Position Statement of the Association of Ringside Physicians on the Younger Fighter

PHYSIOLOGICAL AND MEDICAL CONSIDERATIONS FOR THE YOUNGER COMBAT ATHLETE

Andrea Verburg Hill MD MBA[1], Morgan Heinzelmann-Weisbaum MD[2], Joe Ghorayeb DC MHA[3], Davide Bianche MD[4], Zachary Crockett MD[5], Toqa Afifi MD[5], Mario Iglesias Muñiz MD[6], Ali Khatib M.Sc[7] , Kevin deWeber MD, FAMSSM, FAAFP, FACSM[8]

Affiliations

[1] Medical College of Georgia, Atlanta, Georgia, USA
[2] Emory University, Atlanta, Georgia, USA
[3] University of Medicine and Health Sciences, New York, New York, USA
[4] Medbase Sport Center, Geneva, Switzerland
[5] Harvard Medical School, Boston, Massachusetts, USA
[6] Theresienkrankenhaus Mannheim, Department of Trauma Surgery, Mannheim, Germany
[7] UBC Faculty of Medicine, Vancouver, British Columbia, Canada
[8] Oregon Health and Science University, Portland, Oregon, USA

Abstract and ARP Position Statement

Based on the available body of scientific evidence and with the goal of promoting safe sport, the Association of Ringside Physicians (ARP) recommends the following regarding the young combat sport athlete, defined as less than 19 years of age.

- Clinicians should maintain a high index of suspicion for growth plate injuries and physeal stress overuse injuries among this population. Complaints of persistent bone or joint pain should be evaluated by an orthopedic surgeon or sports medicine physician. Failure to identify and treat such injuries can disrupt long-term growth and development.

- Any child or adolescent with stage 2 hypertension, as determined according to age, height and gender specific parameters, should be restricted from combat sports until blood pressure is under control. Substances that could elevate blood pressure, such as energy drinks, should be discouraged in this age group. All athletes with persistently elevated blood pressure should be evaluated by a cardiologist or sports medicine physician before participation clearance is given.

- Weight cutting should be discouraged and even banned in children and adolescents. The practice of weight cutting reduces blood volume, which can increase cardiovascular strain by decreasing stroke volume and heart rate; the primary compensatory mechanism in children to meet increased cardiac demands associated with exertion. Furthermore, the increased loss of sodium and water makes this age group particularly susceptible to injury from rapid water loss.

- Training should only occur under the supervision of qualified instructors. These instructors should be skilled in the instruction of defensive and offensive techniques and tactics, and should be educated in concussion signs and symptoms.

- Training time should be limited to the amount needed for learning a skill set. Sparring in training should be minimized in those 12 years old and younger due to critical brain development occurring during these early years.

- In competition, head strikes should be discouraged or even banned for athletes under 13 years of age in order to reduce the high risk of developing Chronic Traumatic Encephalopathy associated with head trauma in the young athlete.

- Post-bout exams should be thoroughly conducted and medical suspensions for concussions should be individualized.

Introduction

The participation of young athletes in combat sports has become widely popular within many fields of martial arts and boxing. With the recent increased participation of these younger fighters in the sport of MMA, and with the popularity of MMA constantly on the rise, it is clear that comprehensive guidelines need to be established to aid with increasing safety for these fighters, as well as for those already participating in other combat sports.

A young fighter is defined as one who is under the age of 19. Age-related differences in physiology as well as physical and psychological growth and development present a unique set of challenges for the management of young combat athletes with special consideration to the impact that training and competition have on the musculoskeletal, cardiovascular, hormonal, neurologic and renal systems when compared to adult combat athletes. Participation in martial arts enhances physical fitness across a myriad of domains including cardiorespiratory fitness, speed, agility, strength, flexibility, coordination and balance.

The ARP sets forth these guidelines in order to aid those who supervise these athletes, whether it be coaches, officials, medical commissions, or physicians who examine and treat these athletes.

Musculoskeletal Issues

The period of childhood and adolescence is a time of rapid growth and development. A primary consideration regarding musculoskeletal adaption to physical stress in this population is that muscle, bone, and tendons adapt at different rates to different stimuli throughout the youth developmental cycle.

Given the possibility to disrupt long-term growth and development secondary to injury among young combat sport athletes, special consideration regarding the development and adaptation of bones, muscles and tendons to martial arts training and competition is advised.

The majority of bone mineral density (BMD) accumulation occurs during the pediatric years, with consolidation occurring from 18 to 35 years old.[1] This is followed by an involution phase, whereby BMD decreases over the remainder of the lifespan. Though, this decline can be mitigated with load-bearing exercise.[2] Morphological adaptations to physical training include increased cross-sectional area (CSA), changes in muscle architecture, and changes in fiber type, among others, which are dose-dependent.[3,4] In contrast to skeletal muscle's highly adaptable nature, tendons typically take longer to adapt to loading, as they contain a high concentration of extracellular matrix (ECM) with relatively few fibroblasts interspersed within, which is advantageous for transmitting tensile force generated by skeletal muscles to joints but comes at the cost of slower remodeling and repair.

Common musculoskeletal conditions, described below, arise from mismatches in tissue adaptation in response to the loads placed upon the young combat athlete or loads exceeding the tissues' threshold of adaptation, resulting in injury.

Epiphyseal and osteochondral injuries

Osteochondritis dissecans OCD is a pathology first described in 1888 by König[5] as loose bodies within the joint. The juvenile onset form and adult-onset OCD are considered the same process, but the prognosis in the skeletally immature patient is more favorable. OCD is primarily caused by repetitive trauma that impedes blood supply and subsequently causes necrosis in the absence of traumatic injury. This differs from the osteochondral lesions that are seen in adult patients. Edmonds and Polousky[6] describe the lesions as originating within the unossified epiphyseal cartilage involving the subchondral bone and the articular cartilage.

MR imaging is helpful in assessing the stability of OCD and its prognostication.[7] The chondral fragment is considered the progeny of the parent bone and the ossification of the progeny is a sign of healing, whereas fluid signal intensity in the over-lying articular cartilage and full thickness defects are signs of poor prognosis. MRI features suggestive of normal variance, not OCD, include: posterior location (not intercondylar); absent bone marrow edema; accessory ossification centers and spiculated cortical margins; intact secondary ossification center physis; and young age with a large amount of epiphyseal cartilage.[8]

Acute avulsion fracture of the tibial eminence (ACL attachment site) is common in younger skeletally immature patients between 8-14 years old, especially boys when the intercondylar eminence is incompletely ossified.[9] There are 4 such types of avulsion fractures; type I (non-displaced) epiphyseal osteochondral displacement; type II, a posteriorly hinged attachment with elevation of the anterior margin of the fragment; type III, completely displaced; and type IV, a comminuted or rotated fragment.[10] Radiographs will commonly miss these injuries, so MRI is indicated if they are clinically suspected.

Apophyseal injuries

Apophyseal injuries occur more frequently during puberty and adolescence and are more common than ligament and tendon injuries in this population. Apophyses are growth centers that do not contribute to linear growth. Instead, they serve as the bony attachments to tendons and ligaments.

Acute fractures may occur from sudden and forceful muscle contractions, but more commonly arise from repetitive activities leading to microavulsions at the interface between the bony apophysis and the adjacent cartilaginous physis. Acute apophyseal injuries are most common in the pelvis and chronic overuse apophysitis is most common in the knee and ankle.[8]

Acute patellar sleeve fractures are avulsion injuries at the superior pole of patella (they rarely occur at the inferior pole). The injury occurs when the bony aspect of the patella is pulled out of its cartilage sleeve. It is not a true bony fracture but it is managed in the same manner. Radiographs may show patella alta, a sliver-like patellar fracture fragment, joint effusion and soft tissue swelling. MRI can be useful to confirm the integrity of the patellar tendon and to study the chondral component of the fracture in the event that surgical fixation is indicated.[8]

Chronic avulsive stress in the same location results in inferior patella traction apophysitis known as Sinding-Larsen-Johansson disease. Chronic traction apophysitis at the distal patellar tendon tibial tubercle insertion is called Osgood-Schlatter disease. Traction apophysitis at the Achilles tendon calcaneal insertion is called Sever's disease.[8]

Physeal fractures

The physis (growth plate) is an exclusively cartilaginous structure present during years of growth and is the weakest component of the bone-joint unit in children. Mechanical forces which result in ligamentous or tendinous injury in adults tend to cause physeal fractures in children and adolescents. Increased athletic demand in many middle and upper school children increases the risk of growth plate fractures.[11]

The Salter-Harris classification is the classification system most commonly used for pediatric growth plate fractures. A type I fracture occurs through the physis and can sometimes involve partial separation of the epiphysis from the metaphysis. A type II fracture occurs through both the physis and the metaphysis, type III involves both physis and epiphysis, and type IV involves both the metaphysis and epiphysis. The type V fracture is a crush injury of the physis and carries the worst prognosis.[12]

Complications of physeal fractures include long bone growth arrest and angular long bone deformities. More than 30% of pediatric long bone fractures involve physeal injury, and approximately 15% of these develop post-traumatic growth arrest.[13] The risk of growth disturbances is less related to Salter Harris type than to the specific physis involved, with lower extremity locations and those with undulating physes having highest risk. When the fracture plane separates the physis from the epiphysis, blood supply may be disrupted, leading to the development of vascular communications between the epiphysis and metaphysis may develop allowing a bony bridge to form across the physis.[8] Large, central bridges can lead to limb shortening; smaller more peripheral ones, lead to angular deformity. In the lower extremity physeal fracturs are more common in the distal tibia with up to a third resulting in growth arrest.[8]

Long bone stress injuries

Almost 50% of all stress fractures in athletic children are tibial with the remainder occurring in the fibula, femur, metatarsals and tarsal bones. The sensitivity of early radiographs is as low as 15% and delayed radiographs only reveal findings in 50% of patients. MR imaging with STIR sequences and T2-weighted sequences with frequency selective for fat saturation are very sensitive to the high signal intensity periosteal and marrow edema associated with stress reactions.[8]

Cardiovascular

Impact of Age on Sports Performance; maturation of the CV System

The impact of age on cardiac and vascular structures is significant, making cardiovascular fitness a key area of focus for youth engaged in martial arts. Cardiovascular physiology research predominantly centers on individuals aged 10-17 years, offering insights into cardiopulmonary responses to exercise. However, deciphering these responses is complex due to varying growth rates, body composition changes, and individual biological rhythms.[14] VO2 max is the maximal capacity to transport and utilize oxygen and is often used interchangeably with VO2peak to define aerobic fitness.[15] As children and adolescents mature, their cardiovascular response to intense exercise and peak oxygen uptake (VO2peak) evolves. Stroke volume (SV) rapidly increases at the onset of exercise, plateaus at around 50-60% of VO2 peak, and remains constant.

Heart rate (HR) rises in a more linear fashion, enhancing the cardiac output (CO). Both SV and CO are crucial in the evolution of cardiopulmonary fitness.[14] These cardiac adaptations collectively shape children's unique cardiovascular responses to exercise.[16] These physiological adaptations are particularly true in athletes as young as 12, where cardiac adaptation to training has been demonstrated.[17] Interestingly, the cardiovascular responses to progressive exercise are similar between girls and boys, even when considering differences in age, growth, or maturity.[14]

Martial arts training emerges as a beneficial avenue for children, resulting in improved VO2max and cardiovascular fitness.[18-22] Focusing on activities that improve cardiovascular and respiratory efficiency is key to safely enhancing their VO2 max, a powerful predictor of general health.[23] However, since children exhibit higher relative VO2 values once adjusted for body weight, tailoring the intensity of their training to match their distinct aerobic capacities becomes crucial. Given their reliance on HR for increased cardiac output and a faster respiratory rate, monitoring these parameters can prevent overexertion.[15,24,25] The variable nature of VO2 max across different ages underscores the importance of age-appropriate training programs that accommodate ongoing physiological changes. Exercises should be designed to gradually build muscle strength and endurance, fostering safe cardiovascular development. Additionally, capitalizing on their quicker recovery rates can inform the structuring of training sessions, incorporating suitable rest intervals to prepare young athletes for the rigors of combat sports safely and effectively.[15,21,26]

Varied changes mark the cardiac development and remodeling process in young athletes. The heart adapts to increasing metabolic demands during puberty by enhancing myocardial mass and chamber size, shifting from right ventricular (RV) dominance to a more balanced cardiac structure.[27] The dynamic physiological adaptation involving cardiac hypertrophy and specific morphological changes due to systematic training is known as athlete's heart.[28,29] While generally considered a benign condition, the implications of these changes in children and preadolescents are less understood.[27,29-31]

Long-term Cardiovascular Health in Young Fighters

Engaging young athletes in combat sports provides cardiac health benefits from childhood into adulthood and mitigates the long-term impact of cardiovascular disease.[25,32] These young athletes must sustain a high level of cardiorespiratory fitness that positively impacts body mass index, BP, and microvascular health. Furthermore, there is currently no evidence to suggest that the heart remodeling seen in athletes leads to long-term cardiovascular issues or sudden death. [29]

Heart Rate and Blood Pressure Response

Blood pressure (BP) elevations are normal physiological responses to heightened oxygen demands, engaging the cardiovascular, respiratory, and metabolic systems. However, some children maintain an abnormally high systolic BP during exercise, although the clinical significance of this still needs to be established.[33] Hypertension, commonly seen as an adult issue, can start in childhood and adolescence, significantly impacting long-term cardiovascular health.[34,35] Furthermore, reports of elevated blood pressures and additional potential cardiac risk factors in seemingly healthy young athletes imply that excessive training could negatively impact cardiovascular health.[36] Other factors contributing to the increasing prevalence of hypertension in adolescents are factors such as the use of steroids, energy drinks, and other supplements.[30,35] Therefore, screening and identifying children participating in combat sports for abnormal blood pressure is essential to identify and manage pathological levels of BP.

Based on recommendations from the Association of Ringside Physicians and the American Academy of Pediatrics (AAP), BP classifications for combat sports athletes under the age of 18 must be indexed to gender, age, and height (https://www.nhlbi.nih.gov/files/docs/bp_child_pocket.pdf). AAP also recommends that children and adolescents with stage 1 hypertension without organ damage or heart disease can participate in competitive sports but require blood pressure reevaluation within one to two weeks. If symptoms exist or there is evidence of organ dysfunction, a referral to a pediatric medical subspecialist is necessary.[37] The Association of Ringside Physicians has stated that children suffering from stage 2 hypertension should be restricted from high-static sports such as weightlifting, boxing, mixed martial arts, and wrestling until hypertension is controlled.[38,39] Furthermore, it is recommended that all youth with persistently elevated BP undergo a cardiac workup before athletic participation.[40-42]

Risk of Cardiac Events

The incidence of sudden cardiac death (SCD) in children aged 3 to 13 years and 14 to 25 years has been reported to be 0.61 cases per 100,000 and 1.44 cases per 100,000 people, respectively.[43] Although rare, the risk of SCD in young athletes underscores the importance of preparticipation cardiovascular screening to identify those at risk.[44] SCD is a significant event reported to be triggered by exercise in young athletes.[26] Extra caution is advised for young athletes in combat sports, as blunt trauma to the chest, as seen in other sports such as baseball and football, has been shown as to cause commotio cordis (CC).[45,46] This condition is a leading cause of SCD in young athletes, with a mean age of 15.[46] While no cases of CC have been published among pediatric combat sport athletes to date, an adolescent fatality attributed to multiple organ failure after a prolonged cardiocirculatory arrest from a single karate kick to the trunk has been described.[47] SCD is commonly associated with underlying cardiovascular conditions depending on age, with primary arrhythmia, hypertrophic cardiomyopathy (HCM), and myocarditis being the most common in adolescents and young adults. Therefore, it is important to distinguish between pathological cardiac remodeling like HCM versus physiological causes such as athlete's heart. Other cardiovascular anomalies associated with SCD in young athletes include congenital coronary anomalies and arrhythmogenic right ventricular dysplasia.[29,31,45,48,49]

In an attempt to identify youth vulnerable to SCD, the American Heart Association (AHA) and American Cardiology Association (ACC) recommend a 14-point screening guideline, which includes a detailed history and physical exam and BP measurements before participating in competitive sports.[45,50] However, this approach has been argued by some as inadequate, suggesting that other modalities, such as the use of ECGs, echocardiography, and MRIs for screening, should be more strongly promoted.[51-55] Ultimately, screening for SCD should attempt to minimize the healthcare burden while effectively detecting at-risk conditions by adjusting the screening depth to individual risk factors and available resources.[56]

Renal

Kidney Development

During embryonic development, kidneys go through three different stages of development. These stages are the pronephros, mesonephros, and metanephros, which eventually become the permanent kidneys. The most active nephron development happens particularly in the first year of life. While the tubules and glomeruli epithelium of a 7–9-year-old child look like those in an adult, the distribution of nephrons doesn't fully mature until around age 15. The internal and external kidney vessels continue developing until the age of 18. Although kidneys approach their definitive state by the age of 11, complete development usually finishes around the 22nd year of life.[57]

Physiological Variances in Kidney Function

Significant physiological differences exist between adults and children regarding kidney function. Despite children having a higher proportion of total body water (Child: 60-75%; Adult: 50-55%), their osmotic dilution function matures earlier than their osmotic concentration function (up to age 16), which results in greater water loss, increased susceptibility to rapid fluid loss, and waste of more sodium compared to adults. Infants have a higher proportion of water in the extracellular compartment than older children or adults, making them more susceptible to dehydration.[58,59] These are the reasons why weight cutting in children is more dangerous than in adults. Dehydration symptoms include dry oral mucosa, vomiting, diarrhea, fever, decreased oral intake, oliguria, altered mental status, and hypovolemic shock. Dehydration may increase the risk of other illnesses or injuries, such as renal impairment or concussion.[60] Children also have higher energy and nutrient demands than adults, which can be impacted by weight cutting, potentially affecting growth and development.[61,62]

Impact of weight cutting

Athletes in combat sports are required to meet specific weight categories to compete. As a result, competitors resort to various weight-loss methods to meet the competition weight requirement. These methods include restricting food and fluid intake along with intentional sweating, sauna use and sometimes more extreme or potentially harmful medical practices, such as the use of diuretics.[63]

Weight-cutting practices among young combat athletes are similar to those observed in adults, a trend that warrants concern due to the potential health risks directly involving both the cardiovascular system and renal system.[64,65] Unfortunately, there have been cases of weight-cutting related deaths in combat sports due to these complications.[64,66]

While the specific adverse effects on the cardiovascular system of young athletes from weight cutting are not fully understood, it is hypothesized that these practices may induce cardiovascular strain by decreasing stroke volume and consequently increasing heart rate.[67] Moreover, weight cutting, leading to dehydration and increased blood viscosity, impairs cardiac efficiency and increases the risk for acute cardiovascular issues such as ischemic heart disease and stroke.[63,68,69]

The extreme dehydration suffered by some fighters during weight cutting can also produce elevations in serum creatinine, plasma osmolality and sodium concentration, as well as volume depletion, fall of the glomerular filtration rate, and even ischemia, leading to an acute kidney injury (AKI).[70] Furthermore, in addition to the acute pathology, recurrent episodes of AKI are linked to chronic kidney disease and make fighters who usually dehydrate in excess more prone to suffer long-term kidney complications. In most cases described, adults are the predominant demographic affected.[71,72] However, as previously explained, children are more susceptible to dehydration than adults. Therefore, great caution must be exercised when it comes to children.

High levels of physical exertion, as seen in training camps, add another variable to the complications seen in weight cuts, as this physical exertion can produce excessive muscle cell damage, leading to rhabdomyolysis.[73] The typical rhabdomyolysis triad consists of weakness, muscular pain, and dark urine. However, these three symptoms occur together in less than 15% of the cases, and most frequently rhabdomyolysis appears only as dark urine without any other symptoms.[74] In case of dark urine after excessive weight cutting, a rhabdomyolysis should be promptly considered.[75,76]

Despite its prevalence and perceived benefits, studies indicate that weight-cutting offers a minimal competitive edge. [64,77,78] As mentioned in the previous paragraphs, children and adolescents are at higher risk for dehydration. Considering the critical phases of growth and development during childhood and adolescence and the damage that can be seen with extreme dehydration, imposing stringent regulations or, ideally, a complete ban on weight cutting in these vulnerable age groups is imperative.

Thermal Regulation in Children

Children have a higher body surface area-to-body weight ratio than adults. This results in the redistribution of blood volume to peripheral vessels when the body skin is warmer than the environment, enabling greater dissipation of body heat through dry means. Unlike adults, children depend less on evaporative heat dissipation, making them more prone to an excessive increase in core temperature, especially in extremely high temperatures, such as in a sauna, as they absorb more heat.[62,79]

Sports Participation and Chronic Kidney Disease

In the realm of sports participation among children with renal pathology, the scientific community has shifted its perspective from being highly conservative to slightly more permissive.[80] The primary causes of chronic kidney disease (CKD) include congenital kidney diseases (e.g., renal hypoplasia), inherited conditions (e.g., polycystic kidney disease), acquired diseases (e.g., glomerulonephritis), and metabolic disorders (e.g., cystinosis). Despite diminished sports performance in children with CKD compared to control groups, engaging in sports can offer significant benefits. Goldstein and Montgomery observed improved 6-minute walk distance and lower extremity strength in children over 8 years old after three months of two training sessions per week.[81,82]

Even though there is no consensus on sports participation recommendations for individuals with a single kidney, the American Academy of Pediatrics and the Canadian Urological Association suggest that clinical judgement should be applied with every individual, and that risks should be explained to the primary caregivers.[83] This suggestion is also applicable to all types of CKD and to children undergoing dialysis therapy. However, contact and collision sports should always be avoided in the case of patients with a transplanted kidney or a single kidney situated in the pelvic or iliac region presenting with multicystic characteristics, demonstrating hydronephrosis, or showing ureteropelvic junction abnormalities.[81,84] When discussing inherited and acquired conditions, each case should also be examined independently. For example, in the context of polycystic kidney disease (PKD), it is advisable to abstain from contact sports among individuals with substantial nephromegaly due to an increased risk of cyst rupture. Moreover, any instance of cyst pain or gross hematuria should be immediately reported to the physician.[85]

Hormonal

Endocrine Responses to Martial Arts Training and Competition

Physical activity plays a pivotal role in tissue anabolism and growth among children and adolescents. Training-induced anabolic effects among the pediatric population are largely age- and maturity-dependent, owing to the combination of rapid muscle growth and spontaneous puberty-related increases in anabolic and steroid hormones.

Below is a summary of the effects of combat sports training on the anabolic, catabolic and sex hormones in the pediatric population, based on the body of knowledge available at this time.

Effect on anabolic hormones

The growth hormone-insulin-like growth factor-1 (GH-IGF-1) axis regulates critical life processes and begins at the central nervous system where several neurotransmitters stimulate the hypothalamus to synthesize growth hormone-releasing hormone (GHRH) and somatostatin (SMS) leading to the secretion and inhibition of growth hormone (GH) from the anterior pituitary by GHRH and SMS, respectively.

GH's response to training depends on the duration and intensity of training in addition to the athlete's fitness level, the timing of blood sampling, and other environmental factors.[86]

IGF1 is responsible for most of the anabolic and growth-related effects of GH. It stimulates SMS secretion and inhibits GH by a negative feedback mechanism.[87] Some of IGF1's effects are GH-dependent, while the majority of its effects are due to autocrine or paracrine secretion and regulation that are partially GH-dependent.

In the context of endurance training, sessions should last at least 10 minutes in duration in order to stimulate GH secretion.[88] Training-induced GH secretion peaks around 25-30 minutes of training irrespective of total training session duration.[89,90]

In the context of anaerobic training, significant increases in GH levels can be seen following supramaximal effort in short intervals, as little as 30 seconds in duration.[91]

A study conducted by Eliakim et al.[92] aimed to compare the effects of IGF-1 on male and female late pubertal individual and team sports athletes. The authors reported no difference in GH response between individual and team sport practices. This may be due to several limitations in study design such as the inability to control each participant's fitness level and each practice's intensity level, the nature of the sports chosen and the associated psycho-physiological effects on the athletes engaging in their respective team v individual v combat v noncombat sport.

Effect on sex hormones

The female reproductive system is regulated by the hypothalamic-pituitary-ovarian axis, where pulsatile gonadotropin-secreting hormone (GnRH) secretion stimulates the anterior pituitary secretion of luteinizing hormone (LH) and follicle-stimulating hormone (FSH). An optimal pulsatile frequency and monthly LH and FSH rhythmic stimulation is necessary for ovarian follicle growth and estrogen secretion.

The male reproductive system is regulated by the hypothalamic-pituitary-testicular axis. Similarly, pulsatile hypothalamic GnRH secretion stimulates LH and FSH secretion. Pulsatile FSH secretion stimulates testicular Sertoli cells to promote spermatogenesis while LH pulsatile secretion stimulates testicular Leydig cells to produce testosterone. The anabolic effect of testosterone is due to its interaction with androgen receptors.

The association between testosterone concentration and strength development during growth occurs due to the parallel increase of testosterone and strength in boys. However, in girls, increased strength appears to be proportional to changes in body size, but not to changes in estrogen.[93] In contrast to male athletes, the source of training-induced testosterone production in female athletes is the adrenal gland. Thus, post-training increases in testosterone in female athletes are typically accompanied by an increase in DHEA and androstenedione.[94,95]

Intense physical training has been found to delay the onset of puberty in female athletes by altering normal hormonal development.[96] In general, boys who participate in sports demonstrate normal growth rates and are considered normal or even advanced for their state of skeletal and sexual maturation.[97] Given the nature of weight management associated with combat sports training and competition, a broad concern regarding the physiological stress that accompanies combat sports competition in addition to nutrient/fluid restriction in order to make weight and body mass fluctuations throughout the competitive season has raised speculation regarding slowed somatic growth of adolescent weight-class based combat athletes during crucial periods of growth and development.[98,99] Piskin et al.[100] sought to evaluate the effects of intense training during somatic growth on the onset of puberty and growth development in adolescent wrestlers compared to their sedentary peers across the following domains: somatic growth parameters, maturity of puberty and sex hormone levels. The authors reported no signification differences ($p>0.05$) in terms of resting total testosterone, prolactin, cortisol, IGF1, FSH, LH and DHEA-S levels. TSH was significantly higher in wrestlers compared to controls ($p=0.015$). However, there was no difference in fT4 levels ($p>0.05$). Additionally, the wrestlers had lower body fat and greater energy expenditure per week, though there were no significant differences in height, weight, or body mass index.[100]

Nasri et al.[101] aimed to investigate the correlation between bone parameters, grip strength (GS), explosive legs power (ELP), and hormonal parameters, and to identify the most determinant variables of bone mineral density (BMD) among adolescent combat sport athletes compared to sedentary controls. Combat sport athletes (from judo, karate, Kyokushin karate, kung Fu and boxing) were compared to sedentary subjects who were matched for age, height, and pubertal stage. The average weight, body mass index (BMI), and total lean body mass (LBM) was higher in the athletes compared to the sedentary controls. Both dominant and non-dominant hand GS were higher in the athletes compared with the sedentary group. All bone parameters (BMD of whole body, whole spine, arms, and legs) were statistically higher in the athletes compared to the sedentary group. ELP was significantly higher in the combat athletes participating in judo, karate and Kyokushin karate than in both boxers and the sedentary group. There was no significant difference between the athletes and sedentary group for hormonal parameters (e.g., GH and testosterone). This study confirmed that training in full contact combat sports like judo and Kyokushin karate was associated with higher bone density in lumbar spine, and lower and upper limbs, with the authors concluding that children and adolescents should be encouraged to participate in combat sports with a high osteogenic response.

Cortisol

Cortisol is secreted from the adrenal cortex under the regulation of hypothalamic corticotropin-releasing hormone (CRH) and pituitary adrenocorticotropic hormone (ACTH). Cortisol stimulates gluconeogenesis and lipolysis, inhibits growth factor secretion and function, and inhibits the production of numerous inflammatory factors. Cortisol is considered a catabolic hormone due to its effect in protein degradation and reducing skeletal muscle protein synthesis.

A controlled clinical trial by Pilz-Burstein et al.[102] aimed to evaluate the effect of fighting simulation (3 fights, 6 min each, 30 min rest between fights) on anabolic and catabolic hormones in elite adolescent Taekwondo athletes. Significant decreases in LH and FSH in both sexes were noted following the simulation. Significant decreases in testosterone and free androgen index were noted in males, with milder decreases observed in females. Significant increases in cortisol were seen in both sexes.

Passelergue and Lac[103] aimed to determine variations in salivary cortisol and testosterone in national and international level adolescent wrestlers during and after a two-day competition. Saliva samples were taken during a rest day 3 weeks before competition, throughout the competition, and both 2 hours after the competition and daily for 8 days afterwards. The results of this study revealed higher levels of stress before and during competition, which were to be expected, and were seen with high levels of cortisol with no statistically significant increases in testosterone. During the active recovery period post-competition, a high testosterone:cortisol ratio was associated with a perceived state of fatigue among the athletes, which was thought to be due to a very high psychological strain from the competition, and this ratio normalized over a period of five days of active recovery.

Neurologic

Brain development does not stop at birth as the brain continues to mature through childhood, adolescence and even adult life. Adolescence, categorized as ages 10 to 19 per the WHO, is a specifically significant period for morphological and functional brain transformations.[104]

Adolescence is when synaptic pruning and myelination are most pronounced allowing for reconfiguring the brain "wiring" into the adult form. This is thought to lead to developmental "thinning" of the neocortex and cortical regions contributing to roles such as higher levels of information processing, orchestrating actions, and advanced cognitive functions. Development of subcortical regions may explain the changes in adolescence related to modulating social, aversive and emotional stimuli[1]. Anatomically, brain volume increases in an inverted U-shaped trajectory and reaches 95% of its adult volume by 6 years of age. Cortical thickening is associated with complex cognitive tasks performance and occurs between the ages of 4.9 and 22 years with peak cortical thickness at no later than age 8 years old. Deviations from these trajectories are associated with developmental disorders.[105]

Mild traumatic brain injuries or concussions are known to cause short term deficits such as behavioral changes, cognitive impairment, sleep disturbances, somatic symptoms and emotional symptoms. These symptoms may persist long-term but the mechanism and factors resulting in persistent symptoms or Post-Concussion Syndrome (PCS) are less defined. Literature has shown that children report worse cognitive symptoms one-year post-concussion compared to adults. PCS may have effects on children's personality, school performance, school attendance and athletic performance[106,107] Studies have also shown that the most distressing part of having concussions, as perceived by the young athlete, is the resultant loss of activities whether secondary to the injury or to the prescribed treatment[108] Chronic Traumatic Encephalopathy (CTE), previously thought to occur only in boxing, is a progressive neurodegenerative disease that develops due to sustaining repetitive head injuries[109] CTE is now known to be secondary to repetitive head injuries sustained during multiple sports including football, hockey and wrestling.[106] Studies done on the effect of accumulated subconcussive impacts on contact sport athletes at the collegiate level or younger, mainly within male football athletes in high school or college, revealed no changes in cognitive measures but showed changes in biomarkers and imaging over the season.[110]

Within mixed martial arts (MMA), the data on concussion rates are not well documented in most studies, especially with children and adolescents.[111,112] Studies on concussions and injury patterns in MMA have revealed the most common injuries are head injuries, concussions, lacerations and fractures; however, the order of frequency of these common injuries differed from study to study.[113] Studies on pediatric concussions reported a higher prevalence of concussions in judo compared to karate. Many of these studies on epidemiology of injuries in MMA; however, lacked follow-up evaluations, making it difficult to track these injuries.[113] It is important to note that when new rules were introduced to modify techniques and permissible and forbidden areas, as done by the World Karate Federation, a significant reduction was seen in overall number of head injuries as well as the relative risk of injury for competitors below the age of 18.[114] Similarly, studies done on concussion and head impact incidence rates on youth tackle football showed reduced rate of head impacts and concussion with contact training and practice contact restrictions.[115-117]

The American Academy of Pediatrics had published recommendations for youth participation in Martial Arts in 2016 which emphasized the importance of supervision by properly trained instructors; delaying contact-based training until competency is achieved in noncontact-training with appropriate levels of physical and emotional maturity; limiting excessive force, dangerous techniques and blows to forbidden areas, encouraging training in defensive blocking techniques; and educating the young athlete and their parents on the increased risk of concussion, asphyxia or head and neck injuries during MMA combat fighting.[113] The ARP position statement on headguard use in combat sports highlights that headguard use is highly effective in reducing the incidence of facial lacerations, but cannot be relied upon to reduce the risk of concussion or other traumatic brain injury.[118] Further research is needed in this area. The AAP also strongly opposes participation in boxing and sports where head blows are a central element to the sport.[119] Similarly, in other sports, such as youth tackle football, previous research has indicated that earlier participation in tackle football was associated with worse behavioral, cognitive and neuroimaging outcomes later in life. This was hypothesized to be due to the critical period of brain development in ages 10-12. However, these findings are now challenged by more recent studies which reveal that early participation in high-risk sports is not associated with worse cognitive, behavioral, psychological or physical outcomes.[120-122] These studies suggest that further research is needed into MMA and long-term cognitive, behavioral, psychological, neuroimaging and physical outcomes to allow for more updated recommendations to guide young fighters to safely participate in MMA.

Given these unique considerations for the developing brain, as well as high relative risk of concussion associated with martial arts[123], great efforts should be undertaken to optimize safety and decrease risk for youth athletes who choose to participate in martial arts. These efforts may be focused on (1) pre-bout training, (2) mid-bout fighting, and (3) post-bout evaluation. There is a paucity of literature regarding the risk and prevention of brain injury in youth martial arts, so some considerations are extrapolated from other youth contact sports.

In the pre-bout setting prior to participation, appropriate education regarding the safety participation is essential. [113,124] This education should be geared toward all involved parties, including youth athletes, parents, and coaches; several studies have demonstrated reduced head impacts in child and adolescent American football with comprehensive coach education.[125-128] Once informed consent is obtained for participation, training should only occur in a formal and structured setting. One study found that more than 20% of facial injuries reportedly sustained from boxing/martial arts occurred while fighting a family member/friend or by “accident”.[129] Ensuring that combat is reserved for supervised training and competition settings is a simple way to reduce this risk. Additionally, training should be led by qualified instructors who have intimate knowledge about proper offensive and defensive techniques. Multiple studies investigating head blows and concussions in Taekwondo suggest that development of appropriate stance and blocking skills is important for decreasing injury risk.[124,130,131]

In addition to optimization of technique, personal protective equipment such as mouthguards and headguards have historically been worn depending on the martial arts form being practiced. The role of mouthguards in reducing incidence of orofacial trauma in sports has been well established[132], but studies investigating whether they reduce concussion risk in youth athletes have shown conflicting results.[133] The ARP position statement on mouthguards notes that there is potential for decreased severity of concussions with the use of mouthguards but acknowledges the lack of evidence to support a decreased incidence of concussions with them.[134] Soft headgear may prevent minor facial trauma, but there is a lack of data at this time to suggest that it reduces incidence of concussion or sub-concussive trauma in martial arts.[113] Not only should protective equipment be worn, but it should be appropriately fitted; studies in adolescent football and youth ice hockey identified that secure helmet fit may reduce concussion incidence and severity.[135,136]

In the pre-bout setting, training time has also been associated with injury incidence in youth fighters, with a significant increase in risk of injury after about 3 hours of training per week.[137,138] Furthermore, injury risk doubles with each additional two hours of training.[138] Minimizing training time to that which is required to teach proper technique may be important. Some studies even suggest elimination of training fighting/sparring altogether.[129]

In addition to the pre-bout setting, a focus on mitigating risk of neurologic injury during bouts is also crucial, as youth martial arts athletes were twice as likely to sustain a head/neck injury during competition in comparison to other settings.[139] Competition changes to prioritize safety can be very effective in reducing risk of neurologic injury in martial arts. For example, in 2000, the World Karate Federation strengthened rules to reduce prohibited behaviors such as uncontrolled blows in competition; overall relative risk of head injury was found to be significantly lower after rule implementation in 2002 as compared to 1997, particularly in the competitors <18 years old.[140] One study investigating the epidemiology of martial arts-related injuries presenting to pediatric emergency departments from 2004 to 2021 found a decrease in injury rates specifically between 2013 and 2021; the authors suggest that this may be due to rule and regulation changes.[139]

In other youth sports, rule and regulation modifications designed to reduce head contact altogether in competition has demonstrated variable results. In 2011, bodychecking was banned in youth ice hockey until age 13, resulting in a 58% reduction in sport-related concussion rates and no unintended injury consequences based on a meta-analysis.[141] In 2012-2013, youth lacrosse rules were modified to increase penalties for intentional checking, and concussion risk also decreased significantly.[142] In 2015, heading in soccer was banned for players until age 11, and one study did not find decreased rates in emergency room concussions, but they note several limitations of their study.[143] Currently, some martial arts governing bodies, including the World Taekwondo Federation (WTF), allow strikes to the head for competitors all ages. In fact, WTF increased the number of points awarded for head kicks in to improve technical quality; one study found that this greater incentive to attack the face/head did not result in higher concussion incidence.[144] Other governing bodies, such as the International Mixed Martial Arts Federation (IMMAF), have banned strikes to the head or face at all levels of youth competition before age 18; they have developed additional rules for Youth C (12-13 years), Youth B (14-15 years), and Youth A (16-17 years). There is a paucity of data comparing the neurologic injury profile of youth fighters who participate in these different martial arts forms.

In addition to rule and regulation modification, there is ongoing research to identify a “safe” age at which to allow contact in sport (i.e., hits to the head in the setting of martial arts). As mentioned, this is an important consideration due to critical brain development that occurs in childhood and adolescence. This has not been well investigated in martial arts, but football may serve as the best model from which to extrapolate, given the similar nature of not only concussion but more importantly repetitive, sub-concussive head impacts. Currently, most organizations have not published a recommended age at which to start tackle football. However, it has been established that there are fundamental differences in the younger athlete due to active brain development between the ages 8 to 12 and larger head to neck/body ratios.[145,146] Furthermore, two studies[147,148] have reported worse outcomes in athletes who started tackle football before age 12. The Concussion Legacy Foundation currently recommends delaying tackling until age 14 based on a study[149] in football players that found that risk of developing CTE was correlated to the number of years of play, as opposed to number of concussions. They estimate that this could prevent about 50% of future CTE cases. Based on the currently available data, consideration of delaying head blows in martial arts until age 12 may be appropriate at this time.

Although efforts taken during pre-bout training and in competition fighting do not completely prevent neurologic injury, another safety focus is the proper management of head injury during competition. Similar to other sports settings, this can be achieved through recognition of injury, removal from play, evaluation in the acute setting and re-evaluation in the clinic, recovery time, rehabilitation, and implementation of formal return-to-learn/sport progression.[150] One unique aspect of medical care in martial arts is medical suspension, a specified amount of time that an athlete is prohibited from sparring and/or competing in order to promote time to recover. For example, a significant injury such as a knockout generally comes with the longest suspension at a minimum of three months. Currently, these guidelines are not consistent among martial arts forms and commissions even at the professional level. At the youth level, some martial arts forms remain unregulated or illegal in some states, thus youth athletes are less like to undergo a post-bout evaluation and consideration of medical suspension. Furthermore, suspension timing would need to be tailored to this unique age group. Due to differences in brain development, skull thickness, neck strength, and other physiologic distinctions, youth athletes may require different recovery times than adult athletes; however, the current body of literature is inconsistent regarding whether young age is associated with overall prolonged recovery after concussion,[151] even though cognitive deficits were found to be higher at one year out as comparted to the adult population. A recent systematic review found that youth athletes generally took 10 days to return-to-learn and twice as long to return-to-sport[152], however, these athletes did not sustain knock outs, which is an injury-related characteristic whose relationship to recovery is not clear. [151] One unique consideration regarding medical suspension timing in youth athletes is second impact syndrome (SIS). It is a rare condition - so rare that it is a controversial diagnosis - in which an individual sustains a second head injury prior to complete recovery from a prior head injury, leading to a catastrophic event.[153] Case reports typically describe contact athletes of male sex and aged 13 to 23[154], so this is a notable consideration in youth martial arts.[155]

Psychosocial

Introduction/ Normal Psychosocial development

Psychosocial health is an important component of the overall health of young athletes. Psychosocial health is largely viewed as one's mental and behavioral wellbeing, as influenced by social, cultural, and environmental factors.[156] From 2016 to 2019, the most commonly seen mental health diagnoses amongst pediatric patients within the United States included attention-deficit/hyperactivity disorder (ADHD), anxiety, depression, and behavioral problems.[157] The Center for Disease Control (CDC) recognizes that psychosocial health can impact an adolescent's ability to make daily decisions, manage stress, and form social relationships.[157]

Given the biologic, social, and environmental changes that are unique to adolescence, the pediatric population is particularly susceptible to external influences.[158] When exposed to positive influences, adolescents can better develop strategies for emotional regulation, problem-solving, and conflict-resolution.[158,159] Furthermore, these strategies are shown to carry forward into adulthood and have lifelong impacts on individuals as they age.[160] Qualitative research has suggested that youth athletes who participate in martial arts report more positive socio-psychological responses when asked behavioral and competition-related questions.[161]

Participation in sports has proven to be a powerful factor in improving psychosocial health in children and adolescents. In fact, the social dynamic of sports seems to offer greater benefits for young athletes than physical activity alone.[162] Sports participation has been shown to promote greater levels of self-esteem, as well as lower levels of depression and hopelessness in young athletes.[163,164] When 60 martial arts athletes, aged 5-34, were evaluated for level of self-esteem, it was found that one's self-perception improved in accordance with one's experience and skill level.[165] Martial arts youth athletes were shown to have higher self-reported scores in domains of personal-growth and self-acceptance when compared to other contact sport athletes, as well as a non-sport group comparator.[166]

However, sport-related injury may come with the risk of future injury-related fears, mood disturbances, and decreases in confidence.[167,168] Given these benefits and risks, careful consideration is given regarding the recommendations for young athletes hoping to participate in high-impact or contact sports, such as martial arts.

Combat Sports Data

Mood Disturbances-Anxiety & Depression

Anxiety and depression represent two of the most common mental health illnesses in the pediatric population.[157] Moreover, given the shared proclivity toward negatively biased information processing, it is common for individuals with anxiety to have comorbid depression and vice-versa.[169] As it is known that factors such as physical activity and social interaction greatly influence mood and development in children and adolescence, sports may prove to be a powerful influence in this population.[170,171]

Data suggests that participation in physical activity correlates with improvements in overall mental health such as rates of anxiety and depression[172] A recent meta-analysis including 122,056 adolescent participants, demonstrated that symptoms of anxiety and depression were significantly lower in those involved in sports compared to those that were not.[173] Participation in sports may also have a protective effect against these mood disorders and related suicidal ideation by increasing social support and boosting participants' self-esteem.[174] A recent meta-analysis demonstrated that participation in mixed martial arts training had a significant positive impact on athletes' wellbeing, as characterized by a healthy self-concept and a higher level of self-esteem.[175]

However, some data suggests that, while team-based sport participation may improve overall mental health, individual sport participation could be associated with greater rates of mental health disease including anxiety and depression.[176] A proposed explanation from related studies is that individual sport athletes, such as martial arts, may be more likely to participate in sports for goal-oriented reasons, rather than for enjoyment making the data difficult to interpret.[177]

Aggression

Aggression is a common phenomenon seen in childhood. It is defined as any behavior, including verbal events, which involves attacking another person, animal, or object with the intent of harming the target.[178] Aggression has also been shown to have lasting effects into adulthood, correlating with future social isolation, low socioeconomic status, and criminal behaviors.[179]

It has been proposed that activities that provide an outlet for aggression, such as martial arts, may, in effect, lower rates of aggression in participants.[180] Current literature does suggest that participation in combat sports, such as martial arts, may provide an outlet for lowering levels of aggressive behavior in young athlete Some studies show that sports participation is associated with lower rates of aggression in adolescents.[181] Similarly, youth participation in martial arts was shown to be related to a reduction in aggression.[182]

A school-linked course in martial arts was found to promote improvements in regard to resistance to rules, inappropriate social behavior, and violence.[183] A similar school-based martial arts intervention amongst 3rd, 4th, and 5th graders found that those participating in traditional martial arts were found to have a lower frequency of aggression and greater frequency toward helpful bystanding in situations such as bullying behavior, possibly linked to greater empathy.[184]

While certain studies link participation in combat sports, such as karate, to higher levels of anger, it is important to note that anger was used as a positive trait indicating greater drive to succeed.[185] Though still, in further studies, lower rates of aggression were seen with participation in non-contact sports, with no significant difference found in those participating in contact sports.[186] Future studies may be helpful to better clarify the relationship between participation in combat sports and levels of aggression in young athletes. However, the current literature suggests that participation in combat sports, such as martial arts, may provide an outlet for lowering levels of aggressive behavior in young athlete participants.

Cognitive Ability- Cognitive Flexibility & Processing Speed

Cognitive ability describes how an individual carries out mental processes such as problem-solving, comprehension, and reasoning.[17] Related to cognitive ability are cognitive flexibility and processing speed. Cognitive flexibility is one's ability to adapt to changing tasks or problems.[188] Processing speed is the speed in which and individual carries out cognitive tasks.[189] These are remarkably important characteristics as one's cognitive abilities have been shown to have a broad range of effects throughout one's life, spanning from socioeconomic status to occupational performance to physical health and overall longevity.[190]

Studies have demonstrated that physical activity may have a positive effect on overall cognitive functioning in children.[191] Moreover, participation in sports at a young age could positively affect academic performance in children and adolescents.[192] There is some data that suggests that participation in combat sports such as boxing may improve individual characteristics such as processing speed.[193]

A recent systematic review and meta-analysis analyzed sport participation for individuals between ages 6 and 18 for contact sports including football, taekwondo, and judo. Authors found a large effect size in cognitive flexibility which may be attributable to the need for frequent adaptation to the dynamic environment associated with these sports.[194] In addition, there is evidence that participation in martial arts predicted improvement in youth processing speed.[182] In a study comparing 102 young participants that were involved in either martial arts, a team sports, or no sports, young martial arts athletes were found to score better in executive function tests and overall academic performance.[195]

While there remains limited information that specifically investigates the role of combat sport participation in cognitive development and skill attainment, the current literature suggests that participation in combat sport such as martial arts may have positive effects on a young athlete's cognitive growth.

Discussion

The popularity of youth MMA training and competition has grown in-step with the expansion and growth of MMA worldwide. The health benefits of MMA training and the enhanced capabilities realized are appreciated in light of the global trend of insufficient youth physical inactivity. In the same vein, early sports specialization, overtraining and dangerous practices associated with weight-class sports should be monitored and mitigated by coaches, parents and clinicians This increased popularity is of importance given the global shift of youth inactivity with 81% of adolescents aged 11-17 failing to meet the WHO's recommended levels of physical activity.[196]

While rule sets, supervised training, and thorough pre-participation and post-bout physical examinations help reduce the risk of illness and/or injury, adhering to the Long-Term Development (LTD) in Sport and Physical Activity Framework is critical to risk reduction of stress and overuse injuries.

The LTD framework is a system of training, recovery and competition based on developmental age or maturity through a 9-stage process that provides a variety of pathways for participation, training and competition throughout childhood and adolescence.[197]

The key factors underlying the LTD framework operate at 3 levels: the individual (Personal Factors), each sport and physical activity-supporting organization (Organizational Factors) and across the country system as a whole (System Factors).[198]

A variety of training modalities are included in the LTD framework including: strength training, balance training, plyometric training, agility training, core training and sport specific training. All serving to enhance overall physical preparedness and well-rounded athletic ability through the fundamental sport movements of running, jumping, landing, cutting, and the ability to balance on one leg, which ultimately transfer well to skill development in MMA.

Several combat sport specific LTD frameworks are available to help coaches, clinicians and parents guide young athlete development in boxing[199], Judo[200-202], Taekwondo[203], Wrestling[204,205], and MMA[206].

Recommendations

Based on the available body of scientific evidence and with the goal of promoting safe sport, the Association of Ringside Physicians recommends the following regarding the young combat sport athlete:

- Clinicians should maintain a high index of suspicion for growth plate injuries and physeal stress overuse injuries among this population. Complaints of persistent bone or joint pain should be evaluated by an experienced clinician.

- Any child or adolescent with stage 2 hypertension, as determined according to age, height and gender specific parameters, should be restricted from combat sports until blood pressure is under control. Substances that could elevate blood pressure, such as energy drinks, should be discouraged in this age group. All athletes with persistently elevated blood pressure should be evaluated by an experienced clinician before participation clearance is given.

- Weight cutting should be discouraged and even banned in children and adolescents, due to increased risk of injury to the heart, kidneys, muscle, and fluid/electrolyte balance.

- Training should only occur under the supervision of qualified instructors skilled in teaching defensive and offensive techniques and tactics. Instructors should be educated on concussion signs and symptoms.

- Training time should be limited to the amount needed for learning a skill set. Sparring in training should be avoided in those 12 years old and younger due to critical brain development occurring during these early years.

- In competition, head strikes should be discouraged or even banned for athletes under 13 years of age in order to reduce the high risk of developing Chronic Traumatic Encephalopathy associated with head trauma in the young athlete.

- Post-bout exams should be thoroughly conducted and longer medical suspensions for concussions should be considered as children and adolescents take longer to recover and are at risk academically while recovering.

These guidelines are recommendations to assist ringside physicians, combat sports athletes, trainers, promoters, sanctioning bodies, governmental bodies and others in making decisions and setting policy. These recommendations may be adopted, modified or rejected according to clinical needs and constraints and are not intended to replace local commission laws, regulations or policies already in place. In addition, the guidelines developed by the ARP are not intended as standards or absolute requirements, and their use cannot guarantee any specific outcome. Guidelines are subject to revision as warranted by the evolution of medical knowledge, technology and practice. They provide the basic recommendations that are supported by synthesis and analysis of the current literature, expert and practitioner opinion, commentary and clinical feasibility.

References

1. Bonnet N, Ferrari SL. Exercise and the skeleton: How it works and what it really does. IBMS BoneKEy. 2010;7(7):235-248. doi:https://doi.org/10.1138/20100454
2. Watson SL, Weeks BK, Weis LJ, Harding AT, Horan SA, Beck BR. High-Intensity Resistance and Impact Training Improves Bone Mineral Density and Physical Function in Postmenopausal Women With Osteopenia and Osteoporosis: The LIFTMOR Randomized Controlled Trial [published correction appears in J Bone Miner Res. 2019 Mar;34(3):572. doi: 10.1002/jbmr.3659]. *J Bone Miner Res*. 2018;33(2):211-220. doi:10.1002/jbmr.3284

3. Kanehisa H, Ikegawa S, Tsunoda N, Fukunaga T. Strength and cross-sectional areas of reciprocal muscle groups in the upper arm and thigh during adolescence. *Int J Sports Med*. 1995;16(1):54-60. doi:10.1055/s-2007-972964
4. Kanehisa H, Funato K, Abe T, Fukunaga T. Profiles of muscularity in junior Olympic weight lifters. *J Sports Med Phys Fitness*. 2005;45(1):77-83.
5. König F. Ueber freie Körper in den Gelenken. Deutsche Zeitschrift für Chirurgie. 1888;27(1):90–109. https://doi.org/10.1007/BF02792135.
6. Edmonds EW, Polousky J. A review of knowledge in osteochondritis dissecans: 123 years of minimal evolution from Konig to the ROCK study group. Clin Orthop Relat Res. 2013;471(4):1118–26. https://doi.org/10.1007/s11999-012- 2290- y.
7. De Smet AA, Ilahi OA, Graf BK. Reassessment of the MR criteria for stability of osteochondritis dissecans in the knee and ankle. Skelet Radiol. 1996;25(2):159–63. https://doi.org/10.1007/s002560050054.
8. Ecklund K. Sports-Related Injuries of the Pediatric Musculoskeleton: Lower Extremity. 2021 Apr 13. In: Hodler J, Kubik-Huch RA, von Schulthess GK, editors. Musculoskeletal Diseases 2021-2024: Diagnostic Imaging [Internet]. Cham (CH): Springer; 2021. Chapter 19. Available from: https://www.ncbi.nlm.nih.gov/books/NBK570147/doi: 10.1007/978-3-030-71281-5_19
9. Merrow AC, Reiter MP, Zbojniewicz AM, Laor T. Avulsion fractures of the pediatric knee. Pediatr Radiol. 2014;44(11):1436–45; quiz 3-6. https://doi.org/10.1007/s00247-014- 3126- 6.
10. Meyers MH, Mc KF. Fracture of the intercondylar eminence of the tibia. J Bone Joint Surg Am. 1959;41-A(2):209–20; discussion 20–2.
11. Jaimes C, Chauvin NA, Delgado J, Jaramillo D. MR imaging of normal epiphyseal development and common epiphyseal disorders. Radiographics. 2014;34(2):449–71. https://doi.org/10.1148/rg.342135070.
12. Salter RB, Harris WR. Injuries involving the epiphyseal plate. JBJS. 1963;45(3):587–622. Peterson HA. Physeal fractures: Part 3. Classification. J Pediatr Orthop. 1994;14(4):439–48. https://doi.org/10.1097/01241398-199407000- 00004.
13. Peterson HA. Physeal fractures: Part 3. Classification. J Pediatr Orthop. 1994;14(4):439–48. https://doi.org/10.1097/01241398-199407000- 00004.
14. Armstrong, N. & McManus, A. M. Cardiopulmonary responses to exercise. in *Oxford Textbook of Children's Sport and Exercise Medicine* (eds. Armstrong, N., van Mechelen, W., Armstrong, N. & Mechelen, W. V.) 0 (Oxford University Press, 2023). doi:10.1093/med/9780192843968.003.0010.
15. Takken, T., Bongers, B. C., Van Brussel, M., Haapala, E. A. & Hulzebos, E. H. J. Cardiopulmonary Exercise Testing in Pediatrics. *Ann. Am. Thorac. Soc.* **14**, S123–S128 (2017).
16. Turley, K. R. Cardiovascular Responses to Exercise in Children. *Sports Med.* **24**, 241–257 (1997).
17. McClean, G. *et al.* Electrical and structural adaptations of the paediatric athlete's heart: a systematic review with meta-analysis. *Br. J. Sports Med.* **52**, 230 (2018).
18. Kayihan, G. Comparison of physical fitness levels of adolescents according to sports participation: Martial arts, team sports and non-sports. *Arch. Budo* **10**, 227–232 (2014).

19. Pierantozzi, E. *et al.* Effects of a Long-Term Adapted Judo Program on the Health-Related Physical Fitness of Children with ASD. *Int. J. Environ. Res. Public. Health* **19**, 16731 (2022).
20. Pinto-Escalona, T. *et al.* Effects of a school-based karate intervention on academic achievement, psychosocial functioning, and physical fitness: A multi-country cluster randomized controlled trial. *J. Sport Health Sci.* **13**, 90–98 (2024).
21. Suetake, V. Y. B. *et al.* Effects of 9 Months of Martial Arts Training on Cardiac Autonomic Modulation in Healthy Children and Adolescents. *Pediatr. Exerc. Sci.* **30**, 487–494 (2018).
22. Tsang, T. W., Kohn, M. R., Chow, C. M. & Fiatarone Singh, M. A. Kung Fu Training Improves Physical Fitness Measures in Overweight/Obese Adolescents: The "Martial Fitness" Study. *J. Obes.* **2010**, e672751 (2010).
23. Nabi, T., Rafiq, N. & Qayoom, O. Assessment of cardiovascular fitness [VO2 max] among medical students by Queens College step test. (2015).
24. Pieles, G. E. & Oberhoffer, R. The Assessment of the Paediatric Athlete. *J Cardiovasc. Transl. Res.* **13**, 306–312 (2020).
25. Hauser, C. *et al.* Cardiorespiratory fitness and development of childhood cardiovascular risk: The EXAMIN YOUTH follow-up study. *Front. Physiol.* **14**, (2023).
26. Bhattacharya, P., Chatterjee, S., Mondal, S. & Roy, D. Heart Rate Variability as a Neuroautonomic Marker to Assess the Impact of Karate Training - An Observational Pediatric Study. *Int. J. Exerc. Sci.* **16**, 342–352 (2023).
27. Guasch, E. & Mont, L. Endurance training in young athletes: What happens in childhood, stays in childhood? *Eur. J. Prev. Cardiol.* **26**, 1998–2000 (2019).
28. Bjerring, A. W. *et al.* The developing athlete's heart: a cohort study in young athletes transitioning through adolescence. *Eur. J. Prev. Cardiol.* **26**, 2001–2008 (2019).
29. Maron, B. J. & Pelliccia, A. The Heart of Trained Athletes. *Circulation* **114**, 1633–1644 (2006).
30. Carbone, A. *et al.* Cardiac damage in athlete's heart: When the "supernormal" heart fails! *World J. Cardiol.* **9**, 470–480 (2017).
31. O'Keefe, J. H. *et al.* Potential Adverse Cardiovascular Effects From Excessive Endurance Exercise. *Mayo Clin. Proc.* **87**, 587–595 (2012).
32. Logan, K. *et al.* Youth sports participation and health status in early adulthood: A 12-year follow-up. *Prev. Med. Rep.* **19**, 101107 (2020).
33. Alvarez-Pitti, J. *et al.* Blood pressure response to exercise in children and adolescents. *Front. Cardiovasc. Med.* **9**, (2022).
34. Samuels, J. & Samuel, J. New guidelines for hypertension in children and adolescents. *J. Clin. Hypertens.* **20**, 837–839 (2018).
35. Luckstead, E. F. Cardiac risk factors and participation guidelines for youth sports. *Pediatr. Clin. North Am.* **49**, 681–707 (2002).
36. Grabitz, C. *et al.* Cardiovascular health and potential cardiovascular risk factors in young athletes. *Front. Cardiovasc. Med.* **10**, (2023).
37. Graham, L. AAP updates policy statement on athletic participation by children and adolescents with systemic hypertension. *Am. Fam. Physician* **82**, 1285 (2010).
38. deWeber, K., Ota, K. S. & Dye, C. Pre-bout hypertension in the combat sports athlete: clearance recommendations. *Phys. Sportsmed.* **51**, 210–216 (2023).

39. Black, H. R., Sica, D., Ferdinand, K. & White, W. B. Eligibility and Disqualification Recommendations for Competitive Athletes With Cardiovascular Abnormalities: Task Force 6: Hypertension. *Circulation* **132**, e298–e302 (2015).
40. Baker-Smith, C. M., Pietris, N. & Jinadu, L. Recommendations for exercise and screening for safe athletic participation in hypertensive youth. *Pediatr. Nephrol.* **35**, 743–752 (2020).
41. Flynn, J. T. *et al.* Clinical Practice Guideline for Screening and Management of High Blood Pressure in Children and Adolescents. *Pediatrics* **140**, e20171904 (2017).
42. National High Blood Pressure Education Program Working Group on High Blood Pressure in Children and Adolescents. *Pediatrics* **114**, iv (2004).
43. Meyer, L. *et al.* Incidence, causes, and survival trends from cardiovascular-related sudden cardiac arrest in children and young adults 0 to 35 years of age: a 30-year review. *Circulation* **126**, 1363–1372 (2012).
44. Corrado, D. *et al.* Trends in Sudden Cardiovascular Death in Young Competitive Athletes After Implementation of a Preparticipation Screening Program. *JAMA* **296**, 1593–1601 (2006).
45. Halabchi, F., Seif-Barghi, T. & Mazaheri, R. Sudden Cardiac Death in Young Athletes; a Literature Review and Special Considerations in Asia. *Asian J. Sports Med.* **2**, 1–15 (2011).
46. Tainter, C. R. & Hughes, P. G. Commotio Cordis. in *StatPearls* (StatPearls Publishing, 2024).
47. de Froidmont S, Lobrinus JA, Michaud K, et al. Cardioinhibitory reflex due to a karate kick: a case report. *Am J Forensic Med Pathol*. 2015;36(2):79-83. doi:10.1097/PAF.0000000000000150
48. Corrado, D., Basso, C., Schiavon, M. & Thiene, G. Screening for hypertrophic cardiomyopathy in young athletes. *N. Engl. J. Med.* **339**, 364–369 (1998).
49. Maron, B. J., Doerer, J. J., Haas, T. S., Tierney, D. M. & Mueller, F. O. Sudden deaths in young competitive athletes: analysis of 1866 deaths in the United States, 1980-2006. *Circulation* **119**, 1085–1092 (2009).
50. Maron, B. J. *et al.* Eligibility and Disqualification Recommendations for Competitive Athletes With Cardiovascular Abnormalities: Task Force 2: Preparticipation Screening for Cardiovascular Disease in Competitive Athletes: A Scientific Statement From the American Heart Association and American College of Cardiology. *J. Am. Coll. Cardiol.* **66**, 2356–2361 (2015).
51. Angelini, P. *et al.* Young athletes: Preventing sudden death by adopting a modern screening approach? A critical review and the opening of a debate. *IJC Heart Vasc.* **34**, 100790 (2021).
52. Palermi, S. *et al.* Potential role of an athlete-focused echocardiogram in sports eligibility. *World J. Cardiol.* **13**, 271–297 (2021).
53. Peterson, D. F. *et al.* Aetiology and incidence of sudden cardiac arrest and death in young competitive athletes in the USA: a 4-year prospective study. *Br. J. Sports Med.* **55**, 1196–1203 (2021).
54. Williams, E. A. *et al.* Performance of the American Heart Association (AHA) 14-Point Evaluation Versus Electrocardiography for the Cardiovascular Screening of High School Athletes: A Prospective Study. *J. Am. Heart Assoc.* **8**, e012235 (2019).

55. Pelliccia, A. *et al.* 2020 ESC Guidelines on sports cardiology and exercise in patients with cardiovascular disease: The Task Force on sports cardiology and exercise in patients with cardiovascular disease of the European Society of Cardiology (ESC). *Eur. Heart J.* **42**, 17–96 (2021).
56. Hajduczok, A. G., Ruge, M. & Emery, M. S. Risk Factors for Sudden Death in Athletes, Is There a Role for Screening? *Curr. Cardiovasc. Risk Rep.* **16**, 97–109 (2022).
57. Health Education and Public Health [Internet]. [cited 2024 Mar 21]. Available from: https://healtheducationandpublichealth.com/age-transformations-of-the-kidneys-structure-and-function
58. The science and dangers behind Weight cutting in combat sports – International Federation of Muaythai Associations [Internet]. [cited 2024 Mar 21]. Available from: https://muaythai.sport/the-science-and-dangers-behind-weight-cutting-in-combat-sports/
59. Amaerjiang N, Li M, Xiao H, Zunong J, Li Z, Huang D, et al. Dehydration Status Aggravates Early Renal Impairment in Children: A Longitudinal Study. Nutrients. 2022 Jan 13;14(2):335.
60. The possible role of hydration in concussions and long-term symptoms of concussion for athletes. A review of the evidence - James E Clark, Emily Sirois, 2020 [Internet]. [cited 2024 Mar 21]. Available from: https://journals.sagepub.com/doi/10.1177/2059700220939404
61. Vega RM, Avva U. Pediatric Dehydration. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2024 [cited 2024 Mar 21]. Available from: http://www.ncbi.nlm.nih.gov/books/NBK436022/
62. How Children Are Different - Anatomical and Physiological Differences. 2022. Children's Health Queensland Hospital. Available from: https://www.childrens.health.qld.gov.au/__data/assets/pdf_file/0031/179725/how-children-are-different-anatomical-and-physiological-differences.pdf
63. Barley, O. R., Chapman, D. W. & Abbiss, C. R. The Current State of Weight-Cutting in Combat Sports. *Sports* **7**, 123 (2019).
64. Lakicevic, N. *et al.* Patterns of weight cycling in youth Olympic combat sports: a systematic review. *J. Eat. Disord.* **10**, 75 (2022).
65. LeBlanc, C. M. A., Purcell, L. & AMERICAN ACADEMY OF PEDIATRICS, C. O. S. M. A. F., CANADIAN PAEDIATRIC SOCIETY, HEALTHY ACTIVE LIVING AND SPORTS MEDICINE COMMITTEE. Boxing Participation by Children and Adolescents. *Pediatrics* **128**, 617–623 (2011).
66. Burke, L. M., Slater, G. J., Matthews, J. J., Langan-Evans, C. & Horswill, C. A. ACSM Expert Consensus Statement on Weight Loss in Weight-Category Sports. *Curr. Sports Med. Rep.* **20**, 199 (2021).
67. Brechney, G. C., Cannon, J. & Goodman, S. P. Effects of Weight Cutting on Exercise Performance in Combat Athletes: A Meta-Analysis. *Int. J. Sports Physiol. Perform.* **17**, 995–1010 (2022).
68. Artioli, G. G., Saunders, B., Iglesias, R. T. & Franchini, E. It is Time to Ban Rapid Weight Loss from Combat Sports. *Sports Med.* **46**, 1579–1584 (2016).
69. Lowe, G. D. O., Lee, A. J., Rumley, A., Price, J. F. & Fowkes, F. G. R. Blood viscosity and risk of cardiovascular events: the Edinburgh Artery Study. *Br. J. Haematol.* **96**, 168–173 (1997).

70. Tidmas V, Brazier J, Hawkins J, Forbes SC, Bottoms L, Farrington K. Nutritional and Non-Nutritional Strategies in Bodybuilding: Impact on Kidney Function. Int J Environ Res Public Health. 2022 Apr 3;19(7):4288.
71. Roncal-Jimenez C, Lanaspa MA, Jensen T, Sanchez-Lozada LG, Johnson RJ. Mechanisms by Which Dehydration May Lead to Chronic Kidney Disease. Ann Nutr Metab. 2015;66 Suppl 3:10–3.
72. Kasper AM, Crighton B, Langan-Evans C, Riley P, Sharma A, Close GL, et al. Case Study: Extreme Weight Making Causes Relative Energy Deficiency, Dehydration, and Acute Kidney Injury in a Male Mixed Martial Arts Athlete. Int J Sport Nutr Exerc Metab. 2019 May 1;29(3):331–8.
73. Kadhiresan R. Murugappan et al. Case Study: Fatal Exertional Rhabdomyolysis Possibly Related to Drastic Weight Cutting in: International Journal of Sport Nutrition and Exercise Metabolism Volume 29 Issue 1 (2019) [Internet]. [cited 2024 Mar 21]. Available from: https://journals.humankinetics.com/view/journals/ijsnem/29/1/article-p68.xml
74. Stanley M, Chippa V, Aeddula NR, Quintanilla Rodriguez BS, Adigun R. Rhabdomyolysis. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2024 [cited 2024 Mar 21]. Available from: http://www.ncbi.nlm.nih.gov/books/NBK448168/
75. Helvaci O, Korucu B, Arinsoy T. Another Victim of Rapid Weight Loss? Kidney Int Rep. 2019 Jan 23;4(4):633.
76. Zhuo M, Li J, William JH. Sauna-Induced Fatal Rhabdomyolysis. Kidney Int Rep. 2018 Aug 25;4(1):171–3.
77. Bialowas, D., Laskowski, R., Franchini, E. & Kujach, S. Examining the effects of pre-competition rapid weight loss on hydration status and competition performance in elite judo athletes. *Sci. Rep.* **13**, 14756 (2023).
78. Zubac, D., Karnincic, H. & Sekulic, D. Rapid Weight Loss Is Not Associated With Competitive Success in Elite Youth Olympic-Style Boxers in Europe. *Int. J. Sports Physiol. Perform.* **13**, 860–866 (2018).
79. Smith CJ. Pediatric Thermoregulation: Considerations in the Face of Global Climate Change. Nutrients. 2019 Aug 26;11(9):2010.
80. Johnson B, Christensen C, Dirusso S, Choudhury M, Franco I. A need for reevaluation of sports participation recommendations for children with a solitary kidney. J Urol. 2005 Aug;174(2):686–9; discussion 689.
81. Psooy K, Franc-Guimond J, Kiddoo D, Lorenzo A, MacLellan D. Canadian Urological Association Best Practice Report: Sports and the solitary kidney — What primary caregivers of a young child with a single kidney should know (2019 update). Can Urol Assoc J. 2019 Oct;13(10):315–7.
82. Goldstein LS et al. A pilot study of twice-weekly exercise during hemodialysis in children - PubMed [Internet]. [cited 2024 Mar 21]. Available from: https://pubmed.ncbi.nlm.nih.gov/19093138/
83. Patel DR et al. Chronic kidney disease, exercise, and sports in children, adolescents, and adults - PubMed [Internet]. [cited 2024 Mar 21]. Available from: https://pubmed.ncbi.nlm.nih.gov/20048524/Master
84. Master Sankar Raj V, Patel DR, Ramachandran L. Chronic kidney disease and sports participation by children and adolescents. *Transl Pediatr*. 2017;6(3):207-214. doi:10.21037/tp.2017.06.03

85. Patrick Niaudet, MD. UpToDate. 2023 [cited 2024 Mar 21]. Autosomal dominant polycystic kidney disease (ADPKD) in children. Available from: https://www.uptodate.com/contents/autosomal-dominant-polycystic-kidney-disease-adpkd-in-children#H91671525
86. Eliakim A, Nemet D. Exercise provocation test for growth hormone secretion: methodologic considerations. *Pediatr Exerc Sci*. 2008;20(4):370-378. doi:10.1123/pes.20.4.370
87. Berelowitz M, Szabo M, Frohman LA, Firestone S, Chu L, Hintz RL. Somatomedin-C mediates growth hormone negative feedback by effects on both the hypothalamus and the pituitary. *Science*. 1981;212(4500):1279-1281. doi:10.1126/science.6262917
88. Felsing NE, Brasel JA, Cooper DM. Effect of low and high intensity exercise on circulating growth hormone in men. *J Clin Endocrinol Metab*. 1992;75(1):157-162. doi:10.1210/jcem.75.1.1619005
89. Eliakim A, Brasel JA, Cooper DM. GH response to exercise: assessment of the pituitary refractory period, and relationship with circulating components of the GH-IGF-I axis in adolescent females. *J Pediatr Endocrinol Metab*. 1999;12(1):47-55. doi:10.1515/jpem.1999.12.1.47
90. Wideman L, Weltman JY, Shah N, Story S, Veldhuis JD, Weltman A. Effects of gender on exercise- induced growth hormone release. J Appl Physiol. 1999; 87: 1154– 1162.
91. Stokes KA, Sykes D, Gilbert KL, Chen JW, Frystyk J. Brief, high intensity exercise alters serum ghrelin and growth hormone concentrations but not IGF- I, IGF- II or IGF- I bioactivity. Growth Horm IGF Res. 2010; 20: 289– 294.
92. Eliakim A, Cooper DM, Nemet D. The GH-IGF-I response to typical field sports practices in adolescent athletes: a summary. *Pediatr Exerc Sci*. 2014;26(4):428-433. doi:10.1123/pes.2014-0159
93. Round JM, Jones DA, Honour JW, Nevill AM. Hormonal factors in the development of differences in strength between boys and girls during adolescence: a longitudinal study. *Ann Hum Biol*. 1999;26(1):49-62. doi:10.1080/030144699282976
94. Cumming DC, Wall SR, Galbraith MA, Belcastro AN. Reproductive hormone responses to resistance exercise. *Med Sci Sports Exerc*. 1987;19(3):234-238.
95. Hale RW, Kosasa T, Krieger J, Pepper S. A marathon: the immediate effect on female runners' luteinizing hormone, follicle-stimulating hormone, prolactin, testosterone, and cortisol levels. *Am J Obstet Gynecol*. 1983;146(5):550-556. doi:10.1016/0002-9378(83)90801-3
96. Theintz GE. Endocrine adaptation to intensive physical training during growth. *Clin Endocrinol (Oxf)*. 1994;41(3):267-272. doi:10.1111/j.1365-2265.1994.tb02543.x
97. Malina RM. Physical activity and training: effects on stature and the adolescent growth spurt. *Med Sci Sports Exerc*. 1994;26(6):759-766. doi:10.1249/00005768-199406000-00016
98. Roemmich JN, Sinning WE. Weight loss and wrestling training: effects on growth-related hormones. *J Appl Physiol (1985)*. 1997;82(6):1760-1764. doi:10.1152/jappl.1997.82.6.1760
99. McMurray RG, Proctor CR, Wilson WL. Effect of caloric deficit and dietary manipulation on aerobic and anaerobic exercise. *Int J Sports Med*. 1991;12(2):167-172. doi:10.1055/s-2007-1024662

100. Pişkin İE, Gümüş M, Bayraktaroğlu T, Akalin TC, Yamaner F. Growth and pubertal development in adolescent male wrestlers. *J Sports Med Phys Fitness*. 2018;58(6):852-856. doi:10.23736/S0022-4707.17.07269-3
101. Nasri R, Hassen Zrour S, Rebai H, et al. Grip strength is a predictor of bone mineral density among adolescent combat sport athletes. *J Clin Densitom*. 2013;16(1):92-97. doi:10.1016/j.jocd.2012.07.011
102. Pilz-Burstein R, Ashkenazi Y, Yaakobovitz Y, et al. Hormonal response to Taekwondo fighting simulation in elite adolescent athletes. *Eur J Appl Physiol*. 2010;110(6):1283-1290. doi:10.1007/s00421-010-1612-6
103. Passelergue P, Lac G. Saliva cortisol, testosterone and T/C ratio variations during a wrestling competition and during the post-competitive recovery period. *Int J Sports Med*. 1999;20(2):109-113. doi:10.1055/s-2007-971102
104. Spear LP. Adolescent neurodevelopment. *J Adolesc Health*. 2013;52(2 Suppl 2):S7-S13. doi:10.1016/j.jadohealth.2012.05.006
105. Grigorenko EL. Brain Development: The Effect of Interventions on Children and Adolescents. In: Bundy DAP, Silva ND, Horton S, Jamison DT, Patton GC, eds. *Child and Adolescent Health and Development*. 3rd ed. Washington (DC): The International Bank for Reconstruction and Development / The World Bank; November 20, 2017.
106. Daneshvar DH, Riley DO, Nowinski CJ, McKee AC, Stern RA, Cantu RC. Long-term consequences: effects on normal development profile after concussion. *Phys Med Rehabil Clin N Am*. 2011;22(4):683-ix. doi:10.1016/j.pmr.2011.08.009
107. Khetani A, Rohr CS, Sojoudi A, Bray S, Barlow KM. Alteration in Cerebral Activation during a Working Memory Task after Pediatric Mild Traumatic Brain Injury: A Prospective Controlled Cohort Study. *J Neurotrauma*. 2019;36(23):3274-3283. doi:10.1089/neu.2018.6117
108. Stein CJ, MacDougall R, Quatman-Yates CC, et al. Young Athletes' Concerns About Sport-Related Concussion: The Patient's Perspective. *Clin J Sport Med*. 2016;26(5):386-390. doi:10.1097/JSM.0000000000000268
109. Inserra C. Chronic Traumatic Encephalopathy [Internet]. 2023. Available from: https://www.ncbi.nlm.nih.gov/books/NBK470535/
110. Walter AE, Wilkes JR, Arnett PA, et al. The accumulation of subconcussive impacts on cognitive, imaging, and biomarker outcomes in child and college-aged athletes: a systematic review. *Brain Imaging Behav*. 2022;16(1):503-517. doi:10.1007/s11682-021-00489-6
111. Birrer RB, Birrer CD. Unreported injuries in the Martial Arts. *Br J Sports Med*. 1983;17(2):131-133. doi:10.1136/bjsm.17.2.131
112. Feehan M, Waller AE. Precompetition injury and subsequent tournament performance in full-contact taekwondo. *Br J Sports Med*. 1995;29(4):258-262. doi:10.1136/bjsm.29.4.258
113. Demorest RA, Koutures C; COUNCIL ON SPORTS MEDICINE AND FITNESS. Youth Participation and Injury Risk in Martial Arts. *Pediatrics*. 2016;138(6):e20163022. doi:10.1542/peds.2016-3022
114. Macan J, Bundalo-Vrbanac D, Romić G. Effects of the new karate rules on the incidence and distribution of injuries. *Br J Sports Med*. 2006;40(4):326-330. doi:10.1136/bjsm.2005.022459

115. Pankow MP, Syrydiuk RA, Kolstad AT, et al. Head Games: A Systematic Review and Meta-analysis Examining Concussion and Head Impact Incidence Rates, Modifiable Risk Factors, and Prevention Strategies in Youth Tackle Football. *Sports Med*. 2022;52(6):1259-1272. doi:10.1007/s40279-021-01609-4
116. Kercher KA, Steinfeldt JA, Macy JT, Seo DC, Kawata K. Drill Intensity and Head Impact Exposure in Adolescent Football. *Pediatrics*. 2022;150(5):e2022057725. doi:10.1542/peds.2022-057725
117. Pfaller AY, Brooks MA, Hetzel S, McGuine TA. Effect of a New Rule Limiting Full Contact Practice on the Incidence of Sport-Related Concussion in High School Football Players. *Am J Sports Med*. 2019;47(10):2294-2299. doi:10.1177/0363546519860120
118. deWeber K, Parlee L, Nguyen A, Lenihan MW, Goedecke L. Headguard use in combat sports: position statement of the Association of Ringside Physicians. *Phys Sportsmed*. 2024;52(3):229-238. doi:10.1080/00913847.2023.2242415
119. American Academy of Pediatrics, Council on Sports Medicine And Fitness; Canadian Paediatric Society, Healthy Active Living And Sports Medicine Committee, Purcell L, LeBlanc CM. Policy statement—Boxing participation by children and adolescents. *Pediatrics*. 2011;128(3):617-623. doi:10.1542/peds.2011-1165
120. Caccese JB, Bodt BA, Iverson GL, et al. Estimated Age of First Exposure to Contact Sports and Neurocognitive, Psychological, and Physical Outcomes in Healthy NCAA Collegiate Athletes: A Cohort Study. *Sports Med*. 2020;50(7):1377-1392. doi:10.1007/s40279-020-01261-4
121. Caccese J, Schmidt J, Moody J, et al. Association between sports participation history and age of first exposure to high-risk sports with concussion history. *Res Sports Med*. 2023;31(3):260-272. doi:10.1080/15438627.2021.1966008
122. Brett BL, Huber DL, Wild A, Nelson LD, McCrea MA. Age of First Exposure to American Football and Behavioral, Cognitive, Psychological, and Physical Outcomes in High School and Collegiate Football Players. *Sports Health*. 2019;11(4):332-342. doi:10.1177/1941738119849076
123. Tsushima WT, Siu AM, Ahn HJ, Chang BL, Murata NM. Incidence and Risk of Concussions in Youth Athletes: Comparisons of Age, Sex, Concussion History, Sport, and Football Position. *Arch Clin Neuropsychol Off J Natl Acad Neuropsychol*. 2019;34(1):60-69. doi:10.1093/arclin/acy019
124. Koh JO, Cassidy JD. Incidence study of head blows and concussions in competition taekwondo. *Clin J Sport Med Off J Can Acad Sport Med*. 2004;14(2):72-79. doi:10.1097/00042752-200403000-00004
125. Kerr ZY, Dalton SL, Roos KG, Djoko A, Phelps J, Dompier TP. Comparison of Indiana High School Football Injury Rates by Inclusion of the USA Football "Heads Up Football" Player Safety Coach. *Orthop J Sports Med*. 2016;4(5):2325967116648441. doi:10.1177/2325967116648441
126. Kerr ZY, Yeargin SW, Valovich McLeod TC, Mensch J, Hayden R, Dompier TP. Comprehensive Coach Education Reduces Head Impact Exposure in American Youth Football. *Orthop J Sports Med*. 2015;3(10):2325967115610545. doi:10.1177/2325967115610545
127. Shanley E, Thigpen C, Kissenberth M, et al. Heads Up Football Training Decreases Concussion Rates in High School Football Players. *Clin J Sport Med Off J Can Acad Sport Med*. 2021;31(2):120-126. doi:10.1097/JSM.0000000000000711

128. Kerr ZY, Yeargin S, Valovich McLeod TC, et al. Comprehensive Coach Education and Practice Contact Restriction Guidelines Result in Lower Injury Rates in Youth American Football. *Orthop J Sports Med*. 2015;3(7):2325967115594578. doi:10.1177/2325967115594578
129. Gotlieb RJ, Sorenson TJ, Borad V, Schubert W. Children in Boxing and Martial Arts Should Be Better Guarded From Facial Injuries. *Craniomaxillofacial Trauma Reconstr*. 2022;15(2):104-110. doi:10.1177/19433875211016666
130. Koh JO, Watkinson EJ, Yoon YJ. Video analysis of head blows leading to concussion in competition Taekwondo. *Brain Inj*. 2004;18(12):1287-1296. doi:10.1080/02699050410001719907
131. Ha S, Kim MJ, Jeong HS, Lee I, Lee SY. Mechanisms of Sports Concussion in Taekwondo: A Systematic Video Analysis of Seven Cases. *Int J Environ Res Public Health*. 2022;19(16):10312. doi:10.3390/ijerph191610312
132. Knapik JJ, Hoedebecke BL, Rogers GG, Sharp MA, Marshall SW. Effectiveness of Mouthguards for the Prevention of Orofacial Injuries and Concussions in Sports: Systematic Review and Meta-Analysis. *Sports Med Auckl NZ*. 2019;49(8):1217-1232. doi:10.1007/s40279-019-01121-w
133. Kolstad AT, Eliason PH, Galarneau JM, Black AM, Hagel BE, Emery CA. Protective equipment in youth ice hockey: are mouthguards and helmet age relevant to concussion risk? *Br J Sports Med*. 2023;57(10):571-577. doi:10.1136/bjsports-2022-105585
134. Mouth Guard Use in Combat Sports. A Position Statement from the Association of Ringside Physicians. Available from: https://ringsidearp.org/wp-content/uploads/2022/06/Mouth-Guard-Position-Paper-2021_b.pdf
135. Greenhill DA, Navo P, Zhao H, Torg J, Comstock RD, Boden BP. Inadequate Helmet Fit Increases Concussion Severity in American High School Football Players. *Sports Health*. 2016;8(3):238-243. doi:10.1177/1941738116639027
136. Gamble ASD, Bigg JL, Sick S, et al. Helmet Fit Assessment and Concussion Risk in Youth Ice Hockey Players: A Nested Case-Control Study. *J Athl Train*. 2021;56(8):845-850. doi:10.4085/1062-6050-0294.20
137. Zetaruk MN, Zurakowski D, Violan MA, Micheli LJ. Safety recommendations in Shotokan karate. *Clin J Sport Med Off J Can Acad Sport Med*. 2000;10(2):117-122. doi:10.1097/00042752-200004000-00006
138. Zetaruk MN, Violán MA, Zurakowski D, Micheli LJ. Injuries in martial arts: a comparison of five styles. *Br J Sports Med*. 2005;39(1):29-33. doi:10.1136/bjsm.2003.010322
139. Madireddy SS, McAdams RJ, Roberts KJ, McKenzie LB. Pediatric Martial Arts-Related Injuries Treated in Emergency Departments in the United States From 2004 to 2021. *Am J Sports Med*. 2023;51(10):2723-2731. doi:10.1177/03635465231181086
140. Macan J, Bundalo-Vrbanac D, Romić G. Effects of the new karate rules on the incidence and distribution of injuries. *Br J Sports Med*. 2006;40(4):326-330; discussion 330. doi:10.1136/bjsm.2005.022459
141. Eliason PH, Galarneau JM, Kolstad AT, et al. Prevention strategies and modifiable risk factors for sport-related concussions and head impacts: a systematic review and meta-analysis. *Br J Sports Med*. 2023;57(12):749-761. doi:10.1136/bjsports-2022-106656

142. Guillaume S, Lincoln AE, Hepburn L, Caswell SV, Kerr ZY. Rule Modifications to Reduce Checking-Related Injuries in High School Boys' Lacrosse. *J Athl Train*. 2021;56(4):437-445. doi:10.4085/1062-6050-0489.19
143. Lalji R, Snider H, Chow N, Howitt S. The 2015 U.S. Soccer Federation header ban and its effect on emergency room concussion rates in soccer players aged 10-13. *J Can Chiropr Assoc*. 2020;64(3):187-192.
144. Koh JO. Effects of a greater incentive to attack the head and face region on incidence of head kicks and concussions among male youth taekwondo competitors. *J Sports Med Phys Fitness*. 2020;60(2):263-269. doi:10.23736/S0022-4707.19.10031-X
145. Stamm JM, Koerte IK, Muehlmann M, et al. Age at First Exposure to Football Is Associated with Altered Corpus Callosum White Matter Microstructure in Former Professional Football Players. *J Neurotrauma*. 2015;32(22):1768-1776. doi:10.1089/neu.2014.3822
146. Eckner JT, Oh YK, Joshi MS, Richardson JK, Ashton-Miller JA. Effect of neck muscle strength and anticipatory cervical muscle activation on the kinematic response of the head to impulsive loads. *Am J Sports Med*. 2014;42(3):566-576. doi:10.1177/0363546513517869
147. Alosco ML, Mez J, Tripodis Y, et al. Age of first exposure to tackle football and chronic traumatic encephalopathy. *Ann Neurol*. 2018;83(5):886-901. doi:10.1002/ana.25245
148. Schultz V, Stern RA, Tripodis Y, et al. Age at First Exposure to Repetitive Head Impacts Is Associated with Smaller Thalamic Volumes in Former Professional American Football Players. *J Neurotrauma*. 2018;35(2):278-285. doi:10.1089/neu.2017.5145
149. Mez J, Daneshvar DH, Abdolmohammadi B, et al. Duration of American Football Play and Chronic Traumatic Encephalopathy. *Ann Neurol*. 2020;87(1):116-131. doi:10.1002/ana.25611
150. Patricios JS, Schneider KJ, Dvorak J, et al. Consensus statement on concussion in sport: the 6th International Conference on Concussion in Sport-Amsterdam, October 2022. *Br J Sports Med*. 2023;57(11):695-711. doi:10.1136/bjsports-2023-106898
151. Iverson GL, Gardner AJ, Terry DP, et al. Predictors of clinical recovery from concussion: a systematic review. *Br J Sports Med*. 2017;51(12):941-948. doi:10.1136/bjsports-2017-097729
152. Putukian M, Purcell L, Schneider KJ, et al. Clinical recovery from concussion-return to school and sport: a systematic review and meta-analysis. *Br J Sports Med*. 2023;57(12):798-809. doi:10.1136/bjsports-2022-106682
153. Engelhardt J, Brauge D, Loiseau H. Second Impact Syndrome. Myth or reality? *Neurochirurgie*. 2021;67(3):265-275. doi:10.1016/j.neuchi.2019.12.007
154. McLendon LA, Kralik SF, Grayson PA, Golomb MR. The Controversial Second Impact Syndrome: A Review of the Literature. *Pediatr Neurol*. 2016;62:9-17. doi:10.1016/j.pediatrneurol.2016.03.009
155. May T, Foris LA, Donnally III CJ. Second Impact Syndrome. In: *StatPearls*. StatPearls Publishing; 2024. Accessed February 2, 2024. http://www.ncbi.nlm.nih.gov/books/NBK448119/
156. APA Dictionary of Psychology [Internet]. American Psychological Association. [cited 2024 Jan 15]. Available from: https://dictionary.apa.org/psychosocial

157. Data and Statistics on Children's Mental Health [Internet]. Center for Disease Control and Prevention. 2023 [cited 2024 Jan 15]. Available from: https://www.cdc.gov/childrensmentalhealth/data.html
158. Jaworska N, MacQueen G. Adolescence as a unique developmental period. J Psychiatry Neurosci. 2015;40:291–3. Jaworska N, MacQueen G. Adolescence as a unique developmental period. J Psychiatry Neurosci. 2015;40:291–3.
159. Silvers JA. Adolescence as a pivotal period for emotion regulation development. Curr Opin Psychol. 2022;44:258–63.
160. Aebi M, Giger J, Plattner B, Metzke CW, Steinhausen H-C. Problem coping skills, psychosocial adversities and mental health problems in children and adolescents as predictors of criminal outcomes in young adulthood. Eur Child Adolesc Psychiatry. 2014;23:283–93.
161. Theeboom M, De Knop P, Vertonghen J. Experiences of children in martial arts. European Journal for Sport and Society. 2009;6:19–35.
162. Eime RM, Young JA, Harvey JT, Charity MJ, Payne WR. A systematic review of the psychological and social benefits of participation in sport for children and adolescents: informing development of a conceptual model of health through sport. Int J Behav Nutr Phys Act. 2013;10:98.
163. Taliaferro LA, Rienzo BA, Miller MD, Pigg RM, Dodd VJ. High school youth and suicide risk: exploring protection afforded through physical activity and sport participation. J Sch Health. 2008;78:545–53.
164. Guddal MH, Stensland SØ, Småstuen MC, Johnsen MB, Zwart J-A, Storheim K. Physical activity and sport participation among adolescents: associations with mental health in different age groups. Results from the Young-HUNT study: a cross-sectional survey. BMJ Open. 2019;9:e028555.
165. Charles Richman, Heather Rehberg. The development of self-esteem through the martial arts. International Journal of Sport Psychology. 1986;17:234–9.
166. Steyn B, Roux S. Aggression and psychological well-being of adolescent taekwondo participants in comparison with hockey participants and a non sport group. Af J Phys, Health Edu Rec & Dance [Internet]. 2009 [cited 2024 May 10];15. Available from: http://www.ajol.info/index.php/ajpherd/article/view/44636
167. Haraldsdottir K, Watson AM. Psychosocial Impacts of Sports-related Injuries in Adolescent Athletes. Curr Sports Med Rep. 2021;20:104–8.
168. Kvist J, Ek A, Sporrstedt K, Good L. Fear of re-injury: a hindrance for returning to sports after anterior cruciate ligament reconstruction. Knee Surg Sports Traumatol Arthrosc. 2005;13:393–7.
169. Axelson DA, Birmaher B. Relation between anxiety and depressive disorders in childhood and adolescence. Depress Anxiety. 2001;14:67–78.
170. Zhang X, Zhu W, Kang S, Qiu L, Lu Z, Sun Y. Association between Physical Activity and Mood States of Children and Adolescents in Social Isolation during the COVID-19 Epidemic. Int J Environ Res Public Health. 2020;17:7666.
171. Almeida IL de L, Rego JF, Teixeira ACG, Moreira MR. Social isolation and its impact on child and adolescent development: a systematic review. Rev Paul Pediatr. 2021;40:e2020385.

172. Doré I, O'Loughlin JL, Beauchamp G, Martineau M, Fournier L. Volume and social context of physical activity in association with mental health, anxiety and depression among youth. Prev Med. 2016;91:344–50.
173. Panza MJ, Graupensperger S, Agans JP, Doré I, Vella SA, Evans MB. Adolescent Sport Participation and Symptoms of Anxiety and Depression: A Systematic Review and Meta-Analysis. J Sport Exerc Psychol. 2020;42:201–18.
174. Babiss LA, Gangwisch JE. Sports participation as a protective factor against depression and suicidal ideation in adolescents as mediated by self-esteem and social support. J Dev Behav Pediatr. 2009;30:376–84.
175. Moore B, Dudley D, Woodcock S. The effect of martial arts training on mental health outcomes: A systematic review and meta-analysis. J Bodyw Mov Ther. 2020;24:402–12.
176. Hoffmann MD, Barnes JD, Tremblay MS, Guerrero MD. Associations between organized sport participation and mental health difficulties: Data from over 11,000 US children and adolescents. PLoS One. 2022;17:e0268583.
177. Pluhar E, McCracken C, Griffith KL, Christino MA, Sugimoto D, Meehan WP. Team Sport Athletes May Be Less Likely To Suffer Anxiety or Depression than Individual Sport Athletes. J Sports Sci Med. 2019;18:490–6.
178. Soreff SM, Gupta V, Wadhwa R, Arif H. Aggression. StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2023 [cited 2024 Jan 22]. Available from: http://www.ncbi.nlm.nih.gov/books/NBK448073/
179. Buchmann A, Hohmann S, Brandeis D, Banaschewski T, Poustka L. Aggression in children and adolescents. Curr Top Behav Neurosci. 2014;17:421–42.
180. Carraro A, Gobbi E, Moè A. Brief report: Play fighting to curb self-reported aggression in young adolescents. J Adolesc. 2014;37:1303–7.
181. Trajković N, Pajek M, Sporiš G, Petrinović L, Bogataj Š. Reducing Aggression and Improving Physical Fitness in Adolescents Through an After-School Volleyball Program. Front Psychol. 2020;11:2081.
182. Harwood-Gross A, Lambez B, Feldman R, Zagoory-Sharon O, Rassovsky Y. The Effect of Martial Arts Training on Cognitive and Psychological Functions in At-Risk Youths. Front Pediatr. 2021;9:707047.
183. Zivin G, Hassan NR, DePaula GF, Monti DA, Harlan C, Hossain KD, et al. An effective approach to violence prevention: traditional martial arts in middle school. Adolescence. 2001;36:443–59.
184. Twemlow SW, Biggs BK, Nelson TD, Vernberg EM, Fonagy P, Twemlow SW. Effects of participation in a martial arts–based antibullying program in elementary schools. Psychology in the Schools. 2008;45:947–59.
185. McGowan RW, Miller MJ. Differences in Mood States between Successful and Less Successful Karate Participants. Percept Mot Skills. 1989;68:505–6.
186. Yang Y, Zhu H, Chu K, Zheng Y, Zhu F. Effects of sports intervention on aggression in children and adolescents: a systematic review and meta-analysis. PeerJ. 2023;11:e15504.
187. Huang G, Xie Y, Xu H. Cognitive Ability: Social Correlates and Consequences in Contemporary China. Chin Sociol Rev. 2015;47:287–313.
188. Deák GO, Wiseheart M. Cognitive flexibility in young children: General or task-specific capacity? J Exp Child Psychol. 2015;138:31–53.

189. Takeuchi H, Kawashima R. Effects of processing speed training on cognitive functions and neural systems. Rev Neurosci. 2012;23:289–301.
190. Lövdén M, Fratiglioni L, Glymour MM, Lindenberger U, Tucker-Drob EM. Education and Cognitive Functioning Across the Life Span. Psychol Sci Public Interest. 2020;21:6–41.
191. Bidzan-Bluma I, Lipowska M. Physical Activity and Cognitive Functioning of Children: A Systematic Review. Int J Environ Res Public Health. 2018;15:800.
192. Owen KB, Foley BC, Wilhite K, Booker B, Lonsdale C, Reece LJ. Sport Participation and Academic Performance in Children and Adolescents: A Systematic Review and Meta-analysis. Med Sci Sports Exerc. 2022;54:299–306.
193. Howell DR, Meehan WP, Loosemore MP, Cummiskey J, Grabner von Rosenberg J-P, McDonagh D. Neurological tests improve after Olympic-style boxing bouts: a pretournament and post-tournament study in the 2016 Women's World Boxing Championships. Br J Sports Med. 2017;51:1279–84.
194. Contreras-Osorio F, Campos-Jara C, Martínez-Salazar C, Chirosa-Ríos L, Martínez-García D. Effects of Sport-Based Interventions on Children's Executive Function: A Systematic Review and Meta-Analysis. Brain Sci. 2021;11:755.
195. Giordano G, Gómez-López M, Alesi M. Sports, Executive Functions and Academic Performance: A Comparison between Martial Arts, Team Sports, and Sedentary Children. Int J Environ Res Public Health. 2021;18:11745.
196. Guthold R, Stevens GA, Riley LM, Bull FC. Global trends in insufficient physical activity among adolescents: a pooled analysis of 298 population-based surveys with 1·6 million participants. *Lancet Child Adolesc Health*. 2020;4(1):23-35. doi:10.1016/S2352-4642(19)30323-2
197. Sport for Life Society. *Sport for Life—Long-Term Athlete Development Resource Paper 3.0*. Sport for Life Society; 2019. Accessed July 2, 2024.
198. KEY FACTORS UNDERLYING LONG-TERM DEVELOPMENT IN SPORT AND PHYSICAL ACTIVITY. https://sportforlife.ca/key-factors/#toggle-id-2 Accessed July 2, 2024.
199. Boxing Canada Long-Term Athlete Development. https://boxingontario.com/wp-content/uploads/Boxing-Canada-LTAD.pdf Accessed July 2, 2024.
200. Long-Term Athlete development for Judo Canada: Taking it to the Mat. https://www.judocanada.org/wp-content/uploads/2011/05/00000798_2-JC-LTAD-Model.pdf Accessed July 2, 2024.
201. Judo Canada – Tournament Policy. https://judocanada.org/tournament-policy-ne-waza-2/ Accessed July 2, 2024.
202. Judo Canada – Judo for Children Under the Age of 7. https://www.judocanada.org/wp-content/uploads/2011/05/JC-LTAD-U7-U9.pdf Accessed July 2, 2024.
203. BC Taekwondo LATD Implementation Guide. http://sportpourlavie.ca/wp-content/uploads/2016/08/Taekwondo-BC-Implementation.pdf Accessed July 2, 2024.
204. Wrestling Canada – Long-Term Athlete Development: The Seven Stages. https://wrestling.ca/wp-content/uploads/2018/04/LTAD_E.pdf Accessed July 2, 2024.
205. BC Wrestling CS4L Implementation Plan. https://sportforlife.ca/wp-content/uploads/2018/01/BC_Wrestling_CS4L.pdf Accessed July 2, 2024.

206. IMMAF Participant Pathways. https://immaf.org/get-involved/participant-pathways/ Accessed July 2, 2024.