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Does maturation influence neuromuscular performance and muscle damage after competitive match-play in youth male soccer players?

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Abstract

Purpose: Poor neuromuscular control and fatigue have been proposed as a risk factor for non-contact injuries especially around peak height velocity (PHV). This study explored the effects of competitive soccer match-play on neuromuscular performance and muscle damage in male youth soccer players.

Methods: 24 youth players aged 13-16y were split into a PHV group (-0.5 to 0.5y) and post PHV group (1.0-2.5y) based on maturity off-set. Leg stiffness, reactive strength index (RSI), muscle activation, creatine kinase (CK), and muscle soreness were determined pre and post a competitive soccer match. Paired t-tests were used to explore differences pre and post competitive match play and independent sample t-tests for between groups differences for all outcome measures.

Results: There were no significant fatigue related change in absolute and relative leg stiffness or muscle activation in both groups, except for the gastrocnemius in the post PHV group. RSI, CK and perceived muscle soreness were significantly different after soccer match-play in both groups with small to large effects observed (ES:0.41-2.82). There were no significant differences between the groups pre match-play except for absolute and relative leg stiffness ($P < 0.001$; ES = 1.16 and 0.63 respectively). No significant differences were observed in the fatigue related responses to competitive match play between groups except for perceived muscle soreness.

Conclusions: The influence of competitive match-play on neuromuscular function and muscle damage is similar in male youth around the time of PHV and those post-PHV indicating that other factors must contribute to the heightened injury risk around PHV.

Keywords: youth, soccer, maturation, muscle damage, neuromuscular, stretch-shortening cycle

Introduction

The high-intensity movements involved in soccer result in a notable increase in injury risk, especially where individual growth and maturation may predispose youth players to a higher risk (Bastos, Vanderlei, Vanderlei, Junior & Pastre 2013; Pakkari, Pasanen, Mattila, Kannus & Rimpela 2008). Injury incidence data has shown an increased risk of injury towards the end of soccer game performance, when fatigue is most likely to be present (Ekstrand, Hagglund & Walden 2009), when children progress through puberty, and specifically at periods of rapid changes in growth and maturation (i.e. peak height velocity)(Rumpf & Cronin 2012; Van der Sluis, Elferink-Gemser, Brink & Visscher 2015). Studies of youth athletes and soccer players have demonstrated that the highest incidence of injury and greatest time loss is in 13-15 y-olds and that injuries of the lower extremities account for 70% to 78% of all injuries (Rumpf & Cronin 2012; Read, Oliver, De Ste Croix, Myer & Lloyd 2017).

There is minimal research on the influence of acute fatigue from competitive match-play on injury risk mechanisms in youth populations. A recent review by Ratel and Martin (2015) suggest that there may be a progressive withdrawal of physiological protection against high intensity exercise induced fatigue during puberty. However, the authors are cautious as they conclude that the effects of fatigue on neuromuscular function during adolescence has scarcely been studied, despite this knowledge being able to contribute to the management of training load and recovery in maturing children (Ratel & Martin 2015).Only a few studies have explored the interaction between chronological age and fatigue on muscular and neuromuscular control and these are mainly based on female players and/or do not explore maturational stage (De Ste Croix, Priestley, Lloyd & Oliver 2017; Lehnert et al. 2017a; Lehnert et al. 2017b). Such studies have also predominantly used simulated rather than competitive match play to explore fatigue related changes in injury risk mechanisms.

There are few studies examining the effects of simulated match-play on muscular and neuromuscular capability in male youth (Lehnert et al., 2017a; Lehnert et al., 2017b) and given the sex differences in the timing and tempo of maturation more studies on boys is warranted. The studies that are available show no significant changes in functional hamstring to quadriceps ratio (H/Q_{FUNC}) but leg stiffness and RSI were compromised. Others have identified that altered leg stiffness due to simulated match play is individualised in youth soccer (Oliver, De Ste Croix, Lloyd & Williams 2014). Therefore it remains to be identified if fatigue related changes in leg stiffness are influenced by maturational stage in male youth soccer players (De Ste Croix, Hughes, Lloyd, Oliver & Read 2017).

A recent 10-year longitudinal study exploring risk factors for ACL injury indicated that low RSI was one of eight significant predictors of ACL injury (Raschner et al., 2012). It is hypothesized that low RSI is indicative of poor stretch-shortening-cycle capability which is probably due to greater muscular latency and thus poor neuromuscular activity. However, there are very few studies dealing with RSI as a result of fatigue (Toumi et al. 2006) and only two studies have focused on youth showing both reduced (Lehnert et al. 2017a) and increased (Lehnert et al. 2017b) RSI after simulated soccer. These conflicting findings may be due to the differing methods used to determine RSI from maximal hopping and a drop jump respectively. No studies appear to have explored changes in RSI following competitive match play or across maturational groups.

Only 2 studies appear to have explored changed in neuromusclar function, using EMG, in young boys following simulated match play (Lehnert et al., 2017a; Lehnert et al., 2017b). Interestingly only medial hamstring and quadriceps muscle activtion was compromised compared to the lateral muscles, suggesting a potential weakness in hip extensors when fatigue is present. Whether these effects are similar after competitive rather than simulated soccer and if the responses are different based on maturational stage remains to be identified.

There are few studies in male youth athletes examining changes in creatine kinase (CK) but there is some suggestion that children are low-CK responders in comparison to adults (Webber et al.1989; Soares et al. 1996; Duarte, 1999). The authors suggest that this blunted CK response might be attributed to similar mechanisms recognised in low adult CK responders i.e the presence of CK inhibitors in the blood, a low CK concentration in the muscle, and a lower clearance of CK by the reticuloendothelial system. One of the problems with the current evidence base surrounding CK in children is the protocols used to induce 'damage/fatigue' are from bouts of downhill running or stepping exercise rather than competitive match play. Therefore it remains to be identified if children may be considered CK responders after competitive match up.

Therefore no studies appear to have examined the acute effects of competitive soccer match play on neuromusular function and muscle damage in male youth soccer players when taking maturational stage into account. The aim of this study was to explore how soccer match related fatigue compromises knee joint control, and increases injury risk in male youth athletes duirng the important maturation related period of PHV.

Methods

Participants

A group of 27 youth soccer players (age: 14.3 ± 1.1 y; stature: 168.9 ± 10.7 cm; body mass: 57.4 ± 11.4 kg) from two chronological competition age groups (U14 and U16 y) participated in this study. The players were recruited from a professional soccer club academy, they trained on average five times per week and played one competitive match per week during the season. All tested players were free of musculoskeletal lower-extremity injuries (no injury in the previous 4 weeks or serious injury in the previous 6 months and fully returned to training and competitive match-play), were fully informed about the aim of the study and the testing procedures that would be employed. The study was approved by the Institution's ethics committee and conformed to the Declaration of Helsinki regarding the use of human subjects. Written informed consent to the testing procedures and the use of the data for further research was obtained from the players' parents and the children. Additionally all players provided assent to participate in the study. Players completed a health questionnaire prior to participation in order to be included in the research.

Experimental design

Testing occurred approximately 10 weeks into the competitive season (November). The day before testing, the players were not exposed to any high intensity exercises. Biological maturity was predicted by calculation of age from PHV using the sex appropriate equation of Mirwald et al. (2002). Players were placed into either a PHV (-0.5 to 0.5 y) or post-PHV (1.0-2.5 y) group based on the maturity offset data. Due to an associated error of 0.5 y with the Mirwald equation any players whose maturity offset fell within the 0.5 – 1.0 y range were excluded from the study. Leg length, tibia length, standing and sitting height measures were obtained at the familiarization session using a stadiometer A-226 Anthropometer (Trystom, CR). Body mass was measured using Tanita UM-075 weighing scales (Tanita, Japan). All outcome variables were determined using a randomized 'circuit' style approach 1hr pre and immediately post competitive match play(match time was 70min for U14 and 80min for U16 players). Each outcome variable station was run by an experienced researcher and this approach was used to minimize testing time, especially post competitive match play. The final sample was n = 24 (U14 n = 15, U16 n = 9) as 3 players from the U14 group were excluded as they did not play at least 30min of the match (all players in the U16 group played at least 60min). The mean match time was 59 ± 12min for the U14 and 75 ± 9min for the U16.

Creatine Kinase Sampling

Capillary (fingertip) blood samples were collected to assess CK activity. Approximately 30μL of capillary blood was collected from a finger via a prick made with a spring-loaded lancet (Accu-Check, Roche Diagnostics, Germany) set at 2.3 mm depth. A Reflotron applicator with a 32 μL disposable pipette tip was used to extract a 32 μL sample of blood and place it on a CK magnetic test strip (Reflotron® CK strips, UK). The blood sample was immediately analysed using a Reflotron® systems spectrophotometer (F.Hoffman-La Roche Ltd, Basel, Switzerland) for plasma CK activity. The normal reference range for CK using this method is 50 to 220 IU·L−1 and the assay can accurately detect values between 20 and 2000 IU·L−1, according to the manufacturers' manual.

Perceived Muscle Soreness

Using a visual analogue scale (VAS) participants gave an indication of their current level of perceived muscle soreness on a subjective scale. The scale was 10 cm in length, with 0 (no soreness) and 10 (very, very sore) representing the extreme ends of the scale (Cleak & Eston 1992). Participants were instructed to mark a cross along the line that relates to the amount of muscle soreness that they felt at that current time. To avoid potential bias from previous measurements a blank VAS scale was provided at each testing session. This method has been validated for use with paediatric populations (Cleak & Eston).

Match Intensity Measures

Within half an hour post-match, participants were asked to rate their perceived level of exertion during the match to get an indication of the amount of load induced by the soccer match. The Borg scale was used as it has been previously reported to be a reliable measure of rate of perceived exertion (RPE) regardless of age, or gender and easily learnt by older children and adolescents (Williams, Eston & Stretch 1991). The simplified fixed ten point

Borg CR-10 Scale was used to allow an easy method of measure the level of intensity on a scale ranging from zero to ten, zero representing low intensity/rest up to ten representing maximal effort.

Leg stiffness

Leg stiffness was calculated from contact time data obtained during a sub-maximal bilateral hopping protocol and a coefficient of variation for female youth soccer players has been reported to be 8.2% (De Ste Croix et al., 2017). In the current study, the procedures were repeated twice and an average stiffness value reported. This method improves the reliability by a factor of $1/\sqrt{2}$, giving an adjusted coefficient of variation of 7.2%. For each trial, participants were instructed to perform 20 consecutive hops on a mobile 2-axis force platform PS-2142 (Pasco, Roseville, USA) at a frequency of 2.5 Hz to reflect the typical behaviour of a spring model (Lloyd, Oliver, Hughes & Williams 2009). Hopping frequency was maintained via an audio signal from a quartz Wittner metronome (GmbH & Co. KG, Isny, Germany). Participants were instructed to: a) keep hands on the hips at all times to avoid upper body interference; b) jump and land on the same spot; c) land with legs fully extended and to look forward at a fixed position to aid balance. For data analysis the first 4 hops were discounted and the next 10 consecutive hops closest to the hopping frequency were used. Absolute leg stiffness ($kN \cdot m^{-1}$) was calculated using the equation proposed by Dalleau et al. (2004) and relative leg stiffness was determined by dividing absolute leg stiffness by body mass and limb length to provide a dimensionless value (De Ste Croix et al., 2017; Lloyd et al., 2009).

Reactive strength index

Reactive Strength Index (RSI) was determined during a 5 maximum hop test which was performed on a mobile contact mat (FITRO Jumper, Fitronic, Slovakia). Participants were instructed to maximize jump height and minimize ground contact time (Dalleau et al., 2004) and the RSI variable was calculated using the equation of Flanagan and Comyns (2008). The first hop served as a CMJ (impetus) and was consequently excluded from analysis, with the 4 remaining hops averaged for analysis of RSI. Players performed three trials (one practice, and two measured trials) wearing trainers with 2 min rest between trials.

Muscle activity

Muscle activity was recorded using surface polyelectromyography (Noraxon - Myosystem 1400A) during a squat jump test. The hands remained placed on the hips throughout the test. Participants squatted down until the knees were bent at 90 degrees, keeping the trunk straight and sustaining this position for approximately 3s. Then were instructed to jump vertically as high as possible, and land with both feet hitting the floor at the same time. The take-off and landing were performed with no initial steps or movement. Players performed three trials consecutively (one practice, and two measured trials) with 1 min rest between trials. The 2nd trial was used for subsequent analysis.

Oval-shaped, disposable, self-adhesive Kendall-ARBO silver-silver chlorid electrodes with a solid hydrogel, and with a diameter of 24 mm were used. The signal was captured eight manifolds with 1000 Hz frequency. Resistance poly-EMG device was > 10 MW (24 mm). Electrodes for sensing EMG signal were stuck before the first measurement. Prior to application of the electrodes, the skin in that area was properly cleaned with water and dried. Surface electrodes were placed on the muscle belly in parallel with the process of muscle fibres. The distance between electrodes was 1 cm. A part of the first lead was the reference electrode located in the tibial tuberosity. For the second measurement a new set of electrodes was usually used to reduce impedance and improve the electrode contact with the skin. Electrodes were positioned on preferential lower limb on medial head of gastrocnemius muscle (MG), biceps femoris (BF) and semitendinosus (ST) muscle. For the purpose of this study muscle activity during eccentric flexion and extension was analysed. For analysis the

EMG data program was used MyoResearch XP Master Version 1.03.05. First the raw EMG data was rectified (full wave rectification) and signal smoothing applied. Second the measured values for individual muscles were divided into the resting phase (0.5s during static standing) and phase of muscle activity (determined as the phase from activation onset [10% increase in muscle activity from the resting phase] to peak activation). Mean frequency value (Hz) was determined for each phase. For normalization of electromyography signal ratio between the value of mean frequency in resting phase and the value of phase of muscle activity was used.

Statistical analysis

Statistical analysis were performed using the data analysis software system Statistica, version 12 (StatSoft) and the Statistical Package for Social Sciences (SPSS, v. 23.0 for Windows; SPSS Inc, Chicago). Firstly the distribution of raw data sets was checked for homogeneity and skewness using the Kolmogorov-Smirnov test. Descriptive statistics including means and standard deviation were calculated for each measure. To determine acute effects of match-play Paired T-Tests were used to analyse pre and post-match measures for all outcome variables. Independent sample t-tests were used to explore differences between groups for all outcome measures pre and post competitive match play. The classification of effect sizes was determined by standardized pooled within sample estimate of the population standard deviation and reported as Cohen's *d* (Cohen 1988). Calculated effect sizes were classified as small ($0.00 \leq d \leq 0.49$), medium ($0.50 \leq d \leq 0.79$), and large ($d \geq 0.80$) (Cohen 1988). The level of significance was set at $P \leq 0.05$ for all tests.

Results

Descriptive data for each group can be found in table 1 with the post PHV velocity group being significantly older, taller and heavier than the PHV group.

Table 1: Group mean (±SD) participant characteristics by group

	PHV (n=15)	Post-PHV (n=9)
Age (y)	13.6 ± 0.3	15.8 ± 0.1
Standing Height (cm)	163.0 ± 9.0	178.7 ± 1.9
Sitting Height (cm)	87.6 ± 5.4	91.5 ± 1.7
Body Mass (kg)	52.5 ± 10.2	65.5 ± 7.0
Maturity offset (y)	0.2 ± 0.7	1.8 ± 0.3

There was no statistically significant difference in game intensity RPE between the PHV group (7.6 ± 1.1) and the post PHV group (8.6 ± 0.7). Absolute and relative leg stiffness were significantly greater in the post PHV group pre match play ($P < 0.001$) compared to the PHV group. The effect sizes were large for absolute leg stiffness (ES:1.16), medium for relative leg stiffness (ES: 0.63). There were no statistically significant differences between groups pre match play in any other parameter. A statistically significant increase in CK ($P < 0.001$) and perceived muscle soreness ($P < 0.001$) for both groups was observed (Table 2) and the effects sizes were large (ES: range 0.90 – 2.82). There was a significant difference between the groups pre to post fatigue for perceived muscle soreness with the post-PHV group demonstrating a greater increase with a large effect size ($P < 0.001$, ES: 2.06).

Table 2: Mean (±SD) values for CK ($I \cdot Ul^{-1}$) and VAS pre and post competitive match play by group

Group	CK Pre	CK Post	VAS Pre	VAS Post
PHV	208.9 ± 68.0	360.3 ± 130.2*	1.1 ± 1.3	2.8 ± 2.3*†
Post-PHV	172.6 ± 98.7	384.6 ± 171.8*	1.7 ± 2.1	6.8 ± 1.5*

** Significant difference between pre and post soccer match*
† Significant difference compared to Post-PHV

RSI significantly decreased (P < 0.001) post competitive match-play in both groups. The effect size was small for the PHV group (ES: 0.41) and large for the post-PHV group (ES: 1.33). Contact time significantly increased (P < 0.005) post competitive match play in the post-PHV group only with a medium effect size (ES: 0.63). Flight time significantly decreased with large effect sizes for both the PHV group (P < 0.02, ES: 1.26) and the post-PHV group (P < 0.03, ES: 1.34). There were no significant differences in absolute and relative leg stiffness for both groups pre to post competitive match play (Table 3). There were no significant differences in the fatigue related responses to competitive match play for RSI, absolute or relative leg stiffness between groups.

Table 3: RSI, absolute and relative leg stiffness pre and post competitive match-play by group

Variable/ Group	Pre	Post	Effect Size
RSI			
PHV	2.54 ± 0.31	2.41 ± 0.32*	0.41
Post-PHV	2.94 ± 0.25	2.60 ± 0.26*	1.33
CT (s)			
PHV	0.19 ± 0.02	0.19 ± 0.02	0
Post-PHV	0.18 ± 0.02	0.19 ±0.01*	0.63
FT (s)			
PHV	0.47 ± 0.02	0.45 ± 0.01*	1.26
Post-PHV	0.51 ± 0.01	0.48 ± 0.03*	1.34
Absolute leg stiffness			
PHV	23.2 ± 5.2†	23.1 ± 4.5	0.02
Post-PHV	28.8 ± 4.1	29.6 ± 4.5	0.19
Relative leg stiffness			
PHV	35.6 ± 6.4†	35.3 ± 5.4	0.05
Post-PHV	39.2 ± 4.8	40.0 ± 3.4	0.19

** Significant difference between pre and post soccer match*
† Significant difference compared to Post-PHV

No significant effects of match play on muscle activation were evident for any of the muscle groups for either group except for activation of the gastrocnemius in the post-PHV group which significantly decreased with a medium effect (P < 0.001; ES: 0.71) (Table 4).

Table 4: Muscle activation pre and post competitive match-play by group

Group	Gastrocnemius	Semitendinosis	Biceps Femoris
PHV			
Pre	0.56	0.49	0.50
Post	0.44	0.33	0.44
Post-PHV			
Pre	0.45	0.43*	0.45
Post	0.40	0.33	0.43

** Significant difference between pre and post soccer match*

Discussion

The main findings of the current study indicate that competitive soccer match play significantly compromises reactive strength, and induces significant increases in CK in youth players. However, neuromuscular control (determined as muscle activation) and leg stiffness were not compromised in this group of players following competitive match play. There was also no maturation related differences in the response to competitive match-play between PHV and post-PHV players, except for perceived muscle soreness. The data from this study suggest that toward the end of competitive match play youth players' ability to effectively utilize neuromuscular mechanisms to control joint movement and reduce load on ligaments is not compromised and this in turn may reduce subsequent injury risk. However, SSC capability and potential muscle damage from elevated levels of CK are evident and need to be appropriately managed to reduce the risk of injury and reductions in performance towards the end of match-play, as well as to make sure youth players are recovered and prepared for the next training session.

Previous studies have suggested that children might be referred to as non-CK responders, showing minimal elevation (ranging from 47-72% increase) in CK levels after fatiguing exercise (Webber et al.1989; Soares et al. 1996; Duarte, 1999). However, our data shows a significant increase in CK immediately post competitive match-play (73% and 123% for PHV and post-PHV groups respectively) suggesting that muscle damage is a consideration for youth players and that appropriate recovery strategies should be in place for elite youth male players. Indeed, the large effect sizes for both the PHV (ES: 1.51) and post-PHV (ES: 1.46) reinforce the magnitude of the CK response that is elicited through competitive match-play. These data are comparable to those found by Hughes et al. (Hughes, De Ste Croix, Denton, Lloyd & Oliver 2018) who reported significantly elevated CK levels in 13-16y-old female footballers 80hr post match-play and throughout the training week. The reason for the differences between our study and those referring to children as non-CK responders may be due to the differing methods used to elicit fatigue. Others employed 1RM to exhaustion and a stepping fatigue task (Soares et al. 1996; Duarte, 1999) whereas our study focused on competitive match play. It is also important to note that it is likely that the CK levels reported in the current study will not have peaked immediately post match-play, and that even higher levels would be observed if we measured CK 24-48hr after match play. These data highlight that young male elite soccer players are likely to experience muscle damage from competitive match-play that carries over into the training week, and that this might increase the relative risk of injury if not properly managed. The data are further reinforced by the significant increase in perceived muscle soreness in both groups. Whether elevated CK towards the end of competitive match play is a predisposing factor in the increased risk of soft tissue injury in male youth soccer players remains to be identified. Caution should be taken in directly relating changes in CK to muscle damage as it is well recognised that serum CK levels alone may not provide a fully accurate reflection of structural damage to muscle cells (Baird, Graham, Baker &Bickerstaff 2012).

The significant reduction in RSI in both groups indicates some compromise in SSC capability after competitive match-play, suggesting an inhibitory effect on SSC as youth players fatigue. This could contribute to the fatigue of muscles from high-intensity match play and cause a higher work rate to resist the deformation of the limb during SSC activities, particularly at lower speeds where there would be greater reliance on a muscles strength capacity as opposed to its velocity capacity, following the traditional force–velocity curve concept. This reduction in RSI could lead to increased injury risk in jumping, landing and cutting maneuvers due to the negative effect on leg spring stiffness and muscle mechanics (Comyns Harrison Hennessy 2011. Although no significant group differences were observed large effect sizes (ES 1.33) were seen in the post-PHV compared to the small effect size in the PHV group (ES 0.43). Additionally, a significant increase in contact time (CT) was seen in the post-PHV group compared with the PHV group. To some extent this maturation related effect may reinforce the suggestion of Ratel and Martin (2015) that there may be a progressive withdrawal of physiological protection against high intensity exercise induced fatigue during puberty. Our findings are in agreement with previous studies that have shown decreases in RSI following simulated soccer in male youth players (Lehnert et al., 2017b; Raschner et al., 2012). The exact mechanisms involved in the reduction in RSI at the end of competitive match-play are difficult to prescribe but as RSI represents the strain placed on the musculotendon unit our findings would suggest a reduced tolerance to the eccentric loading placed on the musculotendon unit. More specifically, there may be a reduction in the stretch-reflex contribution, rate-of-force development, and decreased desensitization of Golgi tendon organs representing a compromised neural mechanism resulting in less tolerance of impact forces experienced in the maximal hopping protocol. More work is needed to explore further this potential hypothesis that there is a withdrawal of a protective physiological mechanism against high intensity fatigue during puberty (Ratel & Martin 2015).

Our findings related to leg stiffness support some of the previous literature in youth players that have also identified that acute changes in leg stiffness appear to be very individualised (De Ste Croix et al., 2017; Oliver et al., 2014). Although we found no significant change in either absolute or relative leg stiffness or maturational differences, there was a very individualised response to competitive match-play in terms of the leg stiffness response with some players showing a decline, some an increase and some no relative change. It would seem strange that we found reduction in RSI but not stiffness when they both represent SSC capability. However, one previous study indicated that the RSI demonstrated a limited amount of common variance with leg stiffness (Lloyd, Oliver, Hughes & Williams 2012). The authors also suggested that in maximum hopping (as used to determine the RSI), stiffness was closely connected with maximum power and therefore the ability to recruit motor units was more influential. For those individuals who showed reduction in leg stiffness, this mechanically would typically be characterized by an increased yielding action, greater ground contact times, greater CoM displacement, and less efficient movement when the limb comes into contact with the ground (Komi 2000). The potential consequence of such fatigue-induced reductions in ground reaction forces (and overall leg stiffness) could be an increase in shear force absorption directly by the knee joint, which would have negative permeations for ACL injury risk (Lloyd et al., 2012, Ford, Myer & Hewett 2005). This reduction also has performance-related implications for youth players as leg stiffness has been shown to be related to both sprint speed and jump height (Hennessy & Kilty 2001). These data highlight the need for robustness and movement competency programs to be incorporated in young male players training as early as possible within their athletic development pathways (Myer, Sugimoto, Thomas & Hewett 2013). The observation that leg stiffness increased post-exercise for some individuals in the present study suggests the possibility of a potentiated state within the neuromuscular system. This is supported by the previous suggestion that a stretch reflex can be modulated in a positive way to increase leg stiffness (Hobara, Kanosue & Suzuki 2007). It is clear from our study and from previous work that in youth soccer players the response of competitive and simulated match-play on leg stiffness is an individualised response and therefore group data may not be that meaningful and the individual response needs to be observed.

Our data are in disagreement with previously published studies that have demonstrated compromised neuromuscular function (from muscle activation and EMD data) (De Ste Croix et al., 2015; Lehnert et al., 2017a). We found no significant change in muscle activation, except for the gastrocnemius in the post-PHV group, post competitive match-play. Our findings would seem to suggest that at least during competitive match-play that little, if any, metabolic inhibition of the contractile process and excitation–contraction coupling failure occurred. Thus at least for the large muscle groups that help to control knee joint stability the effect of fatigue is negligible and neuromuscular performance is maintained reducing the risk of injury. Our findings tentatively support previous work that suggests that there may be development of fatigue resistance with chronological age and training status that help to protect the joint (De Ste Croix et al., 2017). The reason why we have found different results to most previous studies examining match related fatigue on neuromuscular function in youth soccer players might be attributed to the fact that we used competitive match-play to induce load on players rather than simulated match-play. The simulated soccer protocol used in previous studies is based on adult data and therefore the activity profile components used in that simulation may induce greater loads than those imposed during actual competitive game play in youth matches. Therefore, those previous studies may have induced greater fatigue related effects than are actually observed during competitive matches. One of the limitations of the current study is that we only observed changes after one competitive match, although the players rated the exertion of those matches high (RPE 7.6 and 8.6 respectively). Further investigation is required to establish if similar patterns of neuromuscular control are evident in repeat competitive match-play.

The compromised activation of the gastrocnemius after competitive match-play in the post-PHV group might be significant in terms of injury risk given the important role that the grstrocnemius plays in both knee and ankle stability and additional ACL loading (Hewett, Zazulak, Myer & Ford 2005). The significant reduction in muscle activation post fatigue indicates a reduced ability of post-PHV players to respond to a physical and visual stimulus and this might be attributed to children's more compliant muscle–tendon system which requires more time to produce a mechanical response given the same stimulus. It would appear that the reduction in muscle activation maybe largely attributed to a failure somewhere in the muscle contraction process such as deterioration in muscle conductive, contractile, or elastic properties. It is difficult to compare our findings to previous literature as no studies appear to have examined changes in activation of the gastrocnemius after competitive match play in youth soccer players. One study on adults has demonstrated fatigue related effects in gastrocnemius activation providing evidence for compromised active muscle control of the joint (Gehring, Melnyk & Gollhofer 2009). It is not clear why these compromised effects are only evident in the post-PHV group but previous studies have suggested that individuals may move to an ankle dominant strategy to help stabilize joints when fatigue is present, which would place extra load on the gastrocnemius. It may be possible that the more mature players, who have a greater training age, may have learnt to use alternative landing and cutting strategies, when fatigue is present, to help stabalize the joint by moving to an ankle dominant strategy. However, it should be noted that voluntary muscular control forms only part of the joint stabilization process and should be explored alongside measures of specific joint and tendon stiffness. Nevertheless, given that a recent injury incidence audit in youth male soccer players has reported that 38% of injuries occurred in the knee and ankle (20% and 18% respectively), any compromise to muscles that help stabalize those joints increases injury risk in youth populations.

Importantly we found no maturation related differences in the response to competitive match play in young players who are around PHV and those classified as post-PHV. Previous incidence studies have suggested that incidence peaks around the time of PHV but the mechanisms associated with this increase risk remain to be identified. The current study would appear to suggest that fatigue related responses to competitive match-play appear not to be a contributing factor to the increased risk around PHV. The significant compromised effects of a reduction in RSI and evidence of muscle damage via elevated CK are the same irrespective of maturation stage. Therefore, other factors must be responsible for the increased injury incidence around PHV. Therefore the maturation related increase in injury incidence around PHV does not appear to be related to compromised neuromuscular control following competitive match-play.

There are certain limitations to undertaking research in real world situations and these include match play time and intensity and the time taken to complete tests post competitive match play (around 45min for all tests). As we have seen no difference between maturational groups it would appear that playing duration may not influence the fatigue related responses of the outcome measures that we have determined in the current study. This is due to that fact that time spent in match play does not provide an accurate description of the loads applied. However, no studies to date have explore the relationship between fatigue related match loads (e.g the number of accelerations and decelerations as well as the distance covered during high intensity running) and RPE in youth players, especially across different maturational stages, and this therefore requires further investigation. Most studies examining fatigue related changes in injury risk factors have used laboratory based methods to induce fatigue (eg repeated muscle actions on an isokinetic dynamometer) or simulated match play. In this study we did measure immediately post competitive match play and used a randomised ‘circuit’ approach to try and reduce data collection time. We acknowledge that this inevitably resulted in differing time gaps between end of play and assessment of the outcome variables, and this may have influenced the findings despite our randomisation technique. It was also not possible for us to split our sample further into a pre PHV group and future studies should look to examine the fatigue related effects in younger less mature groups.

The current study is the first to demonstrate that neuromuscular control, leg stiffness, RSI and muscle damage are influenced the same by competitive match-play irrespective of maturational stage. Some fatigue related effects are present and would still reinforce based on incidence date that in male youth are an “at-risk” group and therefore an emphasis of intervention programs must be to develop neuromuscular functioning and fatigue resistance. Well structured, developmentally appropriate strength and conditioning work should be viewed as a season-long commitment to offset the negative effects of accumulated fatigue.

Due to the fatigue-related effects observed, injury prevention strategies should be related to fatigue resistance as well as movement control and isolated strengthening work.

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