
- Record each repetition where the skater's knee adducts internally, crossing the medial border of the patella to the first ray (big toe).
- Repeat the assessment on the other leg.

MEASUREMENT AND SCORING

- All repetitions that the skater displayed knee valgus will be recorded on the score sheet with a "Y" (for YES knee valgus) and record a "N" for each squat that demonstrates a proper movement pattern and no valgus or deviation (for NO knee valgus).

Squat with no deviation

Squat with medial collapse

Improper free leg squat

SHOULDER MOBILITY ASSESSMENT

EQUIPMENT

Tape measure

SET-UP

First record the length of the hand of the skater by measuring the distance from the distal wrist crease to the tip of the third digit.

- Record the length in cm

ASSESSMENT

- Instruct the skater to make a fist with each hand, placing the thumb inside the fist.
- Have the skater assume a maximally adducted, extended and internally rotated position with one shoulder and a maximally abducted, flexed and externally rotation position with the other shoulder.
- Hands are to remain in a fist during the test and placed on the back in one smooth motion.
- The assessor will measure the distance between the two closest bony prominences.
- Perform up to three trials bilaterally. If the first repetition is completed successfully, there is no reason for a second trail.

MEASUREMENT AND SCORING

- The flexed shoulder identifies the side being tested.
- Record distance on score sheet.

ROTARY STABILITY

EQUIPMENT

Yoga mat with two strips of tape exactly 6" apart

SET-UP

Skater assumes the starting position in quadruped, their shoulder and hips at 90 degree angles relative to the torso with 6" between their hands and feet (as marked by the tape on the mat). Knees are positioned at 90 degrees and the ankles should be dorsiflexed.

ASSESSMENT

- The skater will first attempt a unilateral reach by flexing the shoulder and extend the same side hip and knee.
- The leg and hand are only raised enough to clear the floor, approximately 6".
- The same shoulder is then extended and the knee is flexed enough for the elbow and knee to touch.
- The assessment is then performed bilaterally, up to three trials for each side.
- If the skater is unable to complete this maneuver, they will attempt to perform a diagonal pattern using the opposite shoulder and hip in the same manner as the previous test.
- The skater is allocated up to three trials on the diagonal assessment.

MEASUREMENT AND SCORING

Mark "Yes" or "No" if athlete is able to complete the unilateral and diagonal movements. If the unilateral movement is completed bilaterally there is no need to test diagonally.

TIPS FOR TESTING

- The upper extremity that moves indicates the side being tested. Even if the skater receives a 3, the test must be performed bilaterally with all results recorded on the score sheet.
- The moving limbs must remain over the tape lines to achieve a score of 3.
- The elbow and knee must touch during the flexion part of the movement.
- The spine must be flat, and the hips and shoulders are at right angles to begin the test.
- Provide cueing to let the skater know that he/she does not need to raise the arm and leg more than 6" off the floor.
- When in doubt, score low.
- Do not try to interpret the score when screening.
- Back toes are turned under and the heel remains over the toes, not leaning out to the side during the test.

BALANCE ERROR SCORING SYSTEM

EQUIPMENT

Airex foam mat, stopwatch

SET-UP

Skater will perform a 20 second trial in three different stances on two different surfaces.

ASSESSMENT

- Assessor will conduct 20 second trials on a double leg stance, single leg stance and tandem stance. First on a firm floor surface and then on an Airex mat.
- Assessor will count the number of errors (deviations) from the proper stance.
- Stances will be performed as follows:

Double leg stance: Feet are flat on testing surface approximately pelvic width apart.

Single leg stance: Skater stands on the non-dominant leg with the degrees of knee flexion and neutral position in the frontal plane.

Tandem stance: One foot is placed in front of the other with the heel of the anterior foot touching the toe of the posterior foot. The skater's non-dominant leg is the posterior position and should be determined by kicking preference.

MEASUREMENT AND SCORING

- Assessor will mark errors for each stance on each surface on athlete scoresheet.

ERRORS INCLUDE ALL OF THE FOLLOWING

- Moving hands off the hips.
- Opening the eyes.
- Step, stumble or fall.
- Abduction or flexion of the hip beyond 30 degrees.
- Lifting forefoot or heel off testing surface.
- Remaining out of proper testing position for more than five seconds.

Bipedal stance

Single leg stance

Tandem stance

HPMS REFERENCES

1. Bell D, Guskiewicz K, Clark M, Padua D; Systemetic review fo the balance error scoring system; Sports Health, 2011 May 3:287-295
2. Chang M, Slater LV, Corbett RO, Hart JM, Hertel J. Muscle activation patterns of the lumbo-pelvic-hip complex during walking gait before and after exercise. Gait & Posture. 2016;IN PRESS.
3. Claiborne TL, Armstrong CW, Gandhi V, Pincivero DM. Relationship between hip and knee strength and knee valgus during a single leg squat. J Appl Biomech. 2006;22:41-50.
4. Clark, Michael A., Lucett, Scott C.; NASM Essentials of Corrective Exercies Training. 2011
5. Cook G, Burton L, Hoogenboom B, Voight M; Functional Movement Screening' The use of fundamental movements as an assessment of function- part 2
6. Crossley KM, Zhang W-J, Schache AG, Bryant A, Cowan SM. Performance on the single-leg squat task indicates hip abductor muscle function. Am J Sports Med. 2011;39:866-73.
7. Dubravcic-Simunjak S, Pecina M, Kuipers H, Moran J, Haspl M. The incidence of injuries in elite junior figure skaters. Am J Sports Med. 2003;31:511-7.
8. Edwards TB, Bostick RD, Greene CC, Baratta RV, Drez D. Inter-observer and intra-observer reliability of the measurement of shoulder internal rotation by vertebral level. J Shoulder Elbow Surg. 2002; 11:40-42.
9. Fortin JD, Roberts D. Competitive figure skating injuries. Pain Physician. 2003;6:313
10. Glaws K, Juneau C, Becker L, Di Stasi S, Hewett, T. Intra and Inter Rater reliability of the selective functional movement assessment (SFMA). IJSPT April 2014; 9:195-207
11. Guskiewicz KM. Balance assessment in the management of sport-related concussion. Clin Sports Med. 2011;30:89-102.
12. Herrington L. Knee valgus angle during single leg squat and landing in patellofemoral pain patients and controls. The Knee. 2014;21:514-7.
13. Hoving JL, Buchbinder R, Green S, Forbes A, Bellamy N, Brand C, Buchanan R, Hall S, Patrick M, Ryan P, Stockman A. How reliably do rheumatologists measure shoulder movement? Ann Rheum Dis. 2002; 61: 612-616.
14. McCrea M, Guskiewicz KM, Marshall SW, Barr W, Randolph C, Cantu RC, et al. Acute effects and recovery time following concussion in collegiate football players: the NCAA Concussion Study. JAMA. 203;290:2556-63.
15. Padua DA, Bell DR, Clark MA. Neuromuscular characteristics of individuals displaying excessive medial knee displacement. J Athl Train. 2012;47:525-36.
16. Pilsky PJ, Rauh MJ, Kaminski TW, Underwood FB. Star excursion balance test as a predictor of lower extremity injury in high school basketball players. J Orthop Sports Phys Ther. 206;36:911-9.
17. Smith CA, Chimera NJ, Warren M. Association of y balance test reach asymmetry and injury in division I athletes. Med Sci Sport Exer. 2015;47:136-141

Appendix F. Supplemental videos

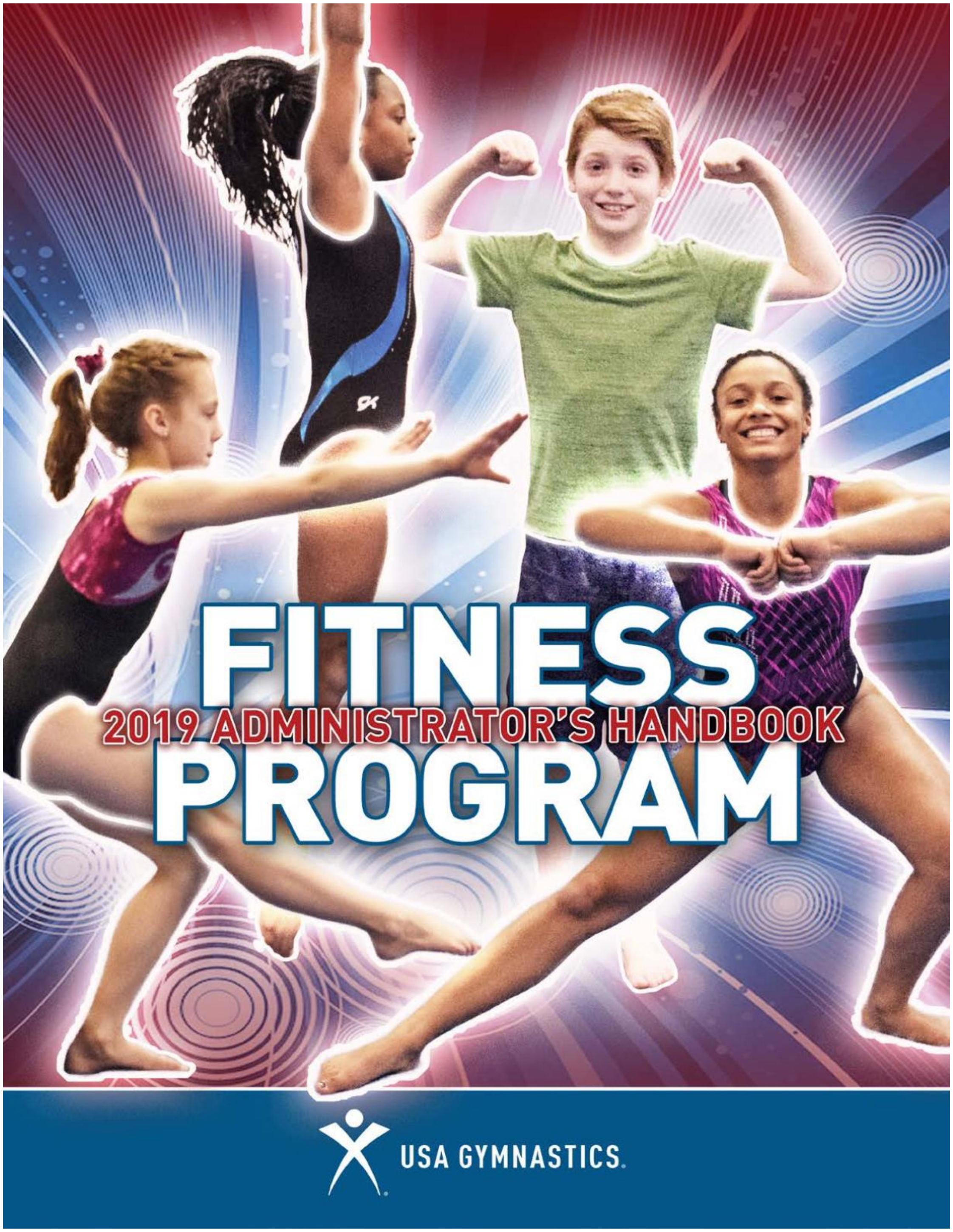
Video F1: https://www.youtube.com/watch?v=hqz0WOu7bRE&list=PL-CheZaoFWwQtDam8Fv62p_lqRHvai0ST&t=1s

Video F2:
https://www.facebook.com/433625946686191/videos/699678550857559

Video F3:
https://www.youtube.com/watch?v=FLvS-oQLeaw&list=PL7Kmj40VqIOqpPIRkTwcbyafbq_GfXNrZ

Video F4:
https://www.youtube.com/watch?v=_dRwJiYjBZw&list=PL7Kmj40VqIOoy7Thm9h3V4BojIn2FCyof

Appendix G. USAG Fitness Program 2019 Administrator's Handbook
Retrieved from: https://usagym.org/pages/home/fitness/handbook.html



Appendix H. Functional Movement Screen
Retrieved from: https://www.simonjarvismovementspecialist.com/movementtests

THE 7 TESTS OF THE FUNCTIONAL MOVEMENT SCREEN

LEARN WHETHER YOU SHOULD TRAIN OR CORRECT EACH MOVEMENT PATTERN.

Deep Squat
(Functional Movement)

- Assess bilateral, symmetrical and functional mobility of the hips, knees, and ankles.

Hurdle Step
(Functional Movement)

- Assess the bilateral functional mobility and stability of the hips, knees, and ankles.

In-Line Lunge
(Functional Movement)

- Assess torso, shoulder, hip and ankle mobility and stability, quadriceps flexibility and knee stability.

Shoulder Mobility
(Fundamental Mobility)

- Assess bilateral shoulder range of motion, combining internal rotation with adduction and external rotation with abduction.

Active Straight Leg Raise
(Fundamental Mobility)

- Assess active hamstring and gastroc-soleus flexibility while maintaining a stable pelvis and active extension of opposite leg.

Trunk Stability Push Up
(Fundamental Core Strength)

- Assess trunk stability in the sagittal plane while a symmetrical upper-extremity motion is performed.

Rotary Stability
(Fundamental Core Stability)

- Assess multi-plane trunk stability during a combined upper and lower extremity motion.