

Review

Eccentric Resistance Training in Youth: Perspectives for Long-Term Athletic Development

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Abstract: The purpose of this narrative review is to discuss the role of eccentric resistance training in youth and how this training modality can be utilized within long-term physical development. Current literature on responses to eccentric exercise in youth has demonstrated that potential concerns, such as fatigue and muscle damage, compared to adults are not supported. Considering the importance of resistance training for youth athletes and the benefits of eccentric training in enhancing strength, power, speed, and resistance to injury, its inclusion throughout youth may be warranted. In this review we provide a brief overview of the physiological responses to exercise in youth with specific reference to the different responses to eccentric resistance training between children, adolescents, and adults. Thereafter, we discuss the importance of ensuring that force absorption qualities are trained throughout youth and how these may be influenced by growth and maturation. In particular, we propose practical methods on how eccentric resistance training methods can be implemented in youth via the inclusion of efficient landing mechanics, eccentric hamstrings strengthening and flywheel inertia training. This article proposes that the use of eccentric resistance training in youth should be considered a necessity to help develop both physical qualities that underpin sporting performance, as well as reducing injury risk. However, as with any other training modality implemented within youth, careful consideration should be given in accordance with an individual's maturity status, training history and technical competency as well as being underpinned by current long-term physical development guidelines.

Keywords: eccentric training; youth athletes; paediatric physiology; landing mechanics; flywheel training; eccentric hamstrings

1. Introduction

The physical development of youth athletes is an important component in promoting the qualities that underpin athletic performance [1]. A number of previous position statements provide practitioners working with youth athletes, training guidelines that support the long-term athletic

development (LTAD) of the individual [2–5]. The overarching consensus of these statements is largely based upon the principles of the youth physical development (YPD) model, which offers a comprehensive approach to the development of both young males and females via the integration and prioritization of training different physical qualities throughout childhood, and beyond [6]. The rationale of this approach is underpinned by the influence of an individual's maturity status on physical and performance capacities in youth [7]. Central to the YPD model is the development of muscular strength, which should be targeted throughout youth, for both males and females, due to its underpinning of performance capabilities. Indeed, the importance of muscular strength in supporting young athletes' performances has been demonstrated on tasks such as change of direction [8,9], vertical jump [9–11], leg stiffness [11], sprint ability [9,12] and balance [13]. Accordingly, as muscular strength is an integral component of youth strength and conditioning programs for performance enhancement [2] and also for reducing the risk of sport-related injuries [14], training modalities that can further develop this component are necessary.

Developing muscular strength via the inclusion of resistance training (RT) methods is pivotal [15]. The use of RT for young athletes in developing strength and power qualities that support athletic performance has been strongly advocated [16] and the physiological adaptations underpinning such benefits discussed [17]. Similarly, a large body of evidence exists highlighting the efficacy of using RT methods to enhance the physical capabilities of youth athletes in both male [18] and female [19] populations. For example, recent meta-analyses on the use of RT in youth athletes have provided important information detailing the role of RT variables [20] as well as the different methods that can be used to improve strength, power and speed [21]. Practically, these studies have highlighted the necessity of a variety of training methods required to elicit further performance gains in individuals who are more mature and have a relatively longer training history. Therefore, for practitioners working with youth athletes, the knowledge of RT modalities that could be used for the development of physical qualities and reduce injury risk is beneficial.

Previously, the benefits of utilizing eccentric resistance training (ERT) to enhance performance has been discussed in detail [22]. Furthermore, the physiological responses and chronic adaptations to eccentric training have been outlined [23,24]. However, although the reported benefits of applying ERT methods to improve aspects such as strength, power, speed, change of direction, hypertrophy and injury resistance in adult athletic/trained individuals [25–59], limited information exists pertaining to its practical application within youth athletes. This is somewhat surprising given that specifically targeting the aforementioned physical qualities throughout youth are widely recommended [2]. Since athletic movements in youth will normally include performance of tasks such as changes of direction, deceleration, landing, and hopping, exposure to eccentric muscle actions may already occur within the demands of sport or even playground activities. Reasons for the paucity of research or application within youth are unknown. Though, it may be postulated that factors that are associated with eccentric exercise such as muscle damage [60], muscle strains [61] and the more detailed application of ERT in higher-trained athletes [62] may contribute to this dearth of research concerning applied training modalities. However, it has been recommended that the execution of eccentric training should be emphasized during later LTAD stages in youth [63]. Importantly, practitioners working with youth athletes should understand the acute responses to eccentric exercise as well as the necessity to include ERT modalities throughout maturation stages to enhance physical performance and injury prevention strategies. Therefore, the aim of this article is to provide an overview of the physiological responses to ERT in youth, and to discuss the potential applications of ERT within LTAD. It is hoped that this knowledge can provide practitioners working with youth athletes' greater awareness of the benefits of including ERT as well as potential training prescription and programming concepts.

1.1. Terminology

The terms 'children' and 'pre-pubertal' refer to girls and boys that are within the pre-peak height velocity maturation stage (pre-PHV), roughly defined as up to the age of 11 for girls and up to the age of 13 for boys. This differs from the terms 'pubertal' and 'adolescent' which normally include

girls aged 12–18 years and boys aged 14–18 years old (circa and post-peak height velocity stages). The use of the word 'athlete' will refer to a person who competes in sport.

1.2. Literature Search

With no date restrictions, a Boolean logic systematic search from online databases including Google Scholar, PubMed and Web of Sciences was undertaken from which only English language articles were considered. The following terms were searched: 'eccentric training', 'eccentric exercise', 'youth athlete', 'maturation', 'nordic hamstring exercise', 'eccentric hamstring strength', 'landing kinematics', 'augmented eccentric training', 'tendon', 'fatigue', 'resistance training', 'flywheel inertia training', 'physiological responses', 'injury' 'muscle damage'. Boolean operators (AND, OR) were used to concentrate the search terms.

2. Neuromuscular and Metabolic Responses to Exercise in Youth

Although the benefits of younger individuals utilizing strength and power methods to enhance physical qualities have been widely documented [21], it is also acknowledged that children and adolescents produce lower levels of muscular force than adults, even when normalized to body mass [64–68]. These differences can be attributed to anatomical and physiological changes occurring throughout growth and maturation [69]. Such factors include muscle size, histology, internal and external joint leverage, tendon mechanical properties and the central nervous system [70]. Furthermore, it is acknowledged that children recover quicker from high-intensity exercise than adults and therefore the same training principles may not apply [71]. An understanding and awareness of these different responses to RT in youth compared to adults is important to allow for appropriate prescription as these responses and adaptations underpin the guidelines used to structure resistance training for youth athletes [6].

2.1. Fatigue Resistance

From a neuromuscular fatigue perspective, it has been demonstrated that younger individuals are more fatigue resistant than adults [72]. The lesser fatigue in youths compared to adults following exercise has been shown within a range of exercise modalities with pre-pubertal boys displaying a greater maintenance of peak torque than adults following dynamic maximum isokinetic [67,73–77] and isometric [65,78,79] actions of the knee extensors and flexors, maximal isometric exercise of the elbow flexors [68], and isometric exercise of the plantar flexors [64]. The lower reductions in force-generating capacity following resistance exercise-induced fatigue in youth compared to adults have been shown to occur in conjunction with smaller alterations of neuromuscular properties including sarcolemma excitability (i.e., M-wave amplitude), excitation–contraction coupling (i.e., low-to-high frequency tetanic force ratio or low-frequency fatigue), muscle contractility (i.e., high-frequency torque) and muscle oxygenation [63,64,68,71–73,78–81]. Conversely, during submaximal isometric RT, differences in fatigue responses including torque and surface electromyography (EMG) have not been observed between children and men [82,83]. The absence of differences during submaximal actions have been attributed to the likely predominance of slow twitch motor units used during submaximal exercise, which are activated according to the size principle [84]. An explanation for this may be that submaximal intensity fatigue protocols encourage both children and adults to initially recruit a low proportion of their fast twitch motor units, thus removing the inherited age-related differences in fatigue occurring during maximal muscular actions [68]. Lower levels of force decrement observed within a bout of resistance exercise in youths has also been accompanied by faster recovery between bouts. For instance, boys have been shown to require shorter rest intervals to maintain peak torque during multiple sets of isokinetic exercise of the knee extensors when compared to adolescents and adults [67,85,86]. Evidence also points to the faster recovery of agonist muscle activation levels following the cessation of resistance exercise in boys, compared to men, the execution of lower limb isokinetic exercise following both maximal [65,77] and submaximal [83] protocols. Similar findings have also been reported during upper-body

resistance training exercise, in which boys and male adolescents achieve significantly greater repetitions than adults during the bench press [87] and chest press [88] exercises when completing the same between-set recovery period.

The lower levels of force produced by children compared to adolescents and adults appears to influence fatigue and recovery responses. Part of these differences have been attributed to the inability of children to voluntarily activate their motor units due to the lower central drive to the motor unit, which affects the resulting force production [70]. Confirmation of reduced voluntary activation (VA) in children compared to adults has been previously demonstrated [79,89–92] although some studies report no such differences [64,93,94]. Reasons for the discrepancies of these results have been proposed to be due to the sex and the muscle group investigated but also the mechanical conditions of muscle actions, and specifically the length at which the muscle was evaluated [70]. Notwithstanding, the lower VA levels observed in pre-pubertal children have been attributed to the immaturity of the corticospinal pathways in which the development of interneuronal synaptic connections both at the cortex and the spinal cord increases between the ages of 8 and 11 years [95]. However, some children may be unable to perform maximal-force muscle actions due to a lack of experience performing at a high intensity and, hence, discomfort and inexperience can impair their ability to fully activate [73]. It has also been proposed that pre-pubertal children possess a greater proportion of type I fibres than adults [96] and therefore have an inability to produce the high-power outputs that would be seen in more mature individuals who may possess a greater amount of type II muscle fibres. Equally, the higher electromyography threshold reported in both boys [97] and girls [98] compared to their adult counterparts might reflect a delayed and shorter onset of recruitment of type II motor units [99].

The variances in fatigue during exercise may be muscle-dependent as well as being influenced by the muscle-tendon unit (MTU) length. This has been observed during isometric fatiguing actions of the plantar flexor (PF) and knee extensor (KE) muscle groups in which boys fatigued similarly to men with the PF muscles but to a lower extent with the KE muscles than men [80]. With regards to the MTU length, neuromuscular fatigue at optimal and long MTU lengths are lower in children compared to adults, which are mainly accounted for by central fatigue (i.e., a reduction in drive to the muscle), rather than peripheral fatigue (i.e., failure in muscle contractility and excitation–contraction coupling (E–C)). Conversely, at short MTU lengths, the differences in neuromuscular fatigue between children and adults are significantly reduced [80]. The lesser performance fatigability and peripheral fatigue at short MTU length could be partly explained by a lower torque level than at optimal length, where greater alterations in peripheral mechanisms (i.e., EC coupling) are observed. The longer exercise duration at short muscle length could also account for the greater central fatigue. These differences point to a specific effect of MTU length in boys and men. Subsequently, it would appear that MTU stiffness plays a role in mediating the force-generating capability during youth [99]. Indeed, it has been suggested that a compliant tendon may act as a mechanical buffer, which could additionally protect the muscles from any extensive damage and subsequent peripheral fatigue [100]. Lastly, the greater decrease in antagonist co-activation of the knee flexors during repeated maximal voluntary isometric contractions in pre-pubertal children may contribute to limit the loss of force of the knee extensors, and therefore to delay fatigue of the agonist muscles [101].

2.2. *Metabolic Responses*

Throughout youth, the metabolic responses to exercise change with growth and maturation [102]. Following resistance and short-term high-intensity exercise, children have been shown to elicit lower post-exercise peak blood lactate concentrations, faster blood lactate clearance rates [67,75,103–109], better blood acid-base regulation [110], lower phosphocreatine (PCr) depletion, faster PCr resynthesis rates [111–114] and faster heart rate recovery [67,75,108,115]. Explanations for the differential responses in youth have been attributed to factors such as accelerated blood circulation due to smaller body size [69], lower relative muscle mass [109] and lower reliance on glycolysis [67]. This predisposition of children to be more reliant on aerobic metabolism for energy

demands has been proposed to occur due to age-dependent metabolic and hormonal responses to exercise compared to adolescents and adults [116]. Indeed, pre-pubertal children have a faster PCr recovery following exercise than adolescents and adults, suggesting that there is a progressive alteration in muscle oxidative capacity throughout youth [117]. A greater reliance on aerobic metabolism in children is also supported by findings that they possess a higher oxidative enzyme activity [118–121] and higher mitochondrial volume density than adults [122]. Due to these physiological predispositions it has been suggested that pre-pubertal children have a similar metabolic profile to that of well-trained endurance adult athletes due to their greater reliance on oxidative metabolism [123]. For example, recent work has shown that pre-pubertal children have a similar net contribution of energy derived from aerobic metabolism, a similar rate of fatigue (i.e., power loss) resulting from short-term high-intensity exercise and comparable post-exercise recovery of oxygen uptake to well-trained adult endurance athletes [115].

2.3. *Exercise-Induced Muscle Damage*

The previously discussed physical differences between youth and adults may also account for the magnitude of exercise-induced muscle damage (EIMD) in response to RT. Therefore, as children and adolescents mature, it is important to consider how EIMD affects muscle function [124]. For instance, it appears that there is a progressive withdrawal of physiological protection against high-intensity exercise-induced fatigue during puberty [125]. Subsequently, as the youth athlete matures and their ability to produce force also increases, there may be a concomitant increase in fatigue and muscle damage responses. Potential magnified responses should be particularly reviewed for eccentric exercise due to the high levels of muscle damage that is caused by this type of movement [60,126]. The muscle damage resulting from eccentric exercise is commonly indicated by decreases in muscle function, delayed onset muscle soreness (DOMS), and increased muscle enzymes and proteins, such as creatine kinase (CK) and myoglobin (Mb) in the blood, respectively [127,128]. Moreover, such effects can last for several days' post-exercise [129]. This is important to consider as EIMD can impair the physiological adaptations to training [130] and can subsequently influence the prescription of training stimuli [131]. The negative consequences EIMD may have on training exposure in youth is important to consider as higher resistance training frequencies are associated with increased performance improvements in youth athletes [132]. In particular, factors such as these should be planned for in youth to ensure that they can be integrated within the required periodization plan to enhance athletic development [133]. Moreover, prescription of ERT within an individuals' LTAD plan needs to consider improving physical qualities, but also reducing injury risk [134–136]. For that reason, the suggested inclusion of eccentric training during LTAD [63] requires careful deliberation.

It has been reported that children experience less EIMD than both adolescents and adults (Table 1). For instance, after eccentric exercise of the elbow flexor muscles, an age-dependent effect has been observed between children, adolescents, and adults in both females [137] and males [138]. Results of these studies reported reductions in maximal concentric strength of the elbow flexors, range of motion (ROM), muscle soreness, plasma CK, and Mb concentrations were reported to be lower in children than both adolescents and adults, and adolescents lower than adults. Moreover, following maximal eccentric voluntary muscle actions of the knee extensors in which relative total work completed was similar, men experienced more severe muscle damage than boys [139]. This was manifested through compromised muscle function (i.e., reduced eccentric, concentric and isometric peak torque) for several days in men whilst children demonstrated no such changes. Similarly, greater increases in muscle damage markers (i.e., DOMS, ROM, CK) lasted up to 96 h for men whilst, in boys, these only persisted for up to 48 h. Differences in DOMS has also been reported in the upper-body too. For example, following completion of an augmented eccentric machine chest press exercise adults reported higher levels of soreness than children 48 hours' post-exercise [140]. A similar augmented eccentric load was also used during the leg curl exercise in females in which CK measured one-, two-, three- and four-days post exercise was higher in adult females compared to female children [141]. Separately, EIMD protocols that have included high volume repetitive

jumping, which subsequently expose participants to high landing forces and the associated eccentric control of these actions [142], have again demonstrated that children experience lower levels of muscle damage compared to adults [143–145]. Moreover, a number of other studies have reported lower symptoms of DOMS between younger individuals compared to adults following exercise modes of RT [146,147], aerobic exercise [148] and downhill running [149].

2.4. *Repeated Bout Effect*

Performing unaccustomed exercise results in a number of muscle damage responses that can be considered symptomatic (e.g., force loss, muscle soreness), systemic (e.g., increased circulating muscle proteins), or histologic (e.g., myofibrillar disruptions) [150]. Skeletal muscle possesses an intrinsic mechanism that reacts to EIMD via providing an adaptive response to subsequent EIMD stimuli (see [150] for more details). This phenomenon is known as the repeated bout effect (RBE) which has primarily been investigated following eccentric muscle actions due to its greater tendency to elicit a muscle damage response [151]. For example, it is well established that the first bout of eccentric-only exercise protects the respective muscle from further muscle damage during subsequent exercise sessions [152]. Indeed, attenuation of muscle damage markers during the second bout of exercise that is completed within several weeks of the initial bout has been evidenced [153]. Mechanisms explaining this improved response may include neural, muscle-tendon complex behaviours, extracellular matrix structural remodelling and a modified inflammatory response [150]. Although the specific mechanisms that are responsible for the RBE are unclear, it would appear that the RBE is multifactorial which is likely to be highly muscle and exercise specific [154]. The beneficial effects conveyed by the RBE is characterized by factors such as faster recovery of muscle strength and ROM, reduced increases in muscle proteins in the blood, and less significant development of swelling and muscle soreness [152,155].

Although muscle damage following eccentric exercise is lower in children and adolescents compared to adults, the RBE does occur in all populations, although to different magnitudes. The lower protective effect observed in the younger groups might be due to the lower levels of muscle damage evident following eccentric exercise. That is, a greater initial degree of muscle damage might induce a greater RBE. The magnitude of the RBE has been shown to correspond with the intensity of the first eccentric exercise bout, such that the higher the intensity, the greater the level of protection provided [156]. For example, after plyometric exercise an RBE was evident for all symptoms examined in men, but only for muscle soreness in boys [145]. Likewise, following plyometric exercise in children, young adults and elderly populations, isometric torque recovery was significantly greater after the second bout of plyometric exercise in all groups, but this improvement was accompanied by a higher level of voluntary activation only in young adult males [144]. Since children are less susceptible to eccentric exercise-induced muscle damage than adolescents and young adults, it may be that the RBE of children is not expressed as strongly. However, following eccentric exercise in both male and female pre-pubescent, pubescent youth, and adults, the magnitude of the RBE was similar [137,138].

The above discussed findings indicate that although children tend to experience less EIMD after the initial bout of eccentric exercise, they may potentially have similar adaptability to eccentric exercise as adults. However, it is necessary to highlight that participants in these prior studies were of untrained status and therefore responses may be different for those youth athletes who are engaged with regular resistance training. For example, it has recently been shown that athletes compared to non-athlete's experienced different responses in which athletes are able to recover quicker despite displaying a greater force decrement following the eccentric bout of exercise [153]. Furthermore, when comparing between resistance-trained and untrained individuals, resistance-trained individuals seem to show less RBE than untrained individuals [157]. Overall, based on current findings it would appear that children and adolescents may adapt to ERT in a similar way as adults. Subsequently, it has been suggested, that an approach of beginning with low-intensity, prior to gradually increasing the intensity and volume based on the progressive

overload principal is suitable for both youth and adults [137]. However, further research investigating the RBE following ERT in well-trained youth athletes is warranted.

2.5. Eccentric Resistance Training Safety Considerations for Youth Athletes

Current research demonstrates the maturation- and age-dependent effects on neuromuscular fatigue, recovery, and muscle damage in which there is a progressive transient from childhood through to adulthood. Particularly, concerns regarding the increased risk of muscle damage in children and adolescents compared to adults appears to be unfounded with younger individuals experiencing less severe symptoms following exercise. These differences may be explained due to the lower force production capacity of children and adolescents, leading to reduced fatigue and muscle damage symptoms. Furthermore, this may also be explained by the greater total work performed during ERT protocols in adults compared to adolescents and adolescents compared to children [138]. It should also be recognized that populations used in previous studies have largely been of untrained status and, therefore, responses in trained youth may be different. Despite this, current evidence suggests that the inclusion of ERT methods in youth should not cause concern with regard to increased levels of muscle damage, fatigue or injury risk when compared to other resistance training modalities in youth that are conventionally used. Indeed, it has previously been suggested that concerns for performing eccentric exercise in youth may be due to its potential for high muscle force production and potential for predisposing children to a higher risk of muscle injury [158]. However, although such concerns may be alleviated by the information presented in this section, the use of ERT in youth requires a well-structured approach that considers a range of elements such as the individual's maturity status, training experience, resistance training background, and movement competency. As such, the next section of this article will present the potential applications for ERT in youth and how these may be implemented within practice.

Table 1. Studies assessing fatigue and exercise induced muscle damage following resistance training between children, adolescents and adults.

Study	Age (years)	Sex	Exercise Protocol	Selected Measurements	Outcome
[137] Lin et al. (2018)	C: 9–10 (<i>n</i> 13) Ad: 14–15 (<i>n</i> 13) A: 20–24 (<i>n</i> 13)	F	5 × 6 reps of eccentric elbow flexors. Dumbbell weight set at 60% iMVC. 2 min rest between sets.	MVC, DOMS, CK, Mb, ROM, MPS.	A > Ad > C
[139] Deli et al. (2017)	C: 11.0 ± 0.2 (<i>n</i> 11) A: 35.3 ± 2.2 (<i>n</i> 15)	M	5 × 15 reps of eccentric knee extensors. Dynamometer Set at 60° s ⁻¹ . 2 min rest between sets.	MVC, DOMS, CK and ROM.	A > C
[143] Lazaridis et al. (2018)	C: 10 ± 0.7 (<i>n</i> 13) A: 25.3 ± 3.3 (<i>n</i> 13)	M	10 × 10 reps of CMJ. 30 s rest between sets.	iMVC, DJ, EMG, K _{stiffness} and RPE.	A > C
[140] dos Santos et al. (2016)	C: 11.3 ± 0.82 (<i>n</i> 10) A: 24.5 ± 5.58 (<i>n</i> 10)	M + F	5 × 15 reps of eccentric machine chest press. Load set at 110% of 10RM concentric chest press. 3 min rest between sets.	DOMS.	NSD
[138] Chen et al. (2014)	C: 9.4 ± 0.5 (<i>n</i> 13) Ad: 14.3 ± 0.4 (<i>n</i> 13) A: 22.6 ± 2.0 (<i>n</i> 13)	M	5 × 6 reps of eccentric elbow flexors. Dynamometer set at 90° s ⁻¹ . 2 min rest between sets.	MVC, DOMS, CK, Mb, ROM and MPS.	A > Ad > C
[144] Gorianovas et al. (2013)	C: 11.8 ± 0.9 (<i>n</i> 11) A: 20.8 ± 1.9 (<i>n</i> 11) E: 63.2 ± 3.6 (<i>n</i> 11)	M	100 drop jumps. DJ box height set at 0.5 m. 30 s rest between reps.	iMVC, LFF, VA, DJ Height, DOMS, CK.	A > E > C
[146] Pullinen et al. (2011)	A: 31 ± 7 (<i>n</i> 8) Ad: 14 ± 0 (<i>n</i> 8)	M	3 × sets until exhaustion of concentric knee extensors. Load set at 40% of 1RM bilateral knee extension. 4 min rest between sets.	iMVC, CK, EMG, HR.	A > Ad
[145] Marginson et al. (2005)	C: 9.9 ± 0.3 (<i>n</i> 10) A: 22.2 ± 2.7 (<i>n</i> 10)	M	8 × 10 reps of CMJ. 1 min rest between sets.	iMVC, DOMS, CMJ, SJ.	A > C
[141] Arnett et al. (2000)	C: 10.5 ± 1.1 (<i>n</i> 15) A: 23.4 ± 6.9 (<i>n</i> 15) E: 59.4 ± 10.9 (<i>n</i> 10)	F	6 × 10 Reps of eccentric leg curl exercise Load Set at 110% 1RM concentric leg curl. 1 min rest between sets.	CK.	A > E > C
[148] Duarte et al. (1999)	Ad: 13.0 ± 0.5 (<i>n</i> 10) Ad: 13.2 ± 0.7 (<i>n</i> 10)	M	Box step up and down until exhaustion. Tempo Set at 1:1 (1 second up – 1 second down) vs 1:2.	iMVC, DOMS and CK.	1:2 > 1:1
[147] Soares et al. (1996)	C: 12.1 ± 0.2 (<i>n</i> 10) A: 28.3 ± 3.5 (<i>n</i> 10)	M	5 Sets × 80% 1RM concentric bench press until exhaustion. 90 s rest between sets.	iMVC, DOMS and CK.	A > C
[149] Webber et al. (1988)	C: 10.4 ± 0.3 (<i>n</i> 16) A: 27.1 ± 0.87 (<i>n</i> 15)	M + F	30 min downhill running @ 10% gradient.	DOMS and CK.	NSD

C: Children; **Ad:** Adolescents; **A:** Adults; **E:** Elderly; **M:** Male; **F:** Female; **Reps:** Repetitions. **MVC:** Maximal voluntary contraction; **iMVC:** Isometric maximal voluntary contraction; **CMJ:** Countermovement jump; **DJ:** Drop Jump; **DOMS:** Delayed onset muscle soreness; **EMG:** Electromyography activity; **CK:** Creatine kinase; **Mb:** Myoglobin; **RM:** repetition maximum strength; **LFF:** Low frequency fatigue; **HR:** Heart rate; **ROM:** Range of motion; **VA:** Voluntary; **NSD:** No significant difference.

3. Implications for Eccentric Resistance Training in Youth

As denoted in Table 1, youths experience less EIMD than adults following exercise. These differences in muscle damage are observed not only in performance of tasks including jumping, running, and conventional RT but also ERT, too. Therefore, although further research is still warranted, concerns regarding the efficacy of using ERT during childhood and adolescence are not currently supported by current evidence. This is important to acknowledge as it is in the authors' experience that the use of ERT within youth is limited. However, youth athletes engage with movement skills such as landing, sprinting and change of direction (COD), which are key within the YPD model [6]. Thus, youth athletes are likely already exposed to such stimuli that requires high levels of force absorption. More advanced RT methods, such as plyometrics, which incorporate substantial eccentric muscle actions during landing, have been advocated for children and adolescents [21]. It is evident that current recommendations for youth athletes already include training modalities that emphasize eccentric muscle actions. However, we would suggest that a more holistic approach for the inclusion of ERT could be provided to support current RT guidelines for youth [41]. Additionally, the role of ERT for injury prevention throughout youth may be beneficial as during peak height velocity (PHV), rapid growth, and subsequent temporary disruptions in motor control can increase injury risk [159–162]. Given current recommendations for integrating ERT for injury prevention purposes in youth athletes [163], the inclusion of eccentric muscle actions into youth training may be particularly important. Therefore, the integration of ERT into current LTAD model(s) could have beneficial implications for those working with youths, particularly regarding performance enhancement and injury prevention. Consequently, the inclusion of ERT for the youth athlete is worth consideration.

3.1. Landing Mechanics

Tasks such as hopping and jumping are classified as fundamental movement skills in youth [164] and can be considered as the “building blocks” for further, more complex, movements [165]. Such movements are deemed important for athletic performance [166]. To perform these movements effectively the individual requires eccentric capabilities during the landing phase [142] to absorb kinetic energy and large vertical forces that are experienced to preserve the integrity of the lower limbs anatomical structures [167,168]. This is important as the inability to absorb such forces experienced during landing has been identified as a mechanism for lower-extremity injuries [169,170]. In particular, a focus on developing correct technique and force absorption qualities within youth is necessary as it has been demonstrated that maturity stage can promote inefficient kinematic and kinetic factors that are associated with increased injury risk [171]. Indeed, children as young as 10 years old demonstrate “risky” movement patterns during landing tasks [172,173], which include neuromuscular risk factors, such as low knee flexion angle (“stiff landing”) and increased knee valgus [174,175]. Furthermore, both boys and girls displayed a longitudinal increase in external knee abduction moments throughout puberty [176,177]. Therefore, the early inclusion of developing appropriate landing mechanics as an injury prevention strategy should be implemented early to avoid these negative outcomes in order to reduce injury risk and promote long-term physical activity [178,179].

Differences in landing mechanics in youth are also influenced by sex and maturation with females displaying more aberrant landing kinematics compared to males throughout all stages of maturation [176,178,180–187]. These differences between young females and male can also be explained by anatomical aspects including an increase in both Q-angle and joint laxity as well as a decrease in notch width [169]. Such maturational effects are not present to the same extent in young males as improvements in knee valgus scores have actually been found with advancing age and stage of maturation [188,189]. This is further confounded in that compared to females, male youth appear to improve their lower limb control, sagittal plane motion, and landing forces during landing as they mature [190–192]. Differences in neuromuscular performance between sexes during and following puberty may contribute to altered biomechanics and resultant forces on the knee. Excessive knee loads, especially in the frontal plane may explain the increased risk of anterior

cruciate ligament (ACL) injury in females following puberty and may help identify the optimal time to implement injury prevention programs [176]. Therefore, it is important to ensure that force attenuation during landing is focused upon throughout youth. Although it has been found that a tendency occurs for more mature male players to reduce their knee valgus scores, a high frequency of circa-PHV and post-PHV players still demonstrated moderate and severe knee valgus scores [188]. Additionally, during circa-PHV in young males, increases in inter-limb knee-valgus asymmetries during landing have been observed as well as an increase in normalized landing forces [188,189], which can lead to temporary decrements in motor control and neuromuscular function due to the rapid growth in limb length [193]. Subsequently, it would appear that throughout maturation, despite there being perhaps certain maturity stages that require a specific focus on certain types of training, the correct execution of landing mechanics and the preparation for these tasks are important and an individualized approach for both females and males is required.

Practitioners implementing exercises to improve landing kinematics should carefully consider the prescription of jump-type activities, particularly the volume and intensity of take-off and landing phases to reduce the risk of injury [194]. The increased risk of injury becomes especially apparent as landing forces of approximately 3.5, 8 and 3 times one's bodyweight have been reported during a single-leg vertical jump, bilateral vertical jump to 50% maximum jump height and single leg hop to 75% maximal horizontal hop distance in youth [172,189,195], respectively. A high ground-reaction force loading rate indicates that an athlete is subjected to high ground-reaction forces upon the initial landing phase, making it difficult to adequately dissipate the forces reaching the knee joint [196]. Practitioners should, therefore, be mindful that greater ground reaction forces, which are present in children compared to adolescents [197,198], may increase risk of injury during landing [199]. For example, performing more intense landing tasks can increase ground reaction forces that negatively influence the frontal plane projection angle (FPPA) [193,200]. Consequently, it would appear that the ability to absorb ground reaction forces may be challenged due to the greater increases in landing forces that are required with increasing drop height during drop landing and drop jump tasks [201–204]. It is thus necessary to develop the ability to effectively absorb ground reaction forces upon landing via developing appropriate eccentric strength qualities to help reduce biomechanical risk factors such as increased knee valgus and joint moments. Indeed, strength training has been reported to positively change FPPA during landing [205]. In particular, eccentric muscle strength of the lower limbs has been shown to positively influence landing kinematics [206–212]. In accordance with these findings it is thus advisable for youth athletes to develop both technical proficiency and eccentric strength qualities to assist development of landing mechanics that may aid in the reduction of injury risk.

As provided in Figure 1, there are a number of approaches that can be proposed to develop force absorption ability throughout youth that should consider aspects of exercise volume, intensity, movement exploration and complexity. For example, the inclusion of activities such as parkour (Exploration) earlier in the child's development may provide varied and diversified training programme [213] that provides individuals with the opportunity to sample different movements to manage forces [214,215]. Previously, it has been revealed that parkour participants are more effective at lowering the kinetic landing variables that are associated with a higher injury risk in comparison to recreationally trained individuals [216]. An approach that promotes movement exploration may be helpful in reducing future injury risk due to issues surrounding sport-specialized youth athletes landing biomechanics [217] and the reported anterior knee pain disorders compared to multi-sport athletes [218]. As the individual reaches PHV, further progressions could be included by integrating exercises that have a unilateral landing (Technical) focus in order to aid in the reduction of any asymmetries that may occur during this stage of maturation [188,219,220]. During this stage, increasing the complexity of the jump-landing can be achieved via increasing the jump velocity (intensity) which will subsequently challenge landing kinematics via achieving a greater jump height [221]. The inclusion of weightlifting derivatives (Specificity), which have been advocated previously in youth [222,223], could also be included, more specifically at the post-PHV period. Inclusion of weightlifting derivatives, such as the jump shrug, hang power clean and hang high pull,

can be also used to improve load absorption characteristics [224,225]. Such an approach would further challenge movement complexity as well as developing concentric neuromuscular power during the propulsive phase of the movement and eccentric force qualities during the landing phase. Based upon previous recommendations to reduce injury risk in youth [226], we would suggest an approach based on participants' maturation status, exercise variations (variations), utilisation of verbal feedback (feedback) and, finally, exercise dosage (volume). Although limited information exists pertaining to the use of training volumes for landing mechanics in youth, it has been shown that sessions including up to six sets of six repetitions when completing the drop landing exercise have improved landing kinematics in adults [227]. As a result, it may be sensible to build training volume towards this level throughout the stages of youth. This may be achieved via varied exercise selection [226] with a frequency of two to three times per week which has been suggested for plyometric exercises in this population [228].

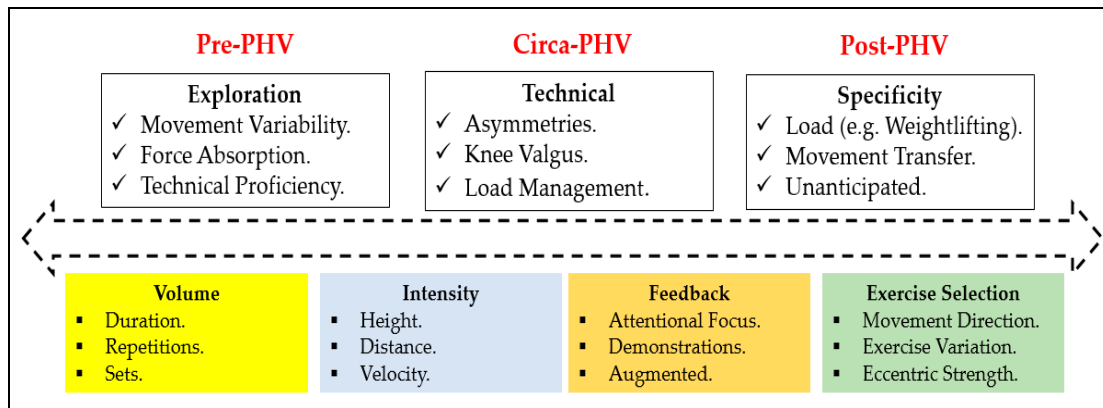


Figure 1. Example conceptual model for the development of landing kinematics throughout youth considering maturity status, injury risk factors and acute training variables. Pre-PHV = pre-peak height velocity. Circa-PHV = circa-peak height velocity. Post-PHV = post-peak height velocity.

3.2. Eccentric Hamstrings Strength

The inclusion of exercises to increase eccentric strength of the knee flexor muscles is considered necessary to help reducing the injury risk of the hamstrings muscles [229]. Typically, these injuries have been suggested to occur during sprinting mainly in the late swing phase in which the hamstrings are highly activated at longer lengths and therefore creating high levels of stress on the MTU [230–233]. Exercises such as the Nordic hamstrings exercise (NHE), used to strengthen the knee flexor muscles eccentrically, is deemed important not only from both an injury prevention perspective but for performance too (e.g., sprinting and change of direction) [50–52,234]. Furthermore, the NHE has also been shown to positively influence performance measures such as sprint speed, change of direction, and jumping in both youth males and females [235,236]. Yet, caution to the use of the NHE was previously been suggested on the basis that it was considered too intense for young, inexperienced athletes [237]. Despite this, as presented in Table 1, the use of eccentric muscle actions does not appear to place the youth athlete at greater risk of muscle damage than adults. Appropriate NHE prescription as well as other exercises that develop eccentric hamstrings strength [238–240] should be permissible in youth. Indeed, the NHE should form part of a holistic injury prevention program within youth to ensure that the hamstrings receive the specialist consideration that they require throughout youth [241]. In support of this, we have recently found eccentric hamstrings strength improvements in male youth soccer players from the age of 10 years [242].

Inclusion of ERT exercises within an injury prevention program (IPP) is advocated across a number of youth sports [243–247]. Although hamstrings strength has been shown to develop throughout all stages of youth [248–257], it is important to ensure that it is specifically trained throughout and begun early on in childhood to reduce future risk. This is particularly essential for

girls as it has been shown that insufficient hamstrings strength is evident in childhood [190,258]. Moreover, it has been found that girls with reduced hamstrings strength display greater biomechanical ACL injury risk factors during landing actions [259]. Specific development of the medial hamstrings has been instructed in female youth to counteract the external knee valgus moments and knee outward rotation moments [260]. Use of the NHE for females may be particularly helpful considering its reported benefits in reducing ground reaction forces during landing [261] and reducing bilateral hamstrings strength imbalance [262]. Requirements for the development of hamstrings strength also applies to male youth as practitioners have reported that players aged 13–16 years are at the greatest risk of injury and that eccentric hamstrings strength is amongst the most important injury risk factors [263]. This would coincide with PHV in which the greatest rate of growth occurs and has been associated with increased injury risk [160–162]. Consequently, it is important to ensure that youth athletes are physically prepared for this accelerated period of growth. This is further evidenced by the reports of decreased hamstrings to quadriceps ratio towards the latter stages of adolescence [248,264] and reduced relative eccentric hamstrings strength scores decreasing at senior level [250]. As provided in Figure 2, eccentric hamstrings strength should be targeted throughout childhood, adolescence and adulthood. Attention needs to focus on areas such as reducing asymmetry throughout the PHV stage and ensuring exercise compliance [265] to help maintain eccentric hamstrings strength levels. Once athletes enter the senior level, training and competition commitments may limit the development of this eccentric hamstrings strength.

Concerns regarding the inclusion of ERT at earlier stages in youth should have been alleviated by the information provided in Section 1 of this article. This is also supported by evidence that increases in hamstrings strength have been shown in basketball players aged 10–12 years following a five-week NHE programme [266]. However, as per previous recommendations, we would also suggest that the NHE should form part of a holistic hamstrings programme [267]. Therefore, although we feel that the inclusion of the NHE in youth should be viewed as a fundamental exercise used to increase eccentric hamstrings strength, other eccentric hamstrings exercises that target both distal and proximal hamstrings regions should be integrated [239] as well as inclusions of concentric [268], isometric [269] and sprinting [270] exercises. These should be completed with correct technique, appropriate progressions and in accordance with current RT guidelines for youth. Additionally, an emphasis during youth should be placed upon developing eccentric hamstrings strength across its full ROM due to the proposition that a shift in the optimum angle of peak torque provided by performing eccentric hamstrings exercises at long muscle lengths reduces hamstrings injury risk [58,271]. Moreover, both male and female senior players possess higher angle specific torque and functional range eccentric knee flexor values compared to their respective youth counterparts [272,273]. Ensuring that exercises target the full range of movement may also aid in the development of the hamstrings muscle architectural properties. This may be because shorter biceps femoris fascicle lengths can increase hamstrings injuries [274]. Considering the positive effects of eccentric exercise on properties such as fascicle length [54,271,274–282], as well as the relatively quick reversal of hamstrings muscle fascicle length and strength adaptations [278–280], perhaps the regular and structured inclusion of eccentric hamstrings exercises throughout youth could be viewed as a preparatory approach to developing architectural properties of the hamstrings and a foundation of eccentric hamstrings strength that can be maintained and progressed at senior levels. This is because it has been proposed that increases in fascicle length typically occur during the pre-pubescent period, whereas substantial increases in muscle cross-sectional area (CSA) typically occur during the pubescent period [283,284]. As a result, it may be advisable to develop structural properties and strength qualities earlier on in youth via the progression of training volume prior to increasing the intensity of the exercise post-PHV, once sufficient absolute and relative eccentric hamstrings strength has been achieved [285]. Indeed, it has been reported that additional loads are required during exercises such as the NHE in order to promote further eccentric hamstrings strength increases and fascicle length [286]. Subsequently, increases in muscle architecture properties at post-PHV status may also be targeted via performing the NHE either pre or post training to elicit specific morphological adaptations [287].

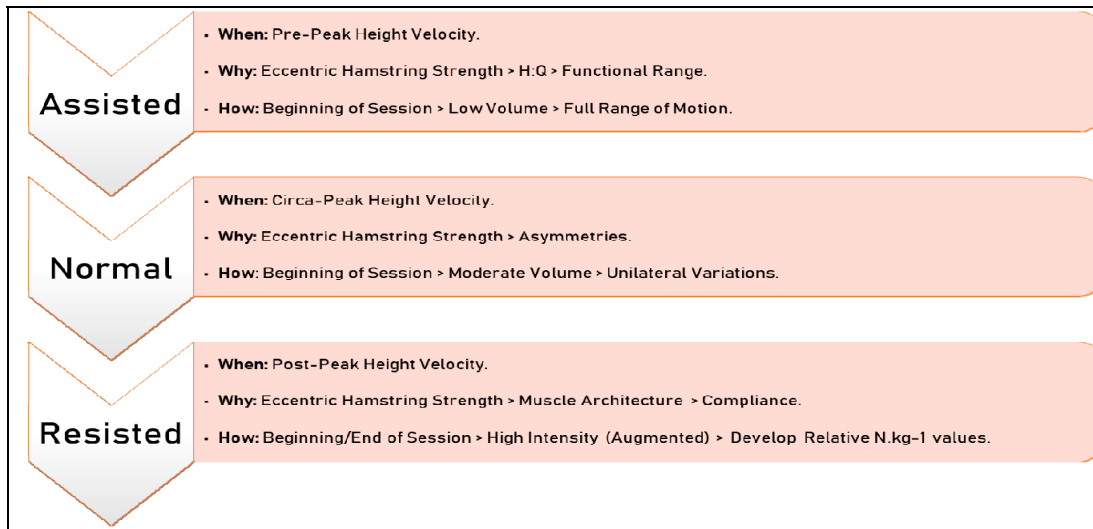


Figure 2. Example progressions for the NHE exercise throughout the different stages of maturation in which the progression of NHE intensity is achieved via assisted and resisted exercises. These progressions are proposed to align with different maturity stages to promote qualities that will aid in the prevention of hamstring injuries.

3.3. Flywheel Inertial Training

Typically, during RT, overload provided during the exercise remains constant for both eccentric and concentric portions of the exercise consequently leading to a lower relative load being lifted during the eccentric phase [288]. This is because greater forces are sustained during eccentric muscle actions compared to that of isometric and concentric actions [289,290]. For example, accentuated eccentric loading (AEL), which includes a load during the eccentric phase that is in excess of the concentric load [22] can be incorporated. AEL is considered an advanced training tactic [291]. Accordingly, we would suggest AEL to be included towards the latter stages of adolescence once an appropriate foundation of eccentric strength and resistance training skill competencies has been developed [63]. An alternative method to create eccentric overload in youth that may be appropriate is that of flywheel inertial training (FIT). FIT offers additional resistance throughout the entire ROM via the use of the inertia of a rotating flywheel to provide a greater overall load during coupled concentric and eccentric muscle actions [292]. The use of FIT in adult populations has been reported to provide many benefits including improvements in physiological, physical and performance factors, such as running economy [293], body composition [294], muscle activation [295,296], acute power enhancement [297–300], muscle architecture [35,301–304], change of direction [35,305,306] as well as force- and power-related qualities [25,306–309].

To date, some evidence does exist relating to the benefits of FIT in youth athletes. For example, in youth team sport athletes FIT has shown to improve performance in tasks such as jumping, sprinting, as well as the ability to increase braking forces during change of direction [47,310,311]. Specifically relating to change of direction (COD), knee extensor eccentric strength has been associated with improved deceleration in youth (16.8 years) male soccer players [312]. Such findings could be expected considering that faster COD performance has been associated with higher levels of braking force application [313,314]. Since during adolescence greater increases in speed [315–317] and strength and power qualities [318–322] are observed it is important that the propulsive forces developed to achieve these are also balanced with the appropriate eccentric strength characteristics too. Without such a focus this may place the youth athlete at greater risk of injury as they may not be able to effectively decelerate from the increased running speeds they can achieve. Indeed, it has been shown that performing cutting movements at greater speeds negatively affects lower extremity biomechanics that are associated with ACL injury risk [222,323]. These factors warrant due attention as increases in body mass also accompany changes in maturity status [324]. These combined

increases will likely result in greater amounts of momentum being produced. For example, in youth rugby union players it has been shown that maturity status is a significant predictor of momentum [325]. Accordingly, it is important that the youth athlete possesses the sufficient eccentric force qualities to tolerate the force demands from such tasks as COD and deceleration that they will be exposed to not only support performance but to aid in reducing injury risk.

Considering that physical qualities, such as COD, speed and strength, are recommended to be developed throughout all stages of youth [6] as well as the aforementioned benefits of FIT, its implementation within youth may be beneficial. This is appealing since the magnitude of eccentric forces encountered by a flywheel device during an exercise is proportionate to the preceding concentric forces [326]. Such an approach may be appropriate in youth as their lower concentric force capability would result in eccentric forces that would be proportionately lower [327]. In addition, it has been demonstrated that the use of higher flywheel inertias can concomitantly provide eccentric overload via increases of kinetic variables such as negative impulse during the descent phase of a movement [328–330]. Therefore, the introduction of low intensity flywheel inertia wheels may represent an appropriate starting point for training progressions along with lower training volumes prior to gradually increasing the load, volume and frequency to that which has been currently reported for FIT in adult populations [25,35,292,302,306] and which reflects current youth resistance training guidelines [17]. Such an approach is provided in Figure 3. Furthermore, since muscle damage following FIT have been shown to reflect those routinely reported following eccentric exercise [331], it important that as the individual reaches post-PHV the inclusion of eccentric overload training within the micro-cycle is further carefully deliberated. The potential greater increases in concentric force production during FIT that would be expected as a product of growth, maturation and training exposure will subsequently result in higher eccentric overload too, which may subsequently heighten fatigue and muscle damage responses that are observed in adults.

Pre-PHV	Circa-PHV	Post-PHV
<ul style="list-style-type: none"> • 1-2 Sets per Exercise. • 6-8 Repetitions. • 1-2 Minutes Rest. • Bilateral. • 0.010-0.025 kg·m². • Low Concentric Effort. • 1 x Weekly. 	<ul style="list-style-type: none"> • 2-3 Sets per Exercise. • 6-8 Repetitions. • 2-3 Minutes Rest. • Bilateral/Unilateral. • 0.025-0.05 kg·m². • Mod Concentric Effort. • 1-2 x Weekly. 	<ul style="list-style-type: none"> • 3-5 Sets per Exercise. • 8-10 Repetitions. • 3-4 Minutes Rest. • Bilateral/Unilateral. • 0.05-0.10 kg·m². • Max Concentric Effort. • 2 x Weekly.

Figure 3. Proposed overview of incorporating FIT methods throughout childhood and adolescence. *Please note, different exercises may require different flywheel inertia intensities. Pre-PHV = pre-peak height velocity. Circa-PHV = circa-peak height velocity. Post-PHV = post-peak height velocity. Mod = Moderate. Max = Maximal.

4. Other Programming Considerations

An important consideration for injury prevention throughout youth is the occurrence of conditions such as tendinopathies and how ERT may be able to aid with this. Prevention of these injuries should be targeted in children and adolescents as it is now understood that these may occur earlier than originally thought [332]. An early approach is necessary as knee-related pain injuries such as these can have a negative impact on athletes’ future performance and career [333]. The risk for tendinopathy injuries throughout youth would appear to be contributed to by factors such as overuse due to the loading of tendons during sports or vigorous activity [334,335]. This is particularly prudent for the youth athlete as it has been shown that sport specific tendon adaptations

such as greater tendon thickness occur in adolescent athletes compared to non-athletes [336,337]. Moreover, a higher prevalence of structural intratendinous changes have been observed in adolescent athletes with patellar tendinopathy symptoms than those without [338]. In addition, intratendinous alterations that were associated with tendinopathies have been reported in adolescent youth athletes compared to recreationally active controls [339]. However, such issues may not only be impacted by training activity but also impacted by growth and maturation processes due to increases in aspects such as moment arm lengths and muscle activation, which leads to a disproportionate increase of muscle strength [340]. Indeed, it has been observed that an imbalance exists between the development of the muscle and tendon in which the greater adaptations and development of the mechanical properties of the tendon occur towards the end stages of adolescence [341–343]. Furthermore, it has been demonstrated that adaptations to training during the earlier stages of youth result in increases in strength but not tendon stiffness [344]. Considering that adaptations of tendon properties to resistance exercise are slower than those of muscle strength [345,346] this may cause an imbalanced adaptation of the muscle and tendon and risk overload and tendon-related injuries [347]. Support for this concept within youth has recently been shown as high levels of tendon strain in adolescent basketball athletes were associated with micro-morphological deterioration of the collagenous network in the proximal patellar tendon, a frequent site affected by tendinopathy [348]. Furthermore, adolescent athletes have been found to reach greater strain magnitudes compared to non-athlete controls indicating an increased mechanical demand for the patellar tendon [349]. Therefore, in light of the aforementioned, specific training that increases tendon stiffness and facilitates a balanced adaptation between muscle and tendon might be important [347–349].

In youth it has been proposed that a combination of growth and loading could act as a “dual” stimulus for tendon growth and improvement of its material properties, increasing the tendon’s stiffness throughout maturation [350]. Furthermore, it has been demonstrated that tendon growth from RT, even in pre-pubertal children can occur [351]. It is plausible that training modalities, such as ERT, may be efficacious in not only enhancing force absorption qualities in youth but also reducing tendinopathies by reducing tendon strain via development of the mechanical properties of the tendon. For example, eccentric muscle actions have been shown to positively influence the mechanical properties of the tendon including CSA and stiffness in adult males [352–354]. Indeed, the efficacy of using eccentric training in treating tendinopathies has been provided previously in adults [355,356]. The use of ERT may provide a favourable modality as morphological adaptations and mechanical properties of the tendon respond more positively to high action intensities ($\geq 85\%$ isometric muscle voluntary action) and long action durations (≥ 3 s;) [357–359]. Indeed, the use of ERT modalities such as FIT has been shown to positively influence the mechanical properties of both the Achilles and patellar tendons enabling them to be more resistant to deformation post-exercise in adult males [360,361]. Also, six weeks of FIT leg press exercise in adult males suffering with chronic patellar tendinopathy improved tendon pain symptoms as well as strength and neuromuscular activation [362]. Interestingly, the inclusion of FIT in adults who are at risk of patellar tendinopathy have shown it to be appropriate during the in-season of basketball and volleyball players in which no complaints regarding patellar tendon pain were provided as well as displaying improvements in lower limb muscle power [363]. Therefore, training modalities that can provide an increase in tendon stiffness that as well as the force generating capacity of the neuromuscular system may be efficacious to help protect against increased strain during maximum muscle actions [347]. As a result, a potential approach in reducing tendinopathy issues throughout youth, particularly patellar tendinopathy, may benefit from a combination of eccentric strength and force absorption approaches that involve 1) development of effective landing mechanics qualities that help reduce joint moments and ground reaction forces (Figure 1); 2) use of ERT methods such as the FIT to aid in the potential development of the MTU (Figure 3); and 3) increasing eccentric muscular strength to further support landing kinematics. However, further research is required to investigate these areas to support this in youth.

5. Conclusions

The inclusion of ERT throughout youth can be incorporated within a well-designed LTAD program that follows current proposed guidelines [6]. However, it should be acknowledged that current research within ERT for youth athletes is its infancy and areas such as training intensities, training volumes, recovery periods and its effects on performance tasks and injury prevention require further investigation. Implementing ERT should be considered as part of a holistic athletic development training programme within youth that should begin during the pre-pubescent stage and progressed throughout all stages of maturation taking into account the individuals technical proficiency, training history, maturity status, and current physical qualities. Initial approaches to the inclusion of ERT may begin within an integrated injury prevention warm up similar to those injury prevention program commonly used for youth but to also ensure a balanced emphasis quality such as landing kinematics, eccentric hamstrings strength, deceleration and COD ability, neuromuscular strength and tendon mechanical properties. Thereafter, specific consideration is required during PHV when injury risk may increase due to maturation-related processes in both male and female adolescents. Once the athlete reaches post-PHV status, further specificity can be provided to elicit greater adaptations due to the athletes' training history and increased benefits observed from RT as this stage [18,19,69]. However, considering that during youth there is a progressive increase of exercise-induced fatigue [125], the inclusion of ERT at this stage may also accompany increased levels of muscle damage symptoms and therefore this should be planned and educated to the youth athlete. Furthermore, we would encourage that recent articles published on the implementation of eccentric training [62,364] act as a point of reference for youth athletes reaching senior levels of performance that is underpinned by a sufficient training history of ERT throughout youth as presented in this article.

Although there may be concerns with regard to the introduction of ERT in youth athletes compared to adults due to factors such as increased risk of fatigue, muscle damage or injury, current evidence would not support these assumptions. Therefore, concomitant to the physiological demands that youth individuals will be exposed to within their sport, it is important that eccentric force qualities are developed throughout youth and not seen as an advanced RT modality. Indeed, in youth, the use of ERT can be viewed as developing aspects such as force absorption/attenuation during tasks such as landing/COD, reducing strength ratios to reduce injury risk as well as potentially acting as a structural mechanism to develop tendon mechanical properties. Importantly, the inclusion of ERT in youth should be seen as part of a holistic LTAD programme that support the development of physical qualities encouraged within LTAD models such as strength, speed, agility, and other factors. Furthermore, throughout childhood and adolescence the use of ERT should be considered a preparatory approach to sufficiently prepare athletes for the demands of elite performance levels and the more intense and specific eccentric training methods that may be trained throughout this period. To improve the current literature, future work should identify the effects of youth eccentric training with regards to training intensity, volumes, recovery periods and its effect on injury prevention in youth. Until such work has been produced, ERT in youth should implemented on an individual approach with low dosages and small progressions in volume and intensity. However, it would appear that the inclusion of ERT in youth may confer numerous benefits and so practitioners working with this population should contemplate its inclusion within LTAD.

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References

1. Ford, P.; de Ste Croix, M.; Lloyd, R.; Meyers, R.; Moosavi, M.; Oliver, J.; Till, K.; Williams, C. The Long-Term Athlete Development Model: Physiological Evidence and Application. *J. Sports Sci.* **2011**, doi:10.1080/02640414.2010.536849.
2. Lloyd, R.S.; Cronin, J.B.; Faigenbaum, A.D.; Haff, G.G.; Howard, R.; Kraemer, W.J.; Micheli, L.J.; Myer, G.D.; Oliver, J.L. National Strength and Conditioning Association Position Statement on Long-Term Athletic Development. *J. Strength Cond. Res.* **2016**, *30*, 1491–1509, doi:10.1519/JSC.0000000000001387.
3. Bergeron, M.F.; Mountjoy, M.; Armstrong, N.; Chia, M.; Côté, J.; Emery, C.A.; Faigenbaum, A.; Hall, G.; Kriemler, S.; Léglise, M.; et al. International Olympic Committee Consensus Statement on Youth Athletic Development. *Br. J. Sports Med.* **2015**, doi:10.1136/bjsports-2015-094962.
4. LaPrade, R.F.; Agel, J.; Baker, J.; Brenner, J.S.; Cordasco, F.A.; Côté, J.; Engebretsen, L.; Feeley, B.T.; Gould, D.; Hainline, B.; et al. AOSSM Early Sport Specialization Consensus Statement. *Orthop. J. Sport. Med.* **2016**, doi:10.1177/2325967116644241.
5. Lloyd, R.S.; Faigenbaum, A.D.; Stone, M.H.; Oliver, J.L.; Jeffreys, I.; Moody, J.A.; Brewer, C.; Pierce, K.C.; McCambridge, T.M.; Howard, R.; et al. Position Statement on Youth Resistance Training: The 2014 International Consensus. *Br. J. Sports Med.* **2014**, doi:10.1136/bjsports-2013-092952.
6. Lloyd, R.S.; Oliver, J.L. The Youth Physical Development Model: A New Approach to Long-Term Athletic Development. *Strength Cond. J.* **2012**, doi:10.1519/SSC.0b013e31825760ea.
7. Pearson, D.T.; Naughton, G.A.; Torode, M. Predictability of Physiological Testing and the Role of Maturation in Talent Identification for Adolescent Team Sports. *J. Sci. Med. Sport.* **2006**, doi:10.1016/j.jsams.2006.05.020.
8. Bourgeois, F.; Gamble, P.; Gill, N.; McGuigan, M. Effects of a Six-Week Strength Training Programme on Change of Direction Performance in Youth Team Sport Athletes. *Sports* **2017**, doi:10.3390/sports5040083.
9. Thomas, C.; Comfort, P.; Jones, P.A.; Dos'Santos, T. A Comparison of Isometric Midhigh-Pull Strength, Vertical Jump, Sprint Speed, and Change-of-Direction Speed in Academy Netball Players. *Int. J. Sports Physiol. Perform.* **2017**, doi:10.1123/ijspp.2016-0317.
10. McKinlay, B.J.; Wallace, P.J.; Dotan, R.; Long, D.; Tokuno, C.; Gabriel, D.A.; Falk, B. Isometric and Dynamic Strength and Neuromuscular Attributes as Predictors of Vertical Jump Performance in 11- to 13-Year-Old Male Athletes. *Appl. Physiol. Nutr. Metab.* **2017**, doi:10.1139/apnm-2017-0111.
11. Secomb, J.L.; Lundgren, L.E.; Farley, O.R.L.; Tran, T.T.; Nimphius, S.; Sheppard, J.M. Relationships between Lower-Body Muscle Structure and Lower-Body Strength, Power, and Muscle-Tendon Complex Stiffness. *J. Strength Cond. Res.* **2015**, doi:10.1519/JSC.0000000000000858.
12. Peñailillo, L.; Espildora, F.; Jannas-Vela, S.; Mujika, I.; Zbinden-Foncea, H. Muscle Strength and Speed Performance in Youth Soccer Players. *J. Hum. Kinet.* **2016**, doi:10.1515/hukin-2015-0157.
13. Hammami, R.; Chaouachi, A.; Makhoulouf, I.; Granacher, U.; Behm, D.G. Associations between Balance and Muscle Strength, Power Performance in Male Youth Athletes of Different Maturity Status. *Pediatr. Exerc. Sci.* **2016**, doi:10.1123/pes.2015-0231.
14. Zwolski, C.; Quatman-Yates, C.; Paterno, M.V. Resistance Training in Youth: Laying the Foundation for Injury Prevention and Physical Literacy. *Sports Health.* **2017**, doi:10.1177/1941738117704153.
15. Peitz, M.; Behringer, M.; Granacher, U. A Systematic Review on the Effects of Resistance and Plyometric Training on Physical Fitness in Youth- What Do Comparative Studies Tell Us? *PLoS ONE* **2018**, doi:10.1371/journal.pone.0205525.
16. Faigenbaum, A.D.; Myer, G.D. Resistance Training among Young Athletes: Safety, Efficacy and Injury Prevention Effects. *Br. J. Sports Med.* **2010**, doi:10.1136/bjism.2009.068098.
17. Legerlotz, K.; Marzilger, R.; Bohm, S.; Arampatzis, A. Physiological Adaptations Following Resistance Training in Youth Athletes-a Narrative Review. *Pediatric Exerc. Sci.* **2016**, doi:10.1123/pes.2016-0023.
18. Moran, J.; Sandercock, G.R.H.; Ramirez-Campillo, R.; Meylan, C.; Collison, J.; Parry, D.A. A Meta-Analysis of Maturation-Related Variation in Adolescent Boy Athletes' Adaptations to Short-Term Resistance Training. *J. Sports Sci.* **2017**, *35*, 1041–1051, doi:10.1080/02640414.2016.1209306.
19. Moran, J.; Sandercock, G.; Ramirez-Campillo, R.; Clark, C.C.T.; Fernandes, J.F.T.; Drury, B. A Meta-Analysis of Resistance Training in Female Youth: Its Effect on Muscular Strength, and Shortcomings in the Literature. *Sports Med.* **2018**, doi:10.1007/s40279-018-0914-4.

20. Lesinski, M.; Prieske, O.; Granacher, U. Effects and Dose-Response Relationships of Resistance Training on Physical Performance in Youth Athletes: A Systematic Review and Meta-Analysis. *Br. J. Sports Med.* **2016**, *781*–795, doi:10.1136/bjsports-2015-095497.
21. Behm, D.G.; Young, J.D.; Whitten, J.H.D.; Reid, J.C.; Quigley, P.J.; Low, J.; Li, Y.; Lima, C.D.; Hodgson, D.D.; Chaouachi, A.; et al. Effectiveness of Traditional Strength vs. Power Training on Muscle Strength, Power and Speed with Youth: A Systematic Review and Meta-Analysis. *Front. Physiol.* **2017**, doi:10.3389/fphys.2017.00423.
22. Wagle, J.P.; Taber, C.B.; Cunanan, A.J.; Bingham, G.E.; Carroll, K.M.; DeWeese, B.H.; Sato, K.; Stone, M.H. Accentuated Eccentric Loading for Training and Performance: A Review. *Sports Med.* **2017**, doi:10.1007/s40279-017-0755-6.
23. Douglas, J.; Pearson, S.; Ross, A.; McGuigan, M. Eccentric Exercise: Physiological Characteristics and Acute Responses. *Sports Med.* **2017**, doi:10.1007/s40279-016-0624-8.
24. Douglas, J.; Pearson, S.; Ross, A.; McGuigan, M. Chronic Adaptations to Eccentric Training: A Systematic Review. *Sports Med.* **2017**, doi:10.1007/s40279-016-0628-4.
25. Sabido, R.; Hernández-Davó, J.L.; Botella, J.; Navarro, A.; Tous-Fajardo, J. Effects of adding a weekly eccentric-overload training session on strength and athletic performance in team-handball players. *Eur. J. Sport Sci.* **2017**, *17*, 530–538.
26. Walker, S.; Blazevich, A.J.; Haff, G.G.; Tufano, J.J.; Newton, R.U.; Häkkinen, K. Greater Strength Gains after Training with Accentuated Eccentric than Traditional Isoinertial Loads in Already Strength-Trained Men. *Front. Physiol.* **2016**, *7*, doi:10.3389/fphys.2016.00149.
27. Papadopoulos, C.; Theodosiou, K.; Bogdanis, G.C.; Gkantiraga, E.; Gissis, I.; Sambanis, M.; Souglis, A.; Sotiropoulos, A. Multiarticular Isokinetic High-Load Eccentric Training Induces Large Increases in Eccentric and Concentric Strength and Jumping Performance. *J. Strength Cond. Res.* **2014**, doi:10.1519/JSC.0000000000000456.
28. Brandenburg, J.P.; Docherty, D. The Effects of Accentuated Eccentric Loading on Strength, Muscle Hypertrophy, and Neural Adaptations in Trained Individuals. *J. Strength Cond. Res.* **2002**, doi:10.1519/1533-4287(2002)016<0025:TEOAEEL>2.0.CO;2.
29. Vikne, H.; Refsnes, P.E.; Ekmark, M.; Medbø, J.I.; Gundersen, V.; Gundersen, K. Muscular Performance after Concentric and Eccentric Exercise in Trained Men. *Med. Sci. Sports Exerc.* **2006**, doi:10.1249/01.mss.0000229568.17284.ab.
30. Douglas, J.; Pearson, S.; Ross, A.; McGuigan, M. Effects of Accentuated Eccentric Loading on Muscle Properties, Strength, Power, and Speed in Resistance-Trained Rugby Players. *J. Strength Cond. Res.* **2018**, doi:10.1519/JSC.0000000000002772.
31. Carothers, K.; Carothers, K.F.; Alvar, B.A.; Dodd, D.J.; Johanson, J.C.; Kincade, B.J.; Kelly, S.B. Comparison of Muscular Strength Gains Utilizing Eccentric, Standard and Concentric Resistance Training Protocols. *J. Strength Cond. Res.* **2010**, doi:10.1097/01.jsc.0000367079.76059.a5.
32. Dolezal, S.M.; Frese, D.L.; Llewellyn, T.L. The effects of eccentric, velocity-based training on strength and power in collegiate athletes. *Int. J. Exerc. Sci.* **2016**, *9*, 657.
33. Douglas, J.; Pearson, S.; Ross, A.; McGuigan, M. Reactive and eccentric strength contribute to stiffness regulation during maximum velocity sprinting in team sport athletes and highly trained sprinters. *J. Sports Sciences.* **2019**, 1–9, doi:10.1080/02640414.2019.1678363.
34. Mike, J.N.; Cole, N.; Herrera, C.; Vandusseldorp, T.; Kravitz, L.; Kerksick, C.M. The Effects of Eccentric Action Duration on Muscle Strength, Power Production, Vertical Jump, and Soreness. *J. Strength Cond. Res.* **2017**, doi:10.1519/JSC.0000000000001675.
35. Núñez, F.J.; Santalla, A.; Carrasquilla, I.; Asian, J.A.; Reina, J.I.; Suarez-Arrones, L.J. The Effects of Unilateral and Bilateral Eccentric Overload Training on Hypertrophy, Muscle Power and COD Performance, and Its Determinants, in Team Sport Players. *PLoS ONE* **2018**, doi:10.1371/journal.pone.0193841.
36. Doan, B.K.; Newton, R.U.; Marsit, J.L.; Triplett-McBride, N.T.; Koziris, L.P.; Fry, A.C.; Kraemer, W.J. Effects of Increased Eccentric Loading on Bench Press 1RM. *J. Strength Cond. Res.* **2002**, doi:10.1519/1533-4287(2002)016<0009:EOIELO>2.0.CO;2.
37. Gonzalo-Skok, O.; Tous-Fajardo, J.; Valero-Campo, C.; Berzosa, C.; Bataller, A.V.; Arjol-Serrano, J.L.; Moras, G.; Mendez-Villanueva, A. Eccentric-Overload Training in Team-Sport Functional Performance:

- Constant Bilateral Vertical versus Variable Unilateral Multidirectional Movements. *Int. J. Sports Physiol. Perform.* **2017**, doi:10.1123/ijsspp.2016-0251.
38. Bridgeman, L.A.; McGuigan, M.R.; Gill, N.D.; Dulson, D.K. The Effects of Accentuated Eccentric Loading on the Drop Jump Exercise and the Subsequent Postactivation Potentiation Response. *J. Strength Cond. Res.* **2017**, doi:10.1519/JSC.0000000000001630.
 39. Munger, C.N.; Archer, D.C.; Leyva, W.D.; Wong, M.A.; Coburn, J.W.; Costa, P.B.; Brown, L.E. Acute Effects of Eccentric Overload on Concentric Front Squat Performance. *J. Strength Cond. Res.* **2017**, doi:10.1519/JSC.0000000000001825.
 40. Sheppard, J.; Newton, R.; McGuigan, M. The Effect of Accentuated Eccentric Load on Jump Kinetics in High-Performance Volleyball Players. *Int. J. Sports Sci. Coach.* **2007**, doi:10.1260/174795407782233209.
 41. Friedmann-Bette, B.; Bauer, T.; Kinscherf, R.; Vorwald, S.; Klute, K.; Bischoff, D.; Müller, H.; Weber, M.A.; Metz, J.; Kauczor, H.U.; et al. Effects of Strength Training with Eccentric Overload on Muscle Adaptation in Male Athletes. *Eur. J. Appl. Physiol.* **2010**, doi:10.1007/s00421-009-1292-2.
 42. Sheppard, J.M.; Young, K. Using Additional Eccentric Loads to Increase Concentric Performance in the Bench Throw. *J. Strength Cond. Res.* **2010**, doi:10.1519/JSC.0b013e3181e2731b.
 43. Aboodarda, S.J.; Byrne, J.M.; Samson, M.; Wilson, B.D.; Mokhtar, A.H.; Behm, D.G. Does Performing Drop Jumps with Additional Eccentric Loading Improve Jump Performance? *J. Strength Cond. Res.* **2014**, doi:10.1519/JSC.0000000000000498.
 44. Hughes, J.D.; Massiah, R.G.; Clarke, R.D. The Potentiating Effect of an Accentuated Eccentric Load on Countermovement Jump Performance. *J. Strength Cond. Res.* **2016**, doi:10.1519/JSC.0000000000001455.
 45. Ong, J.H.; Lim, J.; Chong, E.; Tan, F. The Effects of Eccentric Conditioning Stimuli on Subsequent Counter-Movement Jump Performance. *J. Strength Cond. Res.* **2016**, doi:10.1519/JSC.0000000000001154.
 46. Sheppard, J.; Hobson, S.; Barker, M.; Taylor, K.; Chapman, D.; McGuigan, M.; Newton, R. The Effect of Training with Accentuated Eccentric Load Counter-Movement Jumps on Strength and Power Characteristics of High-Performance Volleyball Players. *Int. J. Sports Sci. Coach.* **2008**, *3*, 355–363, doi:10.1260/174795408786238498.
 47. De Hoyo, M.; Pozzo, M.; Sañudo, B.; Carrasco, L.; Gonzalo-Skok, O.; Domínguez-Cobo, S.; Morán-Camacho, E. Effects of a 10-Week in-Season Eccentric-Overload Training Program on Muscle-Injury Prevention and Performance in Junior Elite Soccer Players. *Int. J. Sports Physiol. Perform.* **2015**, doi:10.1123/ijsspp.2013-0547.
 48. Tous-Fajardo, J.; Gonzalo-Skok, O.; Arjol-Serrano, J.L.; Tesch, P. Enhancing Change-of-Direction Speed in Soccer Players by Functional Inertial Eccentric Overload and Vibration Training. *Int. J. Sports Physiol. Perform.* **2016**, doi:10.1123/ijsspp.2015-0010.
 49. Krommes, K.; Petersen, J.; Nielsen, M.B.; Aagaard, P.; Hölmich, P.; Thorborg, K. Sprint and Jump Performance in Elite Male Soccer Players Following a 10-Week Nordic Hamstring Exercise Protocol: A Randomised Pilot Study. *BMC Res. Notes.* **2017**, doi:10.1186/s13104-017-2986-x.
 50. Siddle, J.; Greig, M.; Weaver, K.; Page, R.M.; Harper, D.; Brogden, C.M. Acute Adaptations and Subsequent Preservation of Strength and Speed Measures Following a Nordic Hamstring Curl Intervention: A Randomised Controlled Trial. *J. Sports Sci.* **2019**, doi:10.1080/02640414.2018.1535786.
 51. Ishøi, L.; Hölmich, P.; Aagaard, P.; Thorborg, K.; Bandholm, T.; Serner, A. Effects of the Nordic Hamstring Exercise on Sprint Capacity in Male Football Players: A Randomized Controlled Trial. *J. Sports Sci.* **2017**, *1–10*, doi:10.1080/02640414.2017.1409609.
 52. Mendiguchia, J.; Martínez-Ruiz, E.; Morin, J.B.; Samozino, P.; Edouard, P.; Alcaraz, P.E.; Esparza-Ros, F.; Mendez-Villanueva, A. Effects of Hamstring-Emphasized Neuromuscular Training on Strength and Sprinting Mechanics in Football Players. *Scand. J. Med. Sci. Sport.* **2015**, doi:10.1111/sms.12388.
 53. Coratella, G.; Schena, F. Eccentric Resistance Training Increases and Retains Maximal Strength, Muscle Endurance, and Hypertrophy in Trained Men. *Appl. Physiol. Nutr. Metab.* **2016**, doi:10.1139/apnm-2016-0321.
 54. Franchi, M.V.; Atherton, P.J.; Reeves, N.D.; Flück, M.; Williams, J.; Mitchell, W.K.; Selby, A.; Beltran Valls, R.M.; Narici, M.V. Architectural, Functional and Molecular Responses to Concentric and Eccentric Loading in Human Skeletal Muscle. *Acta Physiol.* **2014**, doi:10.1111/apha.12225.
 55. Mjøltnes, R.; Arnason, A.; Østhaugen, T.; Raastad, T.; Bahr, R. A 10-Week Randomized Trial Comparing Eccentric vs. Concentric Hamstring Strength Training in Well-Trained Soccer Players. *Scand. J. Med. Sci. Sport.* **2004**, doi:10.1046/j.1600-0838.2003.367.x.

56. Bourne, M.N.; Opar, D.A.; Williams, M.D.; Shield, A.J. Eccentric Knee Flexor Strength and Risk of Hamstring Injuries in Rugby Union. *Am. J. Sports Med.* **2015**, doi:10.1177/0363546515599633.
57. Al Attar, W.S.A.; Soomro, N.; Sinclair, P.J.; Pappas, E.; Sanders, R.H. Effect of Injury Prevention Programs That Include the Nordic Hamstring Exercise on Hamstring Injury Rates in Soccer Players: A Systematic Review and Meta-Analysis. *Sports Med.* **2017**, doi:10.1007/s40279-016-0638-2.
58. Tyler, T.F.; Schmitt, B.M.; Nicholas, S.J.; McHugh, M.P. Rehabilitation after Hamstring-Strain Injury Emphasizing Eccentric Strengthening at Long Muscle Lengths: Results of Long-Term Follow-Up. *J. Sport Rehabil.* **2017**, doi:10.1123/jsr.2015-0099.
59. Croisier, J.L.; Forthomme, B.; Namurois, M.H.; Vanderthommen, M.; Crielaard, J.M. Hamstring muscle strain recurrence and strength performance disorders. *Am. J. Sports Med.* **2002**, *30*, 199–203, doi:10.1177/03635465020300020901.
60. Proske, U.; Morgan, D.L. Muscle Damage from Eccentric Exercise: Mechanism, Mechanical Signs, Adaptation and Clinical Applications. *J. Physiol.* **2001**, doi:10.1111/j.1469-7793.2001.00333.x.
61. Dueweke, J.J.; Awan, T.M.; Mendias, C.L. Regeneration of skeletal muscle after eccentric injury. *J. Sport Rehabil.* **2017**, *26*, 171–179.
62. Suchomel, T.J.; Wagle, J.P.; Douglas, J.; Taber, C.B.; Harden, M.; Haff, G.G.; Stone, M.H. Implementing Eccentric Resistance Training—Part 1: A Brief Review of Existing Methods. *J. Funct. Morphol. Kinesiol.* **2019**, doi:10.3390/jfkm4020038.
63. Granacher, U.; Lesinski, M.; Büsch, D.; Muehlbauer, T.; Prieske, O.; Puta, C.; Gollhofer, A.; Behm, D.G. Effects of Resistance Training in Youth Athletes on Muscular Fitness and Athletic Performance: A Conceptual Model for Long-Term Athlete Development. *Front. Physiol.* **2016**, doi:10.3389/fphys.2016.00164.
64. Hatzikotoulas, K.; Patikas, D.; Ratel, S.; Bassa, E.; Kotzamanidis, C. Central and Peripheral Fatigability in Boys and Men during Maximal Action. *Med. Sci. Sports Exerc.* **2014**, doi:10.1249/MSS.0000000000000239.
65. Armatas, V.; Bassa, E.; Patikas, D.; Kitsas, I.; Zangelidis, G.; Kotzamanidis, C. Neuromuscular Differences between Men and Prepubescent Boys during a Peak Isometric Knee Extension Intermittent Fatigue Test. *Pediatr. Exerc. Sci.* **2010**, doi:10.1123/pes.22.2.205.
66. Dotan, R.; Mitchell, C.J.; Cohen, R.; Gabriel, D.; Klentrou, P.; Falk, B. Explosive Sport Training and Torque Kinetics in Children. *Appl. Physiol. Nutr. Metab.* **2013**, doi:10.1139/apnm-2012-0330.
67. Zafeiridis, A.; Dalamitros, A.; Dipla, K.; Manou, V.; Galanis, N.; Kellis, S. Recovery during High-Intensity Intermittent Anaerobic Exercise in Boys, Teens, and Men. *Med. Sci. Sports Exerc.* **2005**, doi:10.1249/01.MSS.0000155394.76722.01.
68. Halin, R.; Germain, P.; Bercier, S.; Kapitaniak, B.; Buttelli, O. Neuromuscular Response of Young Boys versus Men during Sustained Maximal Action. *Med. Sci. Sports Exerc.* **2003**, doi:10.1249/01.MSS.0000069407.02648.47.
69. Lloyd, R.S.; Radnor, J.M.; De Ste Croix, M.B.A.; Cronin, J.B.; Oliver, J.L. Changes in Sprint and Jump Performances after Traditional, Plyometric, and Combined Resistance Training in Male Youth Pre- and Post-Peak Height Velocity. *J. Strength Cond. Res.* **2016**, doi:10.1519/JSC.0000000000001216.
70. Dotan, R.; Mitchell, C.; Cohen, R.; Klentrou, P.; Gabriel, D.; Falk, B. Child—Adult Differences in Muscle Activation—A Review. *Pediatr. Exerc. Sci.* **2012**, doi:10.1123/pes.24.1.2.
71. Falk, B.; Dotan, R. Child-Adult Differences in the Recovery from High-Intensity Exercise. *Exerc. Sport Sci. Rev.* **2006**, 107–112, doi:10.1249/00003677-200607000-00004.
72. Patikas, D.A.; Williams, C.A.; Ratel, S. Exercise-Induced Fatigue in Young People: Advances and Future Perspectives. *Eur. J. Appl. Physiol.* **2018**, doi:10.1007/s00421-018-3823-1.
73. Murphy, J.R.; Button, D.C.; Chaouachi, A.; Behm, D.G. Prepubescent Males Are Less Susceptible to Neuromuscular Fatigue Following Resistance Exercise. *Eur. J. Appl. Physiol.* **2014**, doi:10.1007/s00421-013-2809-2.
74. Paraschos, I.; Hassani, A.; Bassa, E.; Hatzikotoulas, K.; Patikas, D.; Kotzamanidis, C. Fatigue Differences between Adults and Prepubertal Males. *Int. J. Sports Med.* **2007**, doi:10.1055/s-2007-964984.
75. Dipla, K.; Tsirini, T.; Zafeiridis, A.; Manou, V.; Dalamitros, A.; Kellis, E.; Kellis, S. Fatigue Resistance during High-Intensity Intermittent Exercise from Childhood to Adulthood in Males and Females. *Eur. J. Appl. Physiol.* **2009**, doi:10.1007/s00421-009-1058-x.
76. Croix, M.B.A.D.S.; Deighan, M.A.; Ratel, S.; Armstrong, N. Age- and Sex-Associated Differences in Isokinetic Knee Muscle Endurance between Young Children and Adults. *Appl. Physiol. Nutr. Metab.* **2009**, doi:10.1139/H09-064.

77. Kotzamanidou, M.; Michailidis, I.; Hatzikotoulas, K.; Hasani, A.; Bassa, E.; Kotzamanidis, C. Differences in Recovery Process between Adult and Prepubertal Males after a Maximal Isokinetic Fatigue Task. *Isokinet. Exerc. Sci.* **2005**, *13*, 261–266.
78. Piponnier, E.; Martin, V.; Bontemps, B.; Chalchat, E.; Julian, V.; Bocock, O.; Duclos, M.; Ratel, S. Child-Adult Differences in Neuromuscular Fatigue Are Muscle Dependent. *J. Appl. Physiol.* **2018**, doi:10.1152/jappphysiol.00244.2018.
79. Streckis, V.; Skurvydas, A.; Ratkevicius, A. Children Are More Susceptible to Central Fatigue than Adults. *Muscle Nerve Off. J. Am. Assoc. Electrodiagn. Med.* **2007**, *36*, 357–363, doi:10.1002/mus.20816.
80. Piponnier, E.; Martin, V.; Chalchat, E.; Bontemps, B.; Julian, V.; Bocock, O.; Duclos, M.; Ratel, S. Effect of MTU Length on Child–Adult Difference in Neuromuscular Fatigue. *Med. Sci. Sport. Exerc.* **2019**, doi:10.1249/mss.0000000000001981.
81. Tanina, H.; Nishimura, Y.; Tsuboi, H.; Sakata, T.; Nakamura, T.; Murata, K.Y.; Arakawa, H.; Umezu, Y.; Tajima, F. Fatigue-Related Differences in Erector Spinae between Prepubertal Children and Young Adults Using Surface Electromyographic Power Spectral Analysis. *J. Back Musculoskelet. Rehabil.* **2017**, doi:10.3233/BMR-160705.
82. Hatzikotoulas, K.; Patikas, D.; Bassa, E.; Hadjileontiadis, L.; Koutedakis, Y.; Kotzamanidis, C. Submaximal Fatigue and Recovery in Boys and Men. *Int. J. Sports Med.* **2009**, doi:10.1055/s-0029-1224171.
83. Patikas, D.; Kansizoglou, A.; Koutlianos, N.; Williams, C.A.; Hatzikotoulas, K.; Bassa, E.; Kotzamanidis, C. Fatigue and Recovery in Children and Adults during Sustained Actions at 2 Different Submaximal Intensities. *Appl. Physiol. Nutr. Metab.* **2013**, doi:10.1139/apnm-2012-0469.
84. Mendell, L.M. The Size Principle: A Rule Describing the Recruitment of Motoneurons. *J. Neurophysiol.* **2005**, doi:10.1152/classicessays.00025.2005.
85. Bottaro, M.; Brown, L.E.; Celes, R.; Martorelli, S.; Carregaro, R.; De Brito Vidal, J.C. Effect of Rest Interval on Neuromuscular and Metabolic Responses between Children and Adolescents. *Pediatr. Exerc. Sci.* **2011**, doi:10.1123/pes.23.3.311.
86. Vidal Filho, J.C.D.B.; Ferreira, C.E.S.; Sales, M.P.M.D.; Almeida, J.A.D.; Bottaro, M. Effects of different rest intervals on muscular performance in children. *Rev. Educ. Física UEM* **2011**, *22*, 613–622.
87. Faigenbaum, A.D.; Ratamess, N.A.; McFarland, J.; Kaczmarek, J.; Coraggio, M.J.; Kang, J.; Hoffman, J.R. Effect of Rest Interval Length on Bench Press Performance in Boys, Teens, and Men. *Pediatr. Exerc. Sci.* **2008**, *20*, 457–469, doi:10.1123/pes.20.4.457.
88. Tibana, R.A.; Prestes, J.; Da Cunha Nascimento, D.; Martins, O.V.; De Santana, F.S.; Balsamo, S. Higher Muscle Performance in Adolescents Compared with Adults after a Resistance Training Session with Different Rest Intervals. *J. Strength Cond. Res.* **2012**, doi:10.1519/JSC.0b013e31822dfefb.
89. Martin, V.; Kluka, V.; Garcia Vicencio, S.; Maso, F.; Ratel, S. Children Have a Reduced Maximal Voluntary Activation Level of the Adductor Pollicis Muscle Compared to Adults. *Eur. J. Appl. Physiol.* **2015**, *115*, 1485–1491, doi:10.1007/s00421-015-3132-x.
90. Kluka, V.; Martin, V.; Vicencio, S.G.; Jegu, A.G.; Cardenoux, C.; Morio, C.; Coudeyre, E.; Ratel, S. Effect of Muscle Length on Voluntary Activation Level in Children and Adults. *Med. Sci. Sports Exerc.* **2015**, *47*, 718–724, doi:10.1249/MSS.0000000000000463.
91. O'Brien, T.D.; Reeves, N.D.; Baltzopoulos, V.; Jones, D.A.; Maganaris, C.N. In Vivo Measurements of Muscle Specific Tension in Adults and Children. *Exp. Physiol.* **2010**, doi:10.1113/expphysiol.2009.048967.
92. Grosset, J.F.; Mora, I.; Lambertz, D.; Pérot, C. Voluntary Activation of the Triceps Surae in Prepubertal Children. *J. Electromyogr. Kinesiol.* **2008**, *18*, 455–465, doi:10.1016/j.jelekin.2006.11.002.
93. Kluka, V.; Martin, V.; Vicencio, S.G.; Giustiniani, M.; Morel, C.; Morio, C.; Coudeyre, E.; Ratel, S. Effect of Muscle Length on Voluntary Activation of the Plantar Flexors in Boys and Men. *Eur. J. Appl. Physiol.* **2016**, *116*, 1043–1051, doi:10.1007/s00421-016-3362-6.
94. Belanger, A.Y.; McComas, A.J. Contractile Properties of Human Skeletal Muscle in Childhood and Adolescence. *Eur. J. Appl. Physiol. Occup. Physiol.* **1989**, doi:10.1007/BF00418500.
95. Koh, T.H.H.G.; Eyre, J.A. Maturation of Corticospinal Tracts Assessed by Electromagnetic Stimulation of the Motor Cortex. *Arch. Dis. Child.* **1988**, doi:10.1136/adc.63.11.1347.
96. Lexell, J.; Sjöström, M.; Nordlund, A.-S.; Taylor, C.C. Growth and Development of Human Muscle: A Quantitative Morphological Study of Whole Vastus Lateralis from Childhood to Adult Age. *Muscle Nerve Off. J. Am. Assoc. Electrodiagn. Med.* **1992**, *15*, 404–409. doi:10.1002/mus.880150323.

97. Pitt, B.; Dotan, R.; Millar, J.; Long, D.; Tokuno, C.; O'Brien, T.; Falk, B. The Electromyographic Threshold in Boys and Men. *Eur. J. Appl. Physiol.* **2015**, *115*, 1273–1281, doi:10.1007/s00421-015-3100-5.
98. Long, D.; Dotan, R.; Pitt, B.; McKinlay, B.; O'Brien, T.D.; Tokuno, C.; Falk, B. The Electromyographic Threshold in Girls and Women. *Pediatr. Exerc. Sci.* **2017**, doi:10.1123/pes.2016-0056.
99. Dotan, R. Children's Neuromotor and Muscle-Functional Attributes—Outstanding Issues. *Pediatr. Exerc. Sci.* **2016**, *28*, 202–209, doi:10.1123/pes.2015-0248.
100. Lichtwark, G.A.; Barclay, C.J. A Compliant Tendon Increases Fatigue Resistance and Net Efficiency during Fatiguing Cyclic Actions of Mouse Soleus Muscle. *Acta Physiol.* **2012**, doi:10.1111/j.1748-1716.2011.02361.x.
101. Ratel, S.; Kluka, V.; Vicencio, S.G.; Jegu, A.G.; Cardenoux, C.; Morio, C.; Coudeyre, E.; Martin, V. Insights into the Mechanisms of Neuromuscular Fatigue in Boys and Men. *Med. Sci. Sports Exerc.* **2015**, doi:10.1249/MSS.0000000000000697.
102. Armstrong, N.; Barker, A.R.; McManus, A.M. Muscle Metabolism Changes with Age and Maturation: How Do They Relate to Youth Sport Performance? *Br. J. Sports Med.* **2015**, *49*, 860–864, doi:10.1136/bjsports-2014-094491.
103. Weinstein, Y.; Inbar, O.; Mor-Unikovski, R.; Luder, A.; Dubnov-Raz, G. Recovery of Upper-Body Muscle Power after Short Intensive Exercise: Comparing Boys and Men. *Eur. J. Appl. Physiol.* **2018**, doi:10.1007/s00421-018-3885-0.
104. Engel, F.A.; Sperlich, B.; Stockinger, C.; Hartel, S.; Bos, K.; Holmberg, H.C. The Kinetics of Blood Lactate in Boys during and Following a Single and Repeated All-out Sprints of Cycling Are Different than in Men. *Appl. Physiol. Nutr. Metab.* **2015**, doi:10.1139/apnm-2014-0370.
105. Dotan, R.; Ohana, S.; Bediz, C.; Falk, B. Blood Lactate Disappearance Dynamics in Boys and Men Following Exercise of Similar and Dissimilar Peak-Lactate Concentrations. *J. Pediatr. Endocrinol. Metab.* **2003**, *16*, 419–429, doi:10.1515/JPEM.2003.16.3.419.
106. Ratel, S.; Bedu, M.; Hennegrave, A.; Doré, E.; Duché, P. Effects of Age and Recovery Duration on Peak Power Output during Repeated Cycling Sprints. *Int. J. Sports Med.* **2002**, *23*, 397–402, doi:10.1055/s-2002-33737.
107. Kappenstein, J.; Fernández-Fernández, J.; Engel, F.; Ferrauti, A. Effects of Active and Passive Recovery on Blood Lactate and Blood PH after a Repeated Sprint Protocol in Children and Adults. *Pediatr. Exerc. Sci.* **2015**, *27*, 77–84, doi:10.1123/pes.2013-0187.
108. Buchheit, M.; Duché, P.; Laursen, P.B.; Ratel, S. Postexercise Heart Rate Recovery in Children: Relationship with Power Output, Blood PH, and Lactate. *Appl. Physiol. Nutr. Metab.* **2010**, doi:10.1139/H09-140.
109. Beneke, R.; Hütler, M.; Jung, M.; Leithäuser, R.M. Modeling the Blood Lactate Kinetics at Maximal Short-Term Exercise Conditions in Children, Adolescents, and Adults. *J. Appl. Physiol.* **2005**, doi:10.1152/jappphysiol.00062.2005.
110. Ratel, S.; Duche, P.; Hennegrave, A.; Van Praagh, E.; Bedu, M. Acid-Base Balance during Repeated Cycling Sprints in Boys and Men. *J. Appl. Physiol.* **2002**, *92*, 479–485, doi:10.1152/jappphysiol.00495.2001.
111. McCormack, S.E.; McCarthy, M.A.; Farilla, L.; Hrovat, M.I.; Systrom, D.M.; Grinspoon, S.K.; Fleischman, A. Skeletal Muscle Mitochondrial Function Is Associated with Longitudinal Growth Velocity in Children and Adolescents. *J. Clin. Endocrinol. Metab.* **2011**, doi:10.1210/jc.2011-1218.
112. Ratel, S.; Tonson, A.; Le Fur, Y.; Cozzone, P.; Bendahan, D. Comparative Analysis of Skeletal Muscle Oxidative Capacity in Children and Adults: A 31P-MRS Study. *Appl. Physiol. Nutr. Metab.* **2008**, doi:10.1139/H08-039.
113. Taylor, D.J.; Kemp, G.J.; Thompson, C.H.; Radda, G.K. Ageing: Effects on Oxidative Function of Skeletal Muscle in Vivo. *Mol. Cell. Biochem.* **1997**, doi:10.1023/A:1006802602497.
114. Kappenstein, J.; Ferrauti, A.; Runkel, B.; Fernandez-Fernandez, J.; Müller, K.; Zange, J. Changes in Phosphocreatine Concentration of Skeletal Muscle during High-Intensity Intermittent Exercise in Children and Adults. *Eur. J. Appl. Physiol.* **2013**, *113*, 2769–2779, doi:10.1007/s00421-013-2712-x.
115. Birat, A.; Bourdier, P.; Piponnier, E.; Blazeovich, A.J.; Maciejewski, H.; Duché, P.; Ratel, S. Metabolic and Fatigue Profiles Are Comparable between Prepubertal Children and Well-Trained Adult Endurance Athletes. *Front. Physiol.* **2018**, doi:10.3389/fphys.2018.00387.
116. Boisseau, N.; Delamarche, P. Metabolic and Hormonal Responses to Exercise in Children and Adolescents. *Sports Med.* **2000**, doi:10.2165/00007256-200030060-00003.
117. Fleischman, A.; Makimura, H.; Stanley, T.L.; McCarthy, M.A.; Kron, M.; Sun, N.; Chuzi, S.; Hrovat, M.I.; Systrom, D.M.; Grinspoon, S.K. Skeletal Muscle Phosphocreatine Recovery after Submaximal Exercise in

- Children and Young and Middle-Aged Adults. *J. Clin. Endocrinol. Metab.* **2010**, *95*, E69–E74, doi:10.1210/jc.2010-0527.
118. Berg, A.; Kim, S.S.; Keul, J. Skeletal Muscle Enzyme Activities in Healthy Young Subjects. *Int. J. Sports Med.* **1986**, doi:10.1055/s-2008-1025766.
119. Berg, A.; Keul, J. Biochemical changes during exercise in children. In *Young Athletes/Biological, Psychological and Educational Perspectives*; Malina, R., Ed.; Human Kinetics: Champaign, IL, USA, 1988; pp. 61–77.
120. Eriksson, B.O.; Gollnick, P.D.; Saltin, B. Muscle Metabolism and Enzyme Activities after Training in Boys 11–13 Years Old. *Acta Physiol. Scand.* **1973**, doi:10.1111/j.1748-1716.1973.tb05415.x.
121. Haralambie, G. Enzyme Activities in Skeletal Muscle of 13-15 Years Old Adolescents. *Clin. Respir. Physiol.* **1982**, *18*, 65–74.
122. Hoppeler, H.; Lüthi, P.; Claassen, H.; Weibel, E.R.; Howald, H. The Ultrastructure of the Normal Human Skeletal Muscle—A Morphometric Analysis on Untrained Men, Women and Well-Trained Orienteers. *Pflügers Arch. Eur. J. Physiol.* **1973**, doi:10.1007/BF00588462.
123. Ratel, S.; Blazeovich, A.J. Are Prepubertal Children Metabolically Comparable to Well-Trained Adult Endurance Athletes? *Sports Med.* **2017**, doi:10.1007/s40279-016-0671-1.
124. Eston, R.; Byrne, C.; Twist, C. Muscle function after exercise-induced muscle damage: Considerations for athletic performance in children and adults. *J. Exerc. Sci. Fit.* **2003**, *1*, 85–96.
125. Ratel, S.; Martin, V. Is There a Progressive Withdrawal of Physiological Protections against High-Intensity Exercise-Induced Fatigue during Puberty? *Sports* **2015**, doi:10.3390/sports3040346.
126. Kanda, K.; Sugama, K.; Hayashida, H.; Sakuma, J.; Kawakami, Y.; Miura, S.; Yoshioka, H.; Mori, Y.; Suzuki, K. Eccentric Exercise-Induced Delayed-Onset Muscle Soreness and Changes in Markers of Muscle Damage and Inflammation. *Exerc. Immunol. Rev.* **2013**, *19*, 72–85.
127. Hyldahl, R.D.; Hubal, M.J. Lengthening Our Perspective: Morphological, Cellular, and Molecular Responses to Eccentric Exercise. *Muscle Nerve* **2014**, doi:10.1002/mus.24077.
128. Goodall, S.; Thomas, K.; Barwood, M.; Keane, K.; Gonzalez, J.T.; St Clair Gibson, A.; Howatson, G. Neuromuscular Changes and the Rapid Adaptation Following a Bout of Damaging Eccentric Exercise. *Acta Physiol.* **2017**, doi:10.1111/apha.12844.
129. Cleak, M.J.; Eston, R.G. Muscle Soreness, Swelling, Stiffness and Strength Loss after Intense Eccentric Exercise. *Br. J. Sports Med.* **1992**, doi:10.1136/bjism.26.4.267.
130. Hill, J.; Howatson, G.; van Someren, K.; Leeder, J.; Pedlar, C. Compression Garments and Recovery from Exercise-Induced Muscle Damage: A Meta-Analysis. *Br. J. Sports Med.* **2014**, doi:10.1136/bjsports-2013-092456.
131. Cross, R.; Siegler, J.; Marshall, P.; Lovell, R. Scheduling of Training and Recovery during the In-Season Weekly Micro-Cycle: Insights from Team Sport Practitioners. *Eur. J. Sport Sci.* **2019**, doi:10.1080/17461391.2019.1595740.
132. Winwood, P.W.; Buckley, J.J. Short-Term Effects of Resistance Training Modalities on Performance Measures in Male Adolescents. *J. Strength Cond. Res.* **2019**, doi:10.1519/JSC.0000000000001992.
133. Pichardo, A.W.; Oliver, J.L.; Harrison, C.B.; Maulder, P.S.; Lloyd, R.S. Integrating Resistance Training into High School Curriculum. *Strength Cond. J.* **2019**, doi:10.1519/ssc.0000000000000412.
134. Fort-Vanmeerhaeghe, A.; Romero-Rodriguez, D.; Montalvo, A.M.; Kiefer, A.W.; Lloyd, R.S.; Myer, G.D. Integrative Neuromuscular Training and Injury Prevention in Youth Athletes. Part I: Identifying Risk Factors. *Strength Cond. J.* **2016**, doi:10.1519/SSC.0000000000000229.
135. Fort-Vanmeerhaeghe, A.; Romero-Rodriguez, D.; Lloyd, R.S.; Kushner, A.; Myer, G.D. Integrative Neuromuscular Training in Youth Athletes. Part II: Strategies to Prevent Injuries and Improve Performance. *Strength Cond. J.* **2016**, doi:10.1519/SSC.0000000000000234.
136. Murray, A. Managing the Training Load in Adolescent Athletes. *Int. J. Sports Physiol. Perform.* **2017**, doi:10.1123/ijspp.2016-0334.
137. Lin, M.J.; Nosaka, K.; Ho, C.C.; Chen, H.L.; Tseng, K.W.; Ratel, S.; Chen, T.C.C. Influence of Maturation Status on Eccentric Exercise-Induced Muscle Damage and the Repeated Bout Effect in Females. *Front. Physiol.* **2018**, doi:10.3389/fphys.2017.01118.
138. Chen, T.C.; Chen, H.L.; Liu, Y.C.; Nosaka, K. Eccentric Exercise-Induced Muscle Damage of Pre-Adolescent and Adolescent Boys in Comparison to Young Men. *Eur. J. Appl. Physiol.* **2014**, doi:10.1007/s00421-014-2848-3.

139. Deli, C.K.; Fatouros, I.G.; Paschalis, V.; Georgakouli, K.; Zalavras, A.; Avloniti, A.; Koutedakis, Y.; Jamurtas, A.Z. A Comparison of Exercise-Induced Muscle Damage Following Maximal Eccentric Actions in Men and Boys. *Pediatr. Exerc. Sci.* **2017**, doi:10.1123/pes.2016-0185.
140. Dos Santos, R.R.C.; Rossi, R.R.; Rosa, E.C.C.C. Perception of Delayed Onset Muscle Soreness in Children and Adults Trained, Submitted to a Training Session of Force Eccentric. *Int. J. Sports Sci.* **2016**, *6*, 23–26, doi:10.5923/j.sports.20160602.01.
141. Arnett, M.G.; Hyslop, R.; Dennehy, C.A.; Schneider, C.M. Age-Related Variations of Serum CK and CK MB Response in Females. *Can. J. Appl. Physiol.* **2000**, doi:10.1139/h00-027.
142. Moir, G.; Snyder, B.; Connaboy, C.; Lamont, H.; Davis, S. Using Drop Jumps and Jump Squats to Assess Eccentric and Concentric Force-Velocity Characteristics. *Sports*. **2018**, *6*. doi:10.3390/sports6040125.
143. Lazaridis, S.; Patikas, D.A.; Bassa, E.; Tsatalas, T.; Hatzikotoulas, K.; Ftikas, C.; Kotzamanidis, C. The Acute Effects of an Intense Stretch-Shortening Cycle Fatigue Protocol on the Neuromechanical Parameters of Lower Limbs in Men and Prepubescent Boys. *J. Sports Sci.* **2018**, doi:10.1080/02640414.2017.1287932.
144. Gorianovas, G.; Skurvydas, A.; Streckis, V.; Brazaitis, M.; Kamandulis, S.; McHugh, M.P. Repeated Bout Effect Was More Expressed in Young Adult Males than in Elderly Males and Boys. *Biomed Res. Int.* **2013**, doi:10.1155/2013/218970.
145. Marginson, V.; Rowlands, A.V.; Gleeson, N.P.; Eston, R.G. Comparison of the Symptoms of Exercise-Induced Muscle Damage after an Initial and Repeated Bout of Plyometric Exercise in Men and Boys. *J. Appl. Physiol.* **2005**, doi:10.1152/jappphysiol.01193.2004.
146. Pullinen, T.; Mero, A.; Huttunen, P.; Pakarinen, A.; Komi, P.V. Resistance Exercise-Induced Hormonal Response under the Influence of Delayed Onset Muscle Soreness in Men and Boys. *Scand. J. Med. Sci. Sport.* **2011**, doi:10.1111/j.1600-0838.2010.01238.x.
147. Soares, J.M.C.; Mota, P.; Duarte, J.A.; Appell, H.J. Children Are Less Susceptible to Exercise-Induced Muscle Damage than Adults: A Preliminary Investigation. *Pediatr. Exerc. Sci.* **1996**, doi:10.1123/pes.8.4.361.
148. Duarte, J.A.; Magalhães, J.F.; Monteiro, L.; Almeida-Dias, A.; Soares, J.M.C.; Appell, H.J. Exercise-Induced Signs of Muscle Overuse in Children. *Int. J. Sports Med.* **1999**, doi:10.1055/s-2007-971101.
149. Webber, L.M.; Byrnes, W.C.; Rowland, T.W.; Foster, V.L. Serum Creatine Kinase Activity and Delayed Onset Muscle Soreness in Prepubescent Children: A Preliminary Study. *Pediatr. Exerc. Sci.* **2016**, doi:10.1123/pes.14.351.
150. Hyldahl, R.D.; Chen, T.C.; Nosaka, K. Mechanisms and Mediators of the Skeletal Muscle Repeated Bout Effect. *Exerc. Sport Sci. Rev.* **2017**, doi:10.1249/JES.0000000000000095.
151. Nosaka, K.; Aoki, M.S. Repeated bout effect: Research update and future perspective. *Braz. J. Biomotricity* **2011**, *5*, 5–15.
152. McHugh, M.P.; Connolly, D.A.J.; Eston, R.G.; Gleim, G.W. Exercise-Induced Muscle Damage and Potential Mechanisms for the Repeated Bout Effect. *Sports Medicine*. **1999**, doi:10.2165/00007256-199927030-00002.
153. Bridgeman, L.A.; Gill, N.D.; Dulson, D.K.; Mcguigan, M.R. The Effect of Exercise-Induced Muscle Damage after a Bout of Accentuated Eccentric Load Drop Jumps and the Repeated Bout Effect. *J. Strength Cond. Res.* **2017**, doi:10.1519/JSC.0000000000001725.
154. Pincheira, P.A.; Hoffman, B.W.; Cresswell, A.G.; Carroll, T.J.; Brown, N.A.T.; Lichtwark, G.A. The Repeated Bout Effect Can Occur without Mechanical and Neuromuscular Changes after a Bout of Eccentric Exercise. *Scand. J. Med. Sci. Sport.* **2018**, doi:10.1111/sms.13222.
155. Clarkson, P.M.; Nosaka, K.; Braun, B. Muscle Function after Exercise-Induced Muscle Damage and Rapid Adaptation. *Med. Sci. Sports Exerc.* **1992**, doi:10.1249/00005768-199205000-00004.
156. Chen, T.C.; Nosaka, K.; Sacco, P. Intensity of Eccentric Exercise, Shift of Optimum Angle, and the Magnitude of Repeated-Bout Effect. *J. Appl. Physiol.* **2007**, doi:10.1152/jappphysiol.00425.2006.
157. Kawczyński, A. Force and Electromyographic Responses of the Biceps Brachii after Eccentric Exercise in Athletes and Non-Athletes. *J. Hum. Kinet.* **2019**, doi:10.2478/hukin-2019-0068.
158. Croix, M.D.S.; Deighan, M.; Armstrong, N. Functional Eccentric-Concentric Ratio of Knee Extensors and Flexors in Pre-Pubertal Children, Teenagers and Adult Males and Females. *Int. J. Sports Med.* **2007**, doi:10.1055/s-2007-964985.
159. Philippaerts, R.M.; Vaeyens, R.; Janssens, M.; Van Renterghem, B.; Matthys, D.; Craen, R.; Bourgois, J.; Vrijens, J.; Beunen, G.; Malina, R.M. The Relationship between Peak Height Velocity and Physical Performance in Youth Soccer Players. *J. Sports Sci.* **2006**, doi:10.1080/02640410500189371.

160. Van Der Sluis, A.; Elferink-Gemser, M.T.; Brink, M.S.; Visscher, C. Importance of Peak Height Velocity Timing in Terms of Injuries in Talented Soccer Players. *Int. J. Sports Med.* **2015**, doi:10.1055/s-0034-1385879.
161. Rejeb, A.; Johnson, A.; Farooq, A.; Verrelst, R.; Pullinger, S.; Vaeyens, R.; Witvrouw, E. Sports Injuries Aligned to Predicted Mature Height in Highly Trained Middle-Eastern Youth Athletes: A Cohort Study. *BMJ Open* **2019**, doi:10.1136/bmjopen-2018-023284.
162. Johnson, D.M.; Williams, S.; Bradley, B.; Sayer, S.; Murray Fisher, J.; Cumming, S. Growing Pains: Maturity Associated Variation in Injury Risk in Academy Football. *Eur. J. Sport Sci.* **2019**, doi:10.1080/17461391.2019.1633416.
163. Petushek, E.J.; Sugimoto, D.; Stoolmiller, M.; Smith, G.; Myer, G.D. Evidence-Based Best-Practice Guidelines for Preventing Anterior Cruciate Ligament Injuries in Young Female Athletes: A Systematic Review and Meta-Analysis. *Am. J. Sports Med.* **2019**, doi:10.1177/0363546518782460.
164. Lubans, D.R.; Morgan, P.J.; Cliff, D.P.; Barnett, L.M.; Okely, A.D. Fundamental Movement Skills in Children and Adolescents. *Sport. Med.* **2010**, *40*, 1019–1035, doi:10.2165/11536850-000000000-00000.
165. Collins, H.; Booth, J.N.; Duncan, A.; Fawkner, S. The Effect of Resistance Training Interventions on Fundamental Movement Skills in Youth: A Meta-Analysis. *Sport. Med. Open.* **2019**, doi:10.1186/s40798-019-0188-x.
166. McKeown, I.; Taylor-McKeown, K.; Woods, C.; Ball, N. Athletic Ability Assessment: A Movement Assessment Protocol for Athletes. *Int. J. Sports Phys. Ther.* **2014**, *9*, 862–873.
167. Hewett, T.E.; Myer, G.D.; Ford, K.R.; Heidt, R.S.; Colosimo, A.J.; McLean, S.G.; Van Den Bogert, A.J.; Paterno, M.V.; Succop, P. Biomechanical Measures of Neuromuscular Control and Valgus Loading of the Knee Predict Anterior Cruciate Ligament Injury Risk in Female Athletes: A Prospective Study. *Am. J. Sports Med.* **2005**, doi:10.1177/0363546504269591.
168. Santello, M. Review of Motor Control Mechanisms Underlying Impact Absorption from Falls. *Gait Posture* **2005**, doi:10.1016/j.gaitpost.2004.01.005.
169. Hewett, T.E.; Myer, G.D.; Ford, K.R. Anterior Cruciate Ligament Injuries in Female Athletes: Part 1, Mechanisms and Risk Factors. *Am. J. Sports Med.* **2006**, doi:10.1177/0363546505284183.
170. Dierks, T.A.; Manal, K.T.; Hamill, J.; Davis, I.S. Proximal and Distal Influences on Hip and Knee Kinematics in Runners with Patellofemoral Pain during a Prolonged Run. *J. Orthop. Sports Phys. Ther.* **2008**, doi:10.2519/jospt.2008.2490.
171. Sigward, S.M.; Pollard, C.D.; Powers, C.M. The Influence of Sex and Maturation on Landing Biomechanics: Implications for Anterior Cruciate Ligament Injury. *Scand. J. Med. Sci. Sport.* **2012**, doi:10.1111/j.1600-0838.2010.01254.x.
172. Hass, C.J.; Schick, E.A.; Tillman, M.D.; Chow, J.W.; Brunt, D.; Cauraugh, J.H. Knee Biomechanics during Landings: Comparison of Pre- and Postpubescent Females. *Med. Sci. Sports Exerc.* **2005**, doi:10.1249/01.MSS.0000150085.07169.73.
173. Swartz, E.E.; Decoster, L.C.; Russell, P.J.; Croce, R.V. Effects of Developmental Stage and Sex on Lower Extremity Kinematics and Vertical Ground Reaction Forces during Landing. *J. Athl. Train.* **2005**, *40*, 9.
174. Boden, B.P.; Dean, C.S.; Feagin, J.A.; Garrett, W.E. Mechanisms of Anterior Cruciate Ligament Injury. *Orthopedics* **2000**, *23*, 573–578.
175. Ireland, M.L. Anterior Cruciate Ligament Injury in Female Athletes: Epidemiology. *J. Athl. Train.* **1999**, doi:10.3928/0147-7447-20000601-15.
176. Ford, K.R.; Shapiro, R.; Myer, G.D.; Van Den Bogert, A.J.; Hewett, T.E. Longitudinal Sex Differences during Landing in Knee Abduction in Young Athletes. *Med. Sci. Sports Exerc.* **2010**, doi:10.1249/MSS.0b013e3181dc99b1.
177. Hewett, T.E.; Myer, G.D.; Kiefer, A.W.; Ford, K.R. Longitudinal Increases in Knee Abduction Moments in Females during Adolescent Growth. *Med. Sci. Sports Exerc.* **2015**, doi:10.1249/MSS.0000000000000700.
178. Fort-Vanmeerhaeghe, A.; Benet, A.; Mirada, S.; Montalvo, A.M.; Myer, G.D. Sex and Maturation Differences in Performance of Functional Jumping and Landing Deficits in Youth Athletes. *J. Sport Rehabil.* **2019**, doi:10.1123/jsr.2017-0292.
179. Caine, D.; Purcell, L.; Maffulli, N. The Child and Adolescent Athlete: A Review of Three Potentially Serious Injuries. *BMC Sports Sci. Med. Rehabil.* **2014**, doi:10.1186/2052-1847-6-22.
180. Pollard, C.D.; Sigward, S.M.; Powers, C.M. Limited Hip and Knee Flexion during Landing Is Associated with Increased Frontal Plane Knee Motion and Moments. *Clin. Biomech.* **2010**, doi:10.1016/j.clinbiomech.2009.10.005.

181. Hewett, T.E.; Myer, G.D.; Ford, K.R. Decrease in Neuromuscular Control about the Knee with Maturation in Female Athletes. *J. Bone Jt. Surg. Ser. A* **2004**, doi:10.2106/00004623-200408000-00001.
182. Hewett, T.E.; Myer, G.D.; Ford, K.R.; Heidt, R.S.; Colosimo, A.J.; McLean, S.G.; van den Bogert, A.J.; Paterno, M.V.; Succop, P. Neuromuscular Control and Valgus Loading of the Knee Predict ACL Injury Risk in Female Athletes. *Med. Sci. Sport. Exerc.* **2004**, doi:10.1249/00005768-200405001-01376.
183. Schmitz, R.J.; Shultz, S.J.; Nguyen, A.D. Dynamic Valgus Alignment and Functional Strength in Males and Females during Maturation. *J. Athl. Train.* **2009**, doi:10.4085/1062-6050-44.1.26.
184. Otsuki, R.; Kuramochi, R.; Fukubayashi, T. Effect of Injury Prevention Training on Knee Mechanics in Female Adolescents during Puberty. *Br. J. Sports Med.* **2014**, doi:10.1136/bjsports-2014-093494.236.
185. Holden, S.; Doherty, C.; Boreham, C.; Delahunt, E. Sex Differences in Sagittal Plane Control Emerge during Adolescent Growth: A Prospective Investigation. *Knee Surg. Sport. Traumatol. Arthrosc.* **2019**, doi:10.1007/s00167-018-5069-1.
186. Ford, K.R.; Myer, G.D.; Hewett, T.E. Valgus Knee Motion during Landing in High School Female and Male Basketball Players. *Med. Sci. Sports Exerc.* **2003**, doi:10.1249/01.MSS.0000089346.85744.D9.
187. Yu, B.; McClure, S.B.; Onate, J.A.; Guskiewicz, K.M.; Kirkendall, D.T.; Garrett, W.E. Age and Gender Effects on Lower Extremity Kinematics of Youth Soccer Players in a Stop-Jump Task. *Am. J. Sports Med.* **2005**, doi:10.1177/0363546504273049.
188. Read, P.J.; Oliver, J.L.; De Ste Croix, M.B.A.; Myer, G.D.; Lloyd, R.S. Landing Kinematics in Elite Male Youth Soccer Players of Different Chronologic Ages and Stages of Maturation. *J. Athl. Train.* **2018**, doi:10.4085/1062-6050-493-16.
189. Read, P.J.; Oliver, J.L.; Myer, G.D.; De Ste Croix, M.B.A.; Belshaw, A.; Lloyd, R.S. Altered Landing Mechanics Are Shown by Male Youth Soccer Players at Different Stages of Maturation. *Phys. Ther. Sport* **2018**, doi:10.1016/j.ptsp.2018.07.001.
190. Barber-Westin, S.D.; Noyes, F.R.; Galloway, M. Jump-Land Characteristics and Muscle Strength Development in Young Athletes: A Gender Comparison of 1140 Athletes 9 to 17 Years of Age. *Am. J. Sports Med.* **2006**, doi:10.1177/0363546505281242.
191. Quatman, C.E.; Ford, K.R.; Myer, G.D.; Hewett, T.E. Maturation Leads to Gender Differences in Landing Force and Vertical Jump Performance: A Longitudinal Study. *Am. J. Sports Med.* **2006**, doi:10.1177/0363546505281916.
192. Di Stefano, L.J.; Martinez, J.C.; Crowley, E.; Matteau, E.; Kerner, M.S.; Boling, M.C.; Nguyen, A.D.; Trojian, T.H. Maturation and Sex Differences in Neuromuscular Characteristics of Youth Athletes. *J. Strength Cond. Res.* **2015**, doi:10.1519/JSC.0000000000001052.
193. Lloyd, R.S.; Oliver, J.L.; Myer, G.D.; De Ste Croix, M.; Wass, J.; Read, P.J. Comparison of Drop Jump and Tuck Jump Knee Joint Kinematics in Elite Male Youth Soccer Players: Implications for Injury Risk Screening. *J. Sport Rehabil.* **2019**, doi:10.1123/jsr.2019-0077.
194. Birat, A.; Sebillaud, D.; Bourdier, P.; Doré, E.; Duché, P.; Blazevich, A.J.; Patikas, D.; Ratel, S. Effect of Drop Height on Vertical Jumping Performance in Pre-, Circa-, and Post-Pubertal Boys and Girls. *Pediatr. Exerc. Sci.* **2019**, doi:10.1123/pes.2019-0120.
195. Read, P.J.; Oliver, J.L.; De Ste Croix, M.B.A.; Myer, G.D.; Lloyd, R.S. A Prospective Investigation to Evaluate Risk Factors for Lower Extremity Injury Risk in Male Youth Soccer Players. *Scand. J. Med. Sci. Sport.* **2018**, doi:10.1111/sms.13013.
196. Irmischer, B.S.; Harris, C.; Pfeiffer, R.P.; DeBeliso, M.A.; Adams, K.J.; Shea, K.G. Effects of a Knee Ligament Injury Prevention Exercise Program on Impact Forces in Women. *J. Strength Cond. Res.* **2004**, doi:10.1519/R-13473.1.
197. Hass, C.J.; Schick, E.A.; Chow, J.W.; Tillman, M.D.; Brunt, D.; Cauraugh, J.H. Lower Extremity Biomechanics Differ in Prepubescent and Postpubescent Female Athletes during Stride Jump Landings. *J. Appl. Biomech.* **2003**, doi:10.1123/jab.19.2.139.
198. Leppänen, M.; Pasanen, K.; Kujala, U.M.; Vasankari, T.; Kannus, P.; Äyrämö, S.; Krosshaug, T.; Bahr, R.; Avela, J.; Perttunen, J.; et al. Stiff Landings Are Associated with Increased ACL Injury Risk in Young Female Basketball and Floorball Players. *Am. J. Sports Med.* **2017**, doi:10.1177/0363546516665810.
199. Hewett, T.E.; Myer, G.D.; Ford, K.R.; Slauterbeck, J.R. Preparticipation Physical Examination Using a Box Drop Vertical Jump Test in Young Athletes: The Effects of Puberty and Sex. *Clin. J. Sport Med.* **2006**, doi:10.1097/00042752-200607000-00003.

200. Paz, G.A.; de Freitas Maia, M.; Santana, H.G.; Miranda, H.; Lima, V.; Willson, J.D. Knee Frontal Plane Projection Angle: A Comparison Study between Drop Vertical Jump and Step-down Tests with Young Volleyball Athletes. *J. Sport Rehabil.* **2019**, doi:10.1123/jsr.2017-0204.
201. Ali, N.; Robertson, D.G.E.; Rouhi, G. Sagittal Plane Body Kinematics and Kinetics during Single-Leg Landing from Increasing Vertical Heights and Horizontal Distances: Implications for Risk of Non-Contact ACL Injury. *Knee* **2014**, doi:10.1016/j.knee.2012.12.003.
202. Bobbert, M.F.; Huijing, P.A.; Schenau, G.J.V.I. Drop Jumping. II. The Influence of Dropping Height on the Biomechanics of Drop Jumping. *Med. Sci. Sports Exerc.* **1987**, *19*, 339–346.
203. Makaruk, H.; Sacewicz, T. The Effect of Drop Height and Body Mass on Drop Jump Intensity. *Biol. Sport* **2011**, doi:10.5604/935873.
204. Zhang, S.N.; Bates, B.T.; Dufek, J.S. Contributions of Lower Extremity Joints to Energy Dissipation during Landings. *Med. Sci. Sports Exerc.* **2000**, doi:10.1097/00005768-200004000-00014.
205. Herrington, L.; Munro, A.; Comfort, P. A Preliminary Study into the Effect of Jumping-Landing Training and Strength Training on Frontal Plane Projection Angle. *Man. Ther.* **2015**, doi:10.1016/j.math.2015.04.009.
206. Montgomery, M.M.; Shultz, S.J.; Schmitz, R.J.; Wideman, L.; Henson, R.A. Influence of Lean Body Mass and Strength on Landing Energetics. *Med. Sci. Sports Exerc.* **2012**, doi:10.1249/MSS.0b013e318268fb2d.
207. Jacobs, C.; Mattacola, C. Sex Differences in Eccentric Hip-Abductor Strength and Knee-Joint Kinematics When Landing from a Jump. *J. Sport Rehabil.* **2005**, doi:10.1123/jsr.14.4.346.
208. Boling, M.; Padua, D. Relationship between Hip Strength and Trunk, Hip, and Knee Kinematics during a Jump-Landing Task in Individuals with Patellofemoral Pain. *Int. J. Sports Phys. Ther.* **2013**, *8*, 661.
209. Baldon, R.D.M.; Lobato, D.F.M.; Carvalho, L.P.; Santiago, P.R.P.; Benze, B.G.; Serrão, F.V. Relationship between Eccentric Hip Torque and Lower-Limb Kinematics: Gender Differences. *J. Appl. Biomech.* **2011**, doi:10.1123/jab.27.3.223.
210. Baldon, R.D.M.; Nakagawa, T.H.; Muniz, T.B.; Amorim, C.F.; Maciel, C.D.; Serrão, F.V. Eccentric Hip Muscle Function in Females with and without Patellofemoral Pain Syndrome. *J. Athl. Train.* **2009**, doi:10.4085/1062-6050-44.5.490.
211. Ramskov, D.; Barton, C.; Nielsen, R.O.; Rasmussen, S. High Eccentric Hip Abduction Strength Reduces the Risk of Developing Patellofemoral Pain among Novice Runners Initiating a Self-Structured Running Program: A 1-Year Observational Study. *J. Orthop. Sports Phys. Ther.* **2015**, doi:10.2519/jospt.2015.5091.
212. Wu, X.; Zhang, S.; Liu, Y.; Zhang, D.; Xie, B. Do Knee Concentric and Eccentric Strength and Sagittal-Plane Knee Joint Biomechanics Differ between Jumpers and Non-Jumpers in Landing? *Hum. Mov. Sci.* **2013**, doi:10.1016/j.humov.2013.03.008.
213. Strafford, B.W.; van der Steen, P.; Davids, K.; Stone, J.A. Parkour as a Donor Sport for Athletic Development in Youth Team Sports: Insights Through an Ecological Dynamics Lens. *Sport. Med. Open* **2018**, doi:10.1186/s40798-018-0132-5.
214. Maldonado, G.; Soueres, P.; Watier, B. Strategies of Parkour Practitioners for Executing Soft Precision Landings. *J. Sports Sci.* **2018**, doi:10.1080/02640414.2018.1469226.
215. DiStefano, L.J.; Beltz, E.M.; Root, H.J.; Martinez, J.C.; Houghton, A.; Taranto, N.; Pearce, K.; McConnell, E.; Muscat, C.; Boyle, S.; et al. Sport Sampling Is Associated with Improved Landing Technique in Youth Athletes. *Sports Health* **2018**, doi:10.1177/1941738117736056.
216. Standing, R.J.; Maulder, P.S. A Comparison of the Habitual Landing Strategies from Differing Drop Heights of Parkour Practitioners (Traceurs) and Recreationally Trained Individuals. *J. Sport. Sci. Med.* **2015**, *14*, 723.
217. DiCesare, C.A.; Montalvo, A.; Barber Foss, K.D.; Thomas, S.M.; Ford, K.R.; Hewett, T.E.; Jayanthi, N.A.; Stracciolini, A.; Bell, D.R.; Myer, G.D. Lower Extremity Biomechanics Are Altered across Maturation in Sport-Specialized Female Adolescent Athletes. *Front. Pediatr.* **2019**, doi:10.3389/fped.2019.00268.
218. Hall, R.; Foss, K.B.; Hewett, T.E.; Myer, G.D. Sport Specialization's Association with an Increased Risk of Developing Anterior Knee Pain in Adolescent Female Athletes. *J. Sport Rehabil.* **2015**, doi:10.1123/jsr.2013-0101.
219. Madruga-Parera, M.; Romero-Rodríguez, D.; Bishop, C.; Beltran-Valls, M.R.; Latinjak, A.T.; Beato, M.; Fort-Vanmeerhaeghe, A. Effects of Maturation on Lower Limb Neuromuscular Asymmetries in Elite Youth Tennis Players. *Sports*. **2019**, doi:10.3390/sports7050106.

220. Atkins, S.J.; Bentley, I.; Hurst, H.T.; Sinclair, J.K.; Hesketh, C. The Presence of Bilateral Imbalance of the Lower Limbs in Elite Youth Soccer Players of Different Ages. *J. Strength Cond. Res.* **2016**, doi:10.1519/JSC.0b013e3182987044.
221. Dai, B.; Garrett, W.E.; Gross, M.T.; Padua, D.A.; Queen, R.M.; Yu, B. The Effect of Performance Demands on Lower Extremity Biomechanics during Landing and Cutting Tasks. *J. Sport Heal. Sci.* **2019**, doi:10.1016/j.jshs.2016.11.004.
222. Pichardo, A.W.; Oliver, J.L.; Harrison, C.B.; Maulder, P.S.; Lloyd, R.S.; Kandoi, R. Effects of Combined Resistance Training and Weightlifting on Motor Skill Performance of Adolescent Male Athletes. *J. Strength Cond. Res.* **2019**, doi:10.1519/jsc.0000000000003108.
223. Chaouachi, A.; Hammami, R.; Kaabi, S.; Chamari, K.; Drinkwater, E.J.; Behm, D.G. Olympic Weightlifting and Plyometric Training with Children Provides Similar or Greater Performance Improvements than Traditional Resistance Training. *J. Strength Cond. Res.* **2014**, doi:10.1519/JSC.0000000000000305.
224. Suchomel, T.J.; Lake, J.P.; Comfort, P. Load Absorption Force-Time Characteristics Following the Second Pull of Weightlifting Derivatives. *J. Strength Cond. Res.* **2017**, doi:10.1519/JSC.0000000000001634.
225. Suchomel, T.J.; Giordanelli, M.D.; Geiser, C.F.; Kipp, K. Comparison of Joint Work During Load Absorption Between Weightlifting Derivatives. *J. Strength Cond. Res.* **2018**, doi:10.1519/jsc.0000000000002927.
226. Sugimoto, D.; Myer, G.D.; Barber Foss, K.D.; Pepin, M.J.; Micheli, L.J.; Hewett, T.E. Critical Components of Neuromuscular Training to Reduce ACL Injury Risk in Female Athletes: Meta-Regression Analysis. *Br. J. Sports Med.* **2016**, doi:10.1136/bjsports-2015-095596.
227. Ericksen, H.M.; Thomas, A.C.; Gribble, P.A.; Armstrong, C.; Rice, M.; Pietrosimone, B. Jump-Landing Biomechanics Following a 4-Week Real-Time Feedback Intervention and Retention. *Clin. Biomech.* **2016**, doi:10.1016/j.clinbiomech.2016.01.005.
228. Moran, J.; Sandercock, G.R.H.; Ramírez-Campillo, R.; Meylan, C.; Collison, J.; Parry, D.A. Age-Related Variation in Male Youth Athletes' Countermovement Jump Following Plyometric Training. *J. Strength Cond. Res.* **2016**, doi:10.1519/jsc.0000000000001444.
229. Van Dyk, N.; Behan, F.P.; Whiteley, R. Including the Nordic Hamstring Exercise in Injury Prevention Programmes Halves the Rate of Hamstring Injuries: A Systematic Review and Meta-Analysis of 8459 Athletes. *Br. J. Sports Med.* **2019**, doi:10.1136/bjsports-2018-100045.
230. Kenneally-Dabrowski, C.J.B.; Brown, N.A.T.; Lai, A.K.M.; Perriman, D.; Spratford, W.; Serpell, B.G. Late Swing or Early Stance? A Narrative Review of Hamstring Injury Mechanisms during High-Speed Running. *Scand. J. Med. Sci. Sports* **2019**, doi:10.1111/sms.13437.
231. Higashihara, A.; Nagano, Y.; Ono, T.; Fukubayashi, T. Differences in Hamstring Activation Characteristics between the Acceleration and Maximum-Speed Phases of Sprinting. *J. Sports Sci.* **2018**, doi:10.1080/02640414.2017.1375548.
232. Higashihara, A.; Nagano, Y.; Ono, T.; Fukubayashi, T. Differences in Activation Properties of the Hamstring Muscles during Overground Sprinting. *Gait Posture* **2015**, doi:10.1016/j.gaitpost.2015.07.002.
233. Schache, A.G.; Dorn, T.W.; Wrigley, T.V.; Brown, N.A.T.; Pandy, M.G. Stretch and Activation of the Human Biarticular Hamstrings across a Range of Running Speeds. *Eur. J. Appl. Physiol.* **2013**, doi:10.1007/s00421-013-2713-9.
234. Guex, K.; Millet, G.P. Conceptual Framework for Strengthening Exercises to Prevent Hamstring Strains. *Sports Med.* **2013**, doi:10.1007/s40279-013-0097-y.
235. Chaabene, H.; Negra, Y.; Moran, J.; Prieske, O.; Sammoud, S.; Ramirez-Campillo, R.; Granacher, U. Effects of an Eccentric Hamstrings Training on Components of Physical Performance in Young Female Handball Players. *Int. J. Sports Physiol. Perform.* **2019**, *1*, 1–22, doi:10.1123/ijsp.2019-0005.
236. Markovic, G.; Sarabon, N.; Boban, F.; Zoric, I.; Jelcic, M.; Sos, K.; Scappaticci, M. Nordic Hamstring Strength of Highly Trained Youth Football Players and Its Relation to Sprint Performance. *J. Strength Cond. Res.* **2018**, doi:10.1519/jsc.0000000000002800.
237. Kilding, A.E.; Tunstall, H.; Kuzmic, D. Suitability of FIFA's "The 11" Training Programme for Young Football Players—Impact on Physical Performance. *J. Sport. Sci. Med.* **2008**, *7*, 320.
238. Hegyi, A.; Csala, D.; Péter, A.; Finni, T.; Cronin, N.J. High-Density Electromyography Activity in Various Hamstring Exercises. *Scand. J. Med. Sci. Sport.* **2019**, doi:10.1111/sms.13303.
239. Bourne, M.N.; Williams, M.D.; Opar, D.A.; Al Najjar, A.; Kerr, G.K.; Shield, A.J. Impact of Exercise Selection on Hamstring Muscle Activation. *Br. J. Sports Med.* **2017**, doi:10.1136/bjsports-2015-095739.

240. Tsaklis, P.; Malliaropoulos, N.; Mendiguchia, J.; Korakakis, V.; Tsapralis, K.; Pyne, D.; Malliaras, P. Muscle and Intensity Based Hamstring Exercise Classification in Elite Female Track and Field Athletes: Implications for Exercise Selection during Rehabilitation. *Open Access J. Sport. Med.* **2015**, doi:10.2147/OAJSM.S79189.
241. Valle, X.; Malliaropoulos, N.; Párraga Botero, J.D.; Bikos, G.; Pruna, R.; Mónaco, M.; Maffulli, N. Hamstring and Other Thigh Injuries in Children and Young Athletes. *Scand. J. Med. Sci. Sport.* **2018**, doi:10.1111/sms.13282.
242. Drury, B.; Green, T.; Ramírez-Campillo, R.; Moran, J. Influence of Maturation Status on Eccentric Hamstring Strength Improvements in Youth Male Soccer Players following the Nordic Hamstring Exercise. *IJSP* **2019**, in press.
243. Owoeye, O.B.A.; Akinbo, S.R.A.; Tella, B.A.; Olawale, O.A. Efficacy of the FIFA 11+ Warm-up Programme in Male Youth Football: A Cluster Randomised Controlled Trial. *J. Sport. Sci. Med.* **2014**, *13*, 321.
244. Hislop, M.D.; Stokes, K.A.; Williams, S.; McKay, C.D.; England, M.; Kemp, S.P.T.; Trewartha, G. The Efficacy of a Movement Control Exercise Programme to Reduce Injuries in Youth Rugby: A Cluster Randomised Controlled Trial. *BMJ Open Sport Exerc. Med.* **2016**, doi:10.1136/bmjsem-2015-000043.
245. Achenbach, L.; Krutsch, V.; Weber, J.; Nerlich, M.; Luig, P.; Loose, O.; Angele, P.; Krutsch, W. Neuromuscular Exercises Prevent Severe Knee Injury in Adolescent Team Handball Players. *Knee Surg. Sport. Traumatol. Arthrosc.* **2018**, doi:10.1007/s00167-017-4758-5.
246. Forrest, M.R.L.; Scott, B.R.; Hebert, J.J.; Dempsey, A.R. Injury Prevention Strategies for Adolescent Cricket Pace Bowlers. *Sports Med.* **2018**, doi:10.1007/s40279-018-0981-6.
247. Reis, I.; Rebelo, A.; Krustup, P.; Brito, J. Performance Enhancement Effects of Fédération Internationale de Football Association's "the 11+" Injury Prevention Training Program in Youth Futsal Players. *Clin. J. Sport Med.* **2013**, doi:10.1097/JSM.0b013e318285630e.
248. Peek, K.; Gatherer, D.; Bennett, K.J.M.; Fransen, J.; Watsford, M. Muscle Strength Characteristics of the Hamstrings and Quadriceps in Players from a High-Level Youth Football (Soccer) Academy. *Res. Sport. Med.* **2018**, doi:10.1080/15438627.2018.1447475.
249. Franchi, M.V.; Ellenberger, L.; Javet, M.; Bruhin, B.; Romann, M.; Frey, W.O.; Spörri, J. Maximal Eccentric Hamstrings Strength in Competitive Alpine Skiers: Cross-Sectional Observations from Youth to Elite Level. *Front. Physiol.* **2019**, doi:10.3389/fphys.2019.00088.
250. Roe, M.; Malone, S.; Delahunt, E.; Collins, K.; Gissane, C.; Persson, U.M.C.; Murphy, J.C.; Blake, C. Eccentric Knee Flexor Strength Profiles of 341 Elite Male Academy and Senior Gaelic Football Players: Do Body Mass and Previous Hamstring Injury Impact Performance? *Phys. Ther. Sport.* **2018**, doi:10.1016/j.ptsp.2018.01.006.
251. Ellenbecker, T.S.; Roetert, E.P.; Sueyoshi, T.; Riewald, S. A Descriptive Profile of Age-Specific Knee Extension Flexion Strength in Elite Junior Tennis Players. *Br. J. Sports Med.* **2007**, doi:10.1136/bjism.2007.037085.
252. Gerodimos, V.; Mandou, V.; Zafeiridis, A.; Ioakimidis, P. Isokinetic peak torque and hamstring/quadriceps ratios in young basketball players: Effects of age, velocity, and action mode. *J. Sports Med. Phys. Fit.* **2003**, *43*, 444.
253. Sugimoto, D.; Borg, D.R.; Brilliant, A.N.; Meehan, W.P.; Micheli, L.J.; Geminiani, E.T. Effect of Sports and Growth on Hamstrings and Quadriceps Development in Young Female Athletes: Cross-Sectional Study. *Sports* **2019**, doi:10.3390/sports7070158.
254. Forbes, H.; Bullers, A.; Lovell, A.; McNaughton, L.R.; Polman, R.C.; Siegler, J.C. Relative Torque Profiles of Elite Male Youth Footballers: Effects of Age and Pubertal Development. *Int. J. Sports Med.* **2009**, doi:10.1055/s-0029-1202817.
255. Holm, I.; Steen, H.; Olstad, M. Isokinetic Muscle Performance in Growing Boys from Pre-Teen to Maturity. An Eleven-Year Longitudinal Study. *Isokinet. Exerc. Sci.* **2005**, *13*, 153–158.
256. Buchanan, P.A.; Vardaxis, V.G. Sex-Related and Age-Related Differences in Knee Strength of Basketball Players Ages 11-17 Years. *J. Athl. Train.* **2003**, *38*, 231.
257. Kellis, S.; Gerodimos, V.; Kellis, E.; Manou, V. Bilateral Isokinetic Concentric and Eccentric Strength Profiles of the Knee Extensors and Flexors in Young Soccer Players. *Isokinet. Exerc. Sci.* **2001**, *9*, 31–39.
258. Holm, I.; Vøllestad, N. Significant Effect of Gender on Hamstring-to-Quadriceps Strength Ratio and Static Balance in Prepubescent Children from 7 to 12 Years of Age. *Am. J. Sports Med.* **2008**, doi:10.1177/0363546508317963.

259. Wild, C.Y.; Steele, J.R.; Munro, B.J. Insufficient Hamstring Strength Compromises Landing Technique in Adolescent Girls. *Med. Sci. Sports Exerc.* **2013**, doi:10.1249/MSS.0b013e31827772f6.
260. Bencke, J.; Curtis, D.; Kroghshede, C.; Jensen, L.K.; Bandholm, T.; Zebis, M.K. Biomechanical Evaluation of the Side-Cutting Manoeuvre Associated with ACL Injury in Young Female Handball Players. *Knee Surg. Sport. Traumatol. Arthrosc.* **2013**, doi:10.1007/s00167-012-2199-8.
261. Salci, Y.; Yildirim, A.; Celik, O.; Ak, E.; Kocak, S.; Korkusuz, F. The Effects of Eccentric Hamstring Training on Lower Extremity Strength and Landing Kinetics in Recreational Female Athletes. *Isokinet. Exerc. Sci.* **2013**, doi:10.3233/IES-2012-0466.
262. Anastasi, S.M.; Hamzeh, M.A. Does the Eccentric Nordic Hamstring Exercise Have an Effect on Isokinetic Muscle Strength Imbalance and Dynamic Jumping Performance in Female Rugby Union Players? *Isokinet. Exerc. Sci.* **2011**, doi:10.3233/IES-2011-0420.
263. Read, P.J.; Jimenez, P.; Oliver, J.L.; Lloyd, R.S. Injury Prevention in Male Youth Soccer: Current Practices and Perceptions of Practitioners Working at Elite English Academies. *J. Sports Sci.* **2018**, doi:10.1080/02640414.2017.1389515.
264. Forbes, H.; Sutcliffe, S.; Lovell, A.; McNaughton, L.R.; Siegler, J.C. Isokinetic Thigh Muscle Ratios in Youth Football: Effect of Age and Dominance. *Int. J. Sports Med.* **2009**, doi:10.1055/s-0029-1202337.
265. Goode, A.P.; Reiman, M.P.; Harris, L.; DeLisa, L.; Kauffman, A.; Beltramo, D.; Poole, C.; Ledbetter, L.; Taylor, A.B. Eccentric Training for Prevention of Hamstring Injuries May Depend on Intervention Compliance: A Systematic Review and Meta-Analysis. *Br. J. Sports Med.* **2015**, doi:10.1136/bjsports-2014-093466.
266. Tansel, R.B.; Salci, Y.; Yildirim, A.; Kocak, S.; Korkusuz, F. Effects of eccentric hamstring strength training on lower extremity strength of 10–12-year-old male basketball players. *Isokinet. Exerc. Sci.* **2008**, *16*, 81–85.
267. Oakley, A.J.; Jennings, J.; Bishop, C.J. Holistic Hamstring Health: Not Just the Nordic Hamstring Exercise. *Br. J. Sports Med.* **2018**, doi:10.1136/bjsports-2016-097137.
268. Śliwowski, R.; Jadczyk, Ł.; Hejna, R.; Wiczorek, A. The Effects of Individualized Resistance Strength Programs on Knee Muscular Imbalances in Junior Elite Soccer Players. *PLoS ONE* **2015**, doi:10.1371/journal.pone.0144021.
269. Duarte, J.P.; Valente-Dos-Santos, J.; Coelho-E-Silva, M.J.; Malina, R.M.; Deprez, D.; Philippaerts, R.; Lenoir, M.; Vaeyens, R. Developmental Changes in Isometric Strength: Longitudinal Study in Adolescent Soccer Players. *Int. J. Sports Med.* **2018**, doi:10.1055/s-0044-100389.
270. Freeman, B.W.; Young, W.B.; Talpey, S.W.; Smyth, A.M.; Pane, C.L.; Carlon, T.A. The Effects of Sprint Training and the Nordic Hamstring Exercise on Eccentric Hamstring Strength and Sprint Performance in Adolescent Athletes. *J. Sports Med. Phys. Fitness.* **2019**, doi:10.23736/s0022-4707.18.08703-0.
271. Guex, K.; Degache, F.; Morisod, C.; Saily, M.; Millet, G.P. Hamstring Architectural and Functional Adaptations Following Long vs. Short Muscle Length Eccentric Training. *Front. Physiol.* **2016**, doi:10.3389/fphys.2016.00340.
272. Eustace, S.J.; Page, R.M.; Greig, M. Angle-Specific Isokinetic Metrics Highlight Strength Training Needs of Elite Youth Soccer Players. *J. Strength Cond. Res.* **2018**, doi:10.1519/jsc.0000000000002612.
273. Eustace, S.J.; Page, R.M.; Greig, M. Isokinetic Strength Differences between Elite Senior and Youth Female Soccer Players Identifies Training Requirements. *Phys. Ther. Sport.* **2019**, doi:10.1016/j.ptsp.2019.06.008.
274. Timmins, R.G.; Bourne, M.N.; Shield, A.J.; Williams, M.D.; Lorenzen, C.; Opar, D.A. Short Biceps Femoris Fascicles and Eccentric Knee Flexor Weakness Increase the Risk of Hamstring Injury in Elite Football (Soccer): A Prospective Cohort Study. *Br. J. Sports Med.* **2016**, doi:10.1136/bjsports-2015-095362.
275. Potier, T.G.; Alexander, C.M.; Seynnes, O.R. Effects of Eccentric Strength Training on Biceps Femoris Muscle Architecture and Knee Joint Range of Movement. *Eur. J. Appl. Physiol.* **2009**, doi:10.1007/s00421-008-0980-7.
276. Baroni, B.M.; Geremia, J.M.; Rodrigues, R.; De Azevedo Franke, R.; Karamanidis, K.; Vaz, M.A. Muscle Architecture Adaptations to Knee Extensor Eccentric Training: Rectus Femoris vs. Vastus Lateralis. *Muscle Nerve* **2013**, doi:10.1002/mus.23785.
277. Duclay, J.; Martin, A.; Duclay, A.; Cometti, G.; Pousson, M. Behavior of Fascicles and the Myotendinous Junction of Human Medial Gastrocnemius Following Eccentric Strength Training. *Muscle Nerve Off. J. Am. Assoc. Electrodiagn. Med.* **2009**, *39*, 819–827. doi:10.1002/mus.21297.

278. Presland, J.D.; Timmins, R.G.; Bourne, M.N.; Williams, M.D.; Opar, D.A. The Effect of Nordic Hamstring Exercise Training Volume on Biceps Femoris Long Head Architectural Adaptation. *Scand. J. Med. Sci. Sport.* **2018**, doi:10.1111/sms.13085.
279. Timmins, R.G.; Ruddy, J.D.; Presland, J.; Maniar, N.; Shield, A.J.; Williams, M.D.; Opar, D.A. Architectural Changes of the Biceps Femoris Long Head after Concentric or Eccentric Training. *Med. Sci. Sports Exerc.* **2016**, doi:10.1249/MSS.0000000000000795.
280. Alonso-Fernandez, D.; Docampo-Blanco, P.; Martinez-Fernandez, J. Changes in Muscle Architecture of Biceps Femoris Induced by Eccentric Strength Training with Nordic Hamstring Exercise. *Scand. J. Med. Sci. Sport.* **2018**, doi:10.1111/sms.12877.
281. Lacome, M.; Avrillon, S.; Cholley, Y.; Simpson, B.M.; Guilhem, G.; Buchheit, M. Hamstring Eccentric Strengthening Program: Does Training Volume Matter? *Int. J. Sports Physiol. Perform.* **2019**, doi:10.1123/ijsp.2018-0947.
282. Ribeiro-Alvares, J.B.; Marques, V.B.; Vaz, M.A.; Baroni, B.M. Four Weeks of Nordic Hamstring Exercise Reduce Muscle Injury Risk Factors in Young Adults. *J. Strength Cond. Res.* **2018**, doi:10.1519/JSC.0000000000001975.
283. Morse, C.I.; Tolfrey, K.; Thom, J.M.; Vassilopoulos, V.; Maganaris, C.N.; Narici, M.V. Gastrocnemius Muscle Specific Force in Boys and Men. *J. Appl. Physiol.* **2008**, doi:10.1152/jap.00697.2007.
284. Kubo, K.; Kanehisa, H.; Kawakami, Y.; Fukunaga, T. Growth Changes in the Elastic Properties of Human Tendon Structures. *Int. J. Sports Med.* **2001**, doi:10.1055/s-2001-11337.
285. Buchheit, M.; Cholley, Y.; Nagel, M.; Poulos, N. The Effect of Body Mass on Eccentric Knee-Flexor Strength Assessed with an Instrumented Nordic Hamstring Device (Nordbord) in Football Players. *Int. J. Sports Physiol. Perform.* **2016**, *11*, 721–726, doi:10.1123/ijsp.2015-0513.
286. Pollard, C.W.; Opar, D.A.; Williams, M.D.; Bourne, M.N.; Timmins, R.G. Razor Hamstring Curl and Nordic Hamstring Exercise Architectural Adaptations: Impact of Exercise Selection and Intensity. *Scand. J. Med. Sci. Sport.* **2019**, doi:10.1111/sms.13381.
287. Lovell, R.; Knox, M.; Weston, M.; Siegler, J.C.; Brennan, S.; Marshall, P.W.M. Hamstring Injury Prevention in Soccer: Before or after Training? *Scand. J. Med. Sci. Sport.* **2018**, doi:10.1111/sms.12925.
288. Moir, G.L.; Erny, K.F.; Davis, S.E.; Guers, J.J.; Witmer, C.A. The Development of a Repetition-Load Scheme for the Eccentric-Only Bench Press Exercise. *J. Hum. Kinet.* **2013**, doi:10.2478/hukin-2013-0042.
289. Hahn, D. Stretching the Limits of Maximal Voluntary Eccentric Force Production in Vivo. *J. Sport Heal. Sci.* **2018**, doi:10.1016/j.jshs.2018.05.003.
290. Westing, S.H.; Seger, J.Y.; Karlson, E.; Ekblom, B. Eccentric and Concentric Torque-Velocity Characteristics of the Quadriceps Femoris in Man. *Eur. J. Appl. Physiol. Occup. Physiol.* **1988**, doi:10.1007/BF00636611.
291. Wagle, J.P.; Cunanán, A.J.; Carroll, K.M.; Sams, M.L.; Wetmore, A.; Bingham, G.E.; Taber, C.B.; DeWeese, B.H.; Sato, K.; Stuart, C.A.; et al. Accentuated Eccentric Loading and Cluster Set Configurations in the Back Squat. *J. Strength Cond. Res.* **2018**, doi:10.1519/jsc.0000000000002677.
292. Martinez-Aranda, L.M.; Fernandez-Gonzalo, R. Effects of Inertial Setting on Power, Force, Work, and Eccentric Overload during Flywheel Resistance Exercise in Women and Men. *J. Strength Cond. Res.* **2017**, doi:10.1519/JSC.0000000000001635.
293. Festa, L.; Tarperi, C.; Skroce, K.; Boccia, G.; Lippi, G.; La Torre, A.; Schena, F. Effects of Flywheel Strength Training on the Running Economy of Recreational Endurance Runners. *J. Strength Cond. Res.* **2019**, doi:10.1519/JSC.0000000000002973.
294. Suarez-Arrones, L.; Lara-Lopez, P.; Torreno, N.; Saez de Villarreal, E.; Di Salvo, V.; Mendez-Villanueva, A. Effects of Strength Training on Body Composition in Young Male Professional Soccer Players. *Sports* **2019**, doi:10.3390/sports7050104.
295. Norrbrand, L.; Pozzo, M.; Tesch, P.A. Flywheel Resistance Training Calls for Greater Eccentric Muscle Activation than Weight Training. *Eur. J. Appl. Physiol.* **2010**, doi:10.1007/s00421-010-1575-7.
296. Norrbrand, L.; Tous-Fajardo, J.; Vargas, R.; Tesch, P.A. Quadriceps Muscle Use in the Flywheel and Barbell Squat. *Aviat. Sp. Environ. Med.* **2011**, doi:10.3357/ASEM.2867.2011.
297. Cuenca-Fernández, F.; López-Contreras, G.; Mourão, L.; de Jesus, K.; de Jesus, K.; Zacca, R.; Vilas-Boas, J.P.; Fernandes, R.J.; Arellano, R. Eccentric Flywheel Post-Activation Potentiation Influences Swimming Start Performance Kinetics. *J. Sports Sci.* **2019**, doi:10.1080/02640414.2018.1505183.

298. Cuenca-Fernández, F.; López-Contreras, G.; Arellano, R. Effect on Swimming Start Performance of Two Types of Activation Protocols: Lunge and YoYo Squat. *J. Strength Cond. Res.* **2015**, doi:10.1519/JSC.0000000000000696.
299. Beato, M.; Stiff, A.; Coratella, G. Effects of Postactivation Potentiation After an Eccentric Overload Bout on Countermovement Jump and Lower-Limb Muscle Strength. *J. Strength Cond. Res.* **2019**, doi:10.1519/jsc.0000000000003005.
300. Beato, M.; De Keijzer, K.L.; Leskuskas, Z.; Allen, W.J.; Dello Iacono, A.; McErlain-Naylor, S.A. Effect of Postactivation Potentiation After Medium vs. High Inertia Eccentric Overload Exercise on Standing Long Jump, Countermovement Jump, and Change of Direction Performance. *J. Strength Cond. Res.* **2019**, doi:10.1519/jsc.0000000000003214.
301. Lundberg, T.R.; García-Gutiérrez, M.T.; Mandić, M.; Lilja, M.; Fernandez-Gonzalo, R. Regional and Muscle-Specific Adaptations in Knee Extensor Hypertrophy Using Flywheel versus Conventional Weight-Stack Resistance Exercise. *Appl. Physiol. Nutr. Metab.* **2019**, doi:10.1139/apnm-2018-0774.
302. Illera-Domínguez, V.; Nuell, S.; Carmona, G.; Padullés, J.M.; Padullés, X.; Lloret, M.; Cussó, R.; Alomar, X.; Cadefau, J.A. Early Functional and Morphological Muscle Adaptations during Short-Term Inertial-Squat Training. *Front. Physiol.* **2018**, doi:10.3389/fphys.2018.01265.
303. Seynnes, O.R.; De Boer, M.; Narici, M.V. Early Skeletal Muscle Hypertrophy and Architectural Changes in Response to High-Intensity Resistance Training. *J. Appl. Physiol.* **2007**, doi:10.1152/jappphysiol.00789.2006.
304. Tesch, P.A.; Ekberg, A.; Lindquist, D.M.; Trieschmann, J.T. Muscle Hypertrophy Following 5-Week Resistance Training Using a Non-Gravity-Dependent Exercise System. *Acta Physiol. Scand.* **2004**, doi:10.1046/j.0001-6772.2003.01225.x.
305. Tous-Fajardo, J.; Gonzalo-Skok, O.; Arjol-Serrano, J.L.; Tesch, P. Enhancing Change-of-Direction Speed in Soccer Players by Functional Inertial Eccentric Overload and Vibration Training. *Int. J. Sports Physiol. Perform.* **2016**, doi:10.1123/ijsspp.2015-0010.
306. Maroto-Izquierdo, S.; García-López, D.; De Paz, J.A. Functional and Muscle-Size Effects of Flywheel Resistance Training with Eccentric-Overload in Professional Handball Players. *J. Hum. Kinet.* **2017**, doi:10.1515/hukin-2017-0096.
307. Naczk, M.; Naczk, A.; Brzenczek-Owczarzak, W.; Arlet, J.; Adach, Z. Impact of Inertial Training on Strength and Power Performance in Young Active Men. *J. Strength Cond. Res.* **2016**, doi:10.1097/JSC.0000000000000217.
308. Sabido, R.; Pombero, L.; Hernández-Davó, J.L. Differential effects of low vs high inertial loads during an eccentric-overload training intervention in rugby union players: A preliminary study. *J. Sports Med. Phys. Fit.* **2019**, doi:10.23736/S0022-4707.19.09425-8.
309. Fernandez-Gonzalo, R.; Lundberg, T.R.; Alvarez-Alvarez, L.; De Paz, J.A. Muscle Damage Responses and Adaptations to Eccentric-Overload Resistance Exercise in Men and Women. *Eur. J. Appl. Physiol.* **2014**, doi:10.1007/s00421-014-2836-7.
310. De Hoyo, M.; De La Torre, A.; Pradas, F.; Sañudo, B.; Carrasco, L.; Mateo-Cortes, J.; Domínguez-Cobo, S.; Fernandes, O.; Gonzalo-Skok, O. Effects of Eccentric Overload Bout on Change of Direction and Performance in Soccer Players. *Int. J. Sports Med.* **2015**, doi:10.1055/s-0034-1395521.
311. Horwath, O.; Paulsen, G.; Esping, T.; Seynnes, O.; Olsson, M.C. Isokinetic resistance training combined with eccentric overload improves athletic performance and induces muscle hypertrophy in young ice hockey players. *J. Sci. Med. Sport* **2019**, *22*, 821–826, doi:10.1016/j.jsams.2018.12.017.
312. Harper, D.J.; Jordan, A.R.; Kiely, J. Relationships Between Eccentric and Concentric Knee Strength Capacities and Maximal Linear Deceleration Ability in Male Academy Soccer Players. *J. Strength Cond. Res.* **2018**, doi:10.1519/jsc.0000000000002739.
313. Dos'Santos, T.; Thomas, C.; Jones, P.A.; Comfort, P. Mechanical Determinants of Faster Change of Direction Speed Performance in Male Athletes. *J. Strength Cond. Res.* **2017**, doi:10.1519/JSC.0000000000001535.
314. Spiteri, T.; Newton, R.U.; Binetti, M.; Hart, N.H.; Sheppard, J.M.; Nimphius, S. Mechanical Determinants of Faster Change of Direction and Agility Performance in Female Basketball Athletes. *J. Strength Cond. Res.* **2015**, doi:10.1519/JSC.0000000000000876.
315. Meyers, R.W.; Oliver, J.L.; Hughes, M.G.; Cronin, J.B.; Lloyd, R.S. Maximal Sprint Speed in Boys of Increasing Maturity. *Pediatr. Exerc. Sci.* **2015**, doi:10.1123/pes.2013-0096.

316. McCunn, R.; Weston, M.; Hill, J.K.A.; Johnston, R.D.; Gibson, N.V. Influence of Physical Maturity Status on Sprinting Speed among Youth Soccer Players. *J. Strength Cond. Res.* **2017**, doi:10.1519/JSC.0000000000001654.
317. Rumpf, M.C.; Cronin, J.B.; Oliver, J.; Hughes, M. Kinematics and Kinetics of Maximum Running Speed in Youth across Maturity. *Pediatr. Exerc. Sci.* **2015**, doi:10.1123/pes.2014-0064.
318. Emmonds, S.; Morris, R.; Murray, E.; Robinson, C.; Turner, L.; Jones, B. The Influence of Age and Maturity Status on the Maximum and Explosive Strength Characteristics of Elite Youth Female Soccer Players. *Sci. Med. Footb.* **2017**, doi:10.1080/24733938.2017.1363908.
319. Meylan, C.M.P.; Cronin, J.B.; Oliver, J.L.; Hopkins, W.G.; Contreras, B. The Effect of Maturation on Adaptations to Strength Training and Detraining in 11-15-Year-Olds. *Scand. J. Med. Sci. Sport.* **2014**, *24*, doi:10.1111/sms.12128.
320. Murtagh, C.F.; Brownlee, T.E.; O'Boyle, A.; Morgans, R.; Drust, B.; Erskine, R.M. Importance of Speed and Power in Elite Youth Soccer Depends on Maturation Status. *J. Strength Cond. Res.* **2018**, doi:10.1519/JSC.0000000000002367.
321. Brownlee, T.E.; Murtagh, C.F.; Naughton, R.J.; Whitworth-Turner, C.M.; O'Boyle, A.; Morgans, R.; Morton, J.P.; Erskine, R.M.; Drust, B. Isometric Maximal Voluntary Force Evaluated Using an Isometric Mid-Thigh Pull Differentiates English Premier League Youth Soccer Players from a Maturity-Matched Control Group. *Sci. Med. Footb.* **2018**, doi:10.1080/24733938.2018.1432886.
322. Morris, R.O.; Jones, B.; Myers, T.; Lake, J.; Emmonds, S.; Clarke, N.D.; Singleton, D.; Ellis, M.; Till, K. Isometric Midthigh Pull Characteristics in Elite Youth Male Soccer Players: Comparisons by Age and Maturity Offset. *J. Strength Cond. Res.* **2018**, doi:10.1519/JSC.0000000000002673.
323. Vanrenterghem, J.; Venables, E.; Pataky, T.; Robinson, M.A. The Effect of Running Speed on Knee Mechanical Loading in Females during Side Cutting. *J. Biomech.* **2012**, doi:10.1016/j.jbiomech.2012.06.029.
324. Mirwald, R.L.; Baxter-Jones, A.D.G.; Bailey, D.A.; Beunen, G.P. An Assessment of Maturity from Anthropometric Measurements. *Med. Sci. Sports Exerc.* **2002**, *34*, 689–694.
325. Howard, S.M.A.; Cumming, S.P.; Atkinson, M.; Malina, R.M. Biological Maturity-Associated Variance in Peak Power Output and Momentum in Academy Rugby Union Players. *Eur. J. Sport Sci.* **2016**, doi:10.1080/17461391.2016.1205144.
326. Petré, H.; Wernstål, F.; Mattsson, C.M. Effects of Flywheel Training on Strength-Related Variables: A Meta-Analysis. *Sport. Med. Open* **2018**, doi:10.1186/s40798-018-0169-5.
327. Seger, J.Y.; Thorstensson, A. Muscle Strength and Myoelectric Activity in Prepubertal and Adult Males and Females. *Eur. J. Appl. Physiol. Occup. Physiol.* **1994**, doi:10.1007/BF00867932.
328. Carroll, K.M.; Wagle, J.P.; Sato, K.; Taber, C.B.; Yoshida, N.; Bingham, G.E.; Stone, M.H. Characterising Overload in Inertial Flywheel Devices for Use in Exercise Training. *Sport. Biomech.* **2019**, doi:10.1080/14763141.2018.1433715.
329. Martinez-Aranda, L.M.; Fernandez-Gonzalo, R. Effects of Inertial Setting on Power, Force, Work, and Eccentric Overload during Flywheel Resistance Exercise in Women and Men. *J. Strength Cond. Res.* **2017**, doi:10.1519/JSC.0000000000001635.
330. Sabido, R.; Hernández-Davó, J.L.; Pereyra-Gerber, G.T. Influence of Different Inertial Loads on Basic Training Variables during the Flywheel Squat Exercise. *Int. J. Sports Physiol. Perform.* **2018**, doi:10.1123/ijsp.2017-0282.
331. Piqueras-Sanchiz, F.; Martín-Rodríguez, S.; Martínez-Aranda, L.M.; Lopes, T.R.; Raya-González, J.; García-García, Ó.; Nakamura, F.Y. Effects of Moderate vs. High Iso-Inertial Loads on Power, Velocity, Work and Hamstring Contractile Function after Flywheel Resistance Exercise. *PLoS ONE* **2019**, doi:10.1371/journal.pone.0211700.
332. Simpson, M.; Rio, E.; Cook, J. At What Age Do Children and Adolescents Develop Lower Limb Tendon Pathology or Tendinopathy? A Systematic Review and Meta-Analysis. *Sports Med.* **2016**, doi:10.1007/s40279-015-0438-0.
333. Hagglund, M.; Walden, M.; Zwerver, J.; Ekstrand, J. Epidemiology of Patellar Tendon Injury in Elite Male Soccer Players. *Br. J. Sports Med.* **2011**, doi:10.1136/bjism.2011.084038.41.
334. Le Gall, F.; Carling, C.; Reilly, T.; Vandewalle, H.; Church, J.; Rochcongar, P. Incidence of Injuries in Elite French Youth Soccer Players: A 10-Season Study. *Am. J. Sports Med.* **2006**, doi:10.1177/0363546505283271.
335. Patel, D.R.; Villalobos, A. Evaluation and Management of Knee Pain in Young Athletes: Overuse Injuries of the Knee. *Transl. Pediatr.* **2017**, doi:10.21037/tp.2017.04.05.

336. Cassel, M.; Intziagianni, K.; Risch, L.; Müller, S.; Engel, T.; Mayer, F. Physiological tendon thickness adaptation in adolescent elite athletes: A longitudinal study. *Front. Physiol.* **2017**, *8*, 795, doi:10.3389/fphys.2017.00795.
337. Cassel, M.; Carlsohn, A.; Fröhlich, K.; John, M.; Riegels, N.; Mayer, F. Tendon Adaptation to Sport-Specific Loading in Adolescent Athletes. *Int. J. Sports Med.* **2015**, doi:10.1055/s-0035-1559772.
338. Cassel, M.; Baur, H.; Hirschmüller, A.; Carlsohn, A.; Fröhlich, K.; Mayer, F. Prevalence of Achilles and Patellar Tendinopathy and Their Association to Intratendinous Changes in Adolescent Athletes. *Scand. J. Med. Sci. Sport.* **2015**, doi:10.1111/sms.12318.
339. Cassel, M.; Risch, L.; Intziagianni, K.; Mueller, J.; Stoll, J.; Brecht, P.; Mayer, F. Incidence of Achilles and patellar tendinopathy in adolescent elite athletes. *Int. J. Sports Med.* **2018**, *39*, 726–732, doi:10.1055/a-0633-9098.
340. O'Brien, T.D.; Reeves, N.D.; Baltzopoulos, V.; Jones, D.A.; Maganaris, C.N. Mechanical Properties of the Patellar Tendon in Adults and Children. *J. Biomech.* **2010**, doi:10.1016/j.jbiomech.2009.11.028.
341. Rudavsky, A.; Cook, J.L.; Docking, S. Proximal Patellar Tendon Pathology Can Develop during Adolescence in Young Ballet Dancers—A 2-Year Longitudinal Study. *Scand. J. Med. Sci. Sport.* **2018**, doi:10.1111/sms.13095.
342. Mersmann, F.; Bohm, S.; Schroll, A.; Boeth, H.; Duda, G.N.; Arampatzis, A. Muscle and Tendon Adaptation in Adolescent Athletes: A Longitudinal Study. *Scand. J. Med. Sci. Sport.* **2017**, doi:10.1111/sms.12631.
343. Mersmann, F.; Bohm, S.; Schroll, A.; Boeth, H.; Duda, G.; Arampatzis, A. Evidence of Imbalanced Adaptation between Muscle and Tendon in Adolescent Athletes. *Scand. J. Med. Sci. Sport.* **2014**, doi:10.1111/sms.12166.
344. Pentidis, N.; Mersmann, F.; Bohm, S.; Giannakou, E.; Aggelousis, N.; Arampatzis, A. Triceps Surae Muscle-Tendon Unit Properties in Preadolescent Children: A Comparison of Artistic Gymnastic Athletes and Non-Athletes. *Front. Physiol.* **2019**, doi:10.3389/fphys.2019.00615.
345. Kubo, K.; Ikebukuro, T.; Yata, H.; Tsunoda, N.; Kanehisa, H. Time Course of Changes in Muscle and Tendon Properties during Strength Training and Detraining. *J. Strength Cond. Res.* **2010**, doi:10.1519/JSC.0b013e3181c865e2.
346. Kubo, K.; Ikebukuro, T.; Maki, A.; Yata, H.; Tsunoda, N. Time course of changes in the human Achilles tendon properties and metabolism during training and detraining in vivo. *Eur. J. Appl. Physiol.* **2012**, *112*, 2679–2691.
347. Mersmann, F.; Bohm, S.; Arampatzis, A. Imbalances in the Development of Muscle and Tendon as Risk Factor for Tendinopathies in Youth Athletes: A Review of Current Evidence and Concepts of Prevention. *Front. Physiol.* **2017**, doi:10.3389/fphys.2017.00987.
348. Mersmann, F.; Pentidis, N.; Tsai, M.-S.; Schroll, A.; Arampatzis, A. Patellar Tendon Strain Associates to Tendon Structural Abnormalities in Adolescent Athletes. *Front. Physiol.* **2019**, doi:10.3389/fphys.2019.00963.
349. Charcharis, G.; Mersmann, F.; Bohm, S.; Arampatzis, A. Morphological and Mechanical Properties of the Quadriceps Femoris Muscle-Tendon Unit from Adolescence to Adulthood: Effects of Age and Athletic Training. *Front. Physiol.* **2019**, doi:10.3389/fphys.2019.01082.
350. Waugh, C.M.; Blazeovich, A.J.; Fath, F.; Korff, T. Age-Related Changes in Mechanical Properties of the Achilles Tendon. *J. Anat.* **2012**, doi:10.1111/j.1469-7580.2011.01461.x.
351. Waugh, C.M.; Korff, T.; Fath, F.; Blazeovich, A.J. Effects of Resistance Training on Tendon Mechanical Properties and Rapid Force Production in Prepubertal Children. *J. Appl. Physiol.* **2014**, doi:10.1152/jappphysiol.00325.2014.
352. Lee, W.-C.; Ng, G.Y.-F.; Zhang, Z.-J.; Malliaras, P.; Masci, L.; Fu, S.-N. Changes on Tendon Stiffness and Clinical Outcomes in Athletes Are Associated with Patellar Tendinopathy After Eccentric Exercise. *Clin. J. Sport Med.* **2017**, doi:10.1097/jsm.0000000000000562.
353. Geremia, J.M.; Baroni, B.M.; Bobbert, M.F.; Bini, R.R.; Lanferdini, F.J.; Vaz, M.A. Effects of High Loading by Eccentric Triceps Surae Training on Achilles Tendon Properties in Humans. *Eur. J. Appl. Physiol.* **2018**, doi:10.1007/s00421-018-3904-1.
354. Malliaras, P.; Kamal, B.; Nowell, A.; Farley, T.; Dhamu, H.; Simpson, V.; Morrissey, D.; Langberg, H.; Maffulli, N.; Reeves, N.D. Patellar Tendon Adaptation in Relation to Load-Intensity and Action Type. *J. Biomech.* **2013**, doi:10.1016/j.jbiomech.2013.04.022.

355. Frizziero, A.; Vittadini, F.; Fusco, A.; Giombini, A.; Masiero, S. Efficacy of Eccentric Exercise in Lower Limb Tendinopathies in Athletes. *J. Sports Med. Phys. Fit.* **2016**, *56*, 1352–1358.
356. O'Neill, S.; Watson, P.J.; Barry, S. Why are eccentric exercises effective for achilles tendinopathy? *Int. J. Sports Phys. Ther.* **2015**, *10*, 552.
357. Arampatzis, A.; Peper, A.; Bierbaum, S.; Albracht, K. Plasticity of Human Achilles Tendon Mechanical and Morphological Properties in Response to Cyclic Strain. *J. Biomech.* **2010**, doi:10.1016/j.jbiomech.2010.08.014.
358. Bohm, S.; Mersmann, F.; Tettke, M.; Kraft, M.; Arampatzis, A. Human Achilles Tendon Plasticity in Response to Cyclic Strain: Effect of Rate and Duration. *J. Exp. Biol.* **2014**, doi:10.1242/jeb.112268.
359. Kongsgaard, M.; Qvortrup, K.; Larsen, J.; Aagaard, P.; Doessing, S.; Hansen, P.; Kjaer, M.; Magnusson, S.P. Fibril Morphology and Tendon Mechanical Properties in Patellar Tendinopathy. *Am. J. Sports Med.* **2010**, doi:10.1177/0363546509350915.
360. Sanz-López, F.; Berzosa, C.; Hita-Contreras, F.; Martínez-Amat, A. Effects of Eccentric Overload Training on Patellar Tendon and Vastus Lateralis in Three Days of Consecutive Running. *Knee* **2017**, doi:10.1016/j.knee.2017.03.002.
361. Sanz-López, F.; Martínez-Amat, A.; Hita-Contreras, F.; Valero-Campo, C.; Berzosa, C. Thermographic Assessment of Eccentric Overload Training Within Three Days of a Running Session. *J. Strength Cond. Res.* **2016**, doi:10.1519/JSC.0000000000001071.
362. Romero-Rodríguez, D.; Gual, G.; Tesch, P.A. Efficacy of an Inertial Resistance Training Paradigm in the Treatment of Patellar Tendinopathy in Athletes: A Case-Series Study. *Phys. Ther. Sport* **2011**, doi:10.1016/j.ptsp.2010.10.003.
363. Gual, G.; Fort-Vanmeerhaeghe, A.; Romero-Rodríguez, D.; Tesch, P.A. Effects of In-Season Inertial Resistance Training with Eccentric Overload in a Sports Population at Risk for Patellar Tendinopathy. *J. Strength Cond. Res.* **2016**, doi:10.1519/JSC.0000000000001286.
364. Suchomel, T.J.; Wagle, J.P.; Douglas, J.; Taber, C.B.; Harden, M.; Haff, G.G.; Stone, M.H. Implementing Eccentric Resistance Training—Part 2: Practical Recommendations. *J. Funct. Morphol. Kinesiol.* **2019**, doi:10.3390/jfmk4020038.

