Title: Neuromuscular Fatigue Following A Singles Badminton Match

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Keywords: Badminton, neuromuscular fatigue, muscle soreness.

INTRODUCTION

Badminton has gained popularity since its inclusion in the Olympic Games and has been recorded as the world's fastest racket sport, with the shuttlecock reaching a maximum velocity of 100 m·s^{-1} (360 km·h^{-1}) and an average velocity of 50 – 75 m·s^{-1} during match-play? (Gowitzke and Waddle, 1978). It has been documented that the activity pattern in a badminton match is intermittent with short duration movements interspersed with short rest periods (Lees, 2003).

According to Kuntze et al. (2010), winning a point during intense rallies in an international-level singles badminton match is strongly associated with the ability to move rapidly around the court. Furthermore, it was also identified that lunges were the most frequently performed movement (15%) of all movements which consisted of running, crossover sidestepping, sidestepping, jumping, scrambling and other unclassified movements. Additionally, two different types of lunges have been identified; full and half lunge, which might have contributed to the impact of neuromuscular fatigue of the body and also to the muscle functions of the knee extensors differently. This suggests that strength loss and alterations to muscle function would likely be associated with the different type of lunges executed from a singles badminton match (Cronin et al., 2003; and Jonhagen et al., 2009). It was also noted that lunge frequency was higher in international-level (17.9% ± 4.9%) than national-level (14.3 ± 4.5%) matches (Kuntze et al., 2010).

The ability to execute a lunge in badminton is important as it allows the player to rapidly halt the body's momentum, remain relatively stationary in preparation for effective stroke performance, and to return back to position in preparation for the following shot (Kuntze et al., 2010 and Cronin et al., 2003). A lung movement requires the activation of the quadriceps, hamstrings and gluteal muscles during eccentric contractions to produce the braking reaction force and is normally executed using the leg on the same side as the arm holding the racket as the impact loading will be solely placed on that leg (Jonhagen et al., 2009; Kuntze et al., 2010). Thus, it is assumed that the impact of the lunging movement would contribute to the accumulation of muscle fatigue. A lunge can be grouped into five phases; initial impact (heel strike), secondary impact (loading), amortization (force reduction), and weight acceptance (loading) and drive off (Kuntze et al., 2010). As the lunging action is performed mainly with the dominant leg, it is therefore assumed that neuromuscular fatigue profiles would differ between legs, although this has not been explicitly tested.

With the high frequency of lunges executed during a badminton match it could be assumed that the movement would cause muscle discomfort after a singles badminton match as it was expected that lunging causes muscle stiffness, loss of muscle function, muscle pain and eventually impair performance as a result of muscle damage (Cronin et al, 2003; Jonhagen et al., 2009; Kuntze et al., 2010). Furthermore, it is assumed that a greater frequency and intensity of

lunges could result in greater neuromuscular fatigue and muscle damage to the knee extensor muscles. However, previous studies have not investigated the effects of lunges in relation to neuromuscular fatigue and muscle damage during a badminton match. Therefore, the aim of this study was to investigate changes in knee extensor neuromuscular function after a simulated 1 hour badminton singles match in relation to the number of lunges performed in the match.

METHODS

Participants

Ten competitive singles male badminton participants from the Western Australia badminton team with at least 5 years of senior state level playing experience volunteered to participate in this study. Participants were requested to abstain from taking caffeine for at least 6 hours and alcohol for at least 24 hour prior to testing. All diets were standardise and kept similar for all testing days. Before participating in the study, each participant was informed of the risks and procedures of the study and the Physical Activity Readiness Questionnaire (PAR-Q) was used to assess the participants' risks for participation in the study. Prior to the participation, informed consent was obtained from each participant. Ethical clearance was obtained from the Edith Cowan University Human Research Ethics Committee before commencement of the study.

Methods

Simulated Match

A 5 min standardised warm up period was performed prior to commencement of the simulated badminton match play. Participants were permitted to rest for a maximum of 120 s as per indicated by the Badminton World Federation rule; between sets, after which, a changeover of sides for both participants. During the 1-hour simulated match, participants were permitted and encouraged to consume a maximum of 250 ml water every 30 min. All matches were video recorded as mentioned in section - *video analysis*; for game and motion analysis. Blood lactate was assessed before and 10 min post-match and RPE was obtained before and immediately post-match using a modified rating of perceived exertion scale (Category Ratio 10 scale). The participants were required to indicate a scale of between 0 (Nothing at all) and 10 (Maximal) by answering the question, "What is your overall perceived exertion?" immediately post-match.

Muscle Function Measurements

Prior to the simulated match play, participants performed a hand grip strength test so as to attest the level of central fatigue after a 1 hour singles badminton match; for both arms before the muscle function measurements of the knee extensors. The muscle function measures were performed for the leg that correspond to the same side of the arm holding the racket first (dominant leg), followed by the opposite leg (non-dominant leg) before, and 1 hour and 24 hours after a match. At approximately 10 min after a match, the muscle function measures were performed only from the dominant leg. An isokinetic dynamometer (Biodex System 3 Pro, NY) was used to measure the muscle function of the knee extensors, with the trunk-thigh angle positioned at 90° and the lateral femoral epicondyle was aligned to the axis of rotation of the dynamometer with the knee fixed at 60° of flexion (0° corresponding to full knee extension) as 60° was the optimum angle to produce highest torque (Brughelli et al. 2010). Both femoral nerve and muscle electrical stimulations were used in the present study. Prior to the testing, stimulation

electrode placement was based on the study by Girard et al. (2007) and Verges et al. (2009). Briefly, for the muscle stimulation, the electrode for cathode electrode was positioned on the belly of the VL and the anode electrode on the end of VM. Furthermore, for femoral nerve stimulation, the cathode electrode was positioned 5 cm below the inguinal ligament and the anode electrode located 10 cm lateral to the cathode (around the greater trochanter). The electrodes were secured onto the subject throughout the badminton match and that the electrodes were free of obstruction during the whole match play. Before placing all the electrodes, the skin was shaved, abraded and cleaned with alcohol. Each participant performed three isometric knee extensions at 30, 60 and 80% of the perceived maximal voluntary contraction (MVC) at the knee angle of 60° with 30-s rest between contractions. Participant was instructed to perform 1 maximal trial of two MVCs before the commencement of the actual measurements. Following the warm up contractions, two maximum isometric voluntary contractions were performed as 'fast and hard as possible' twice over 4 s with 60 s rest between contractions. From the torque data, peak torque was calculated from each contraction, and the higher value of the two was identified and was used for further analysis.

During the MVC torque measures, maximal voluntary activation was estimated by using interpolated-doublet technique with two sets of electrically evoked stimuli (10 ms apart) being superimposed when the torque reaches a plateau, with the aid of a constant current stimulator (DS7, Digitimer Ltd., Welwyn Garden City, UK). Control doublet was given 5 s after the end of each MVC for the calculation of voluntary activation (Girard et. al, 2006). The voluntary muscle activation level had been estimated according to the following formula (Allen et. al, 1995):

$$Voluntary\ activation = [1 - (superimposed\ doublet/potentiated\ doublet)] \times 100$$

In addition to the knee extensor MVC measures, MVC torque of the knee flexors was measured at the same setting as that of the knee extensors without electrical stimulation following the muscle function measurements of the knee extensors as illustrated in Figure 1. Muscle function measurements for the non-dominant leg consisted of knee extensions and knee flexions without the electrical stimulation as illustrated in Figure 1. The femoral nerve of the dominant leg was electrically stimulated using a stimulator (DS7, Digitimer Ltd., Welwyn Garden City, UK) to assess the twitch contractile properties of the knee extensors muscle. Before commencing the test, square-wave paired pulse electrical stimulations (width of 200 µs) were evoked progressively (10 mA increment) until a plateau for the doublet twitch amplitude was observed. The intensity was then further increased by 20% and maintained throughout the testing session. A doublet stimulus was delivered prior to the execution of the MVC. Peak doublet torque (DT) was assessed following a doublet stimulation during the execution of the MVC (Girard et al. 2010).

To understand the catch- vs. non-catch-induced trains of stimuli which might be presented to the subjects; the 20:80 Hz stimulation ratio was included with the use of a high-frequency (80-Hz) 0.75 s and low-frequency 0.75 s (20-Hz) stimulation (Girard et al. 2008). The intensity set for all muscle stimulations were 50% of MVC as suggested by Gabriel (2013); which appears to be more bearable and still being able to obtain a good reading to study the E-C coupling effect.

For the handgrip strength measurement, it is carried out by using a manual handheld dynamometer before the muscle function of the knee extensors. Each participant was required to grip as hard as possible using the dominant arm followed by the non-dominant arm. Participants performed two efforts for each hand with a rest interval of 1 min between attempts. During the test, the elbow joint was extended straight out with the arm parallel to the body and the wrist in

neutral position. The distance from the handle to the base of the dynamometer was set based on participant comfort and kept consistent between trials. The higher value of the two measurements was used for analysis.

Video Analysis

All matches are recorded with two video recorders (Sony HD 1080i, Japan) being placed at 2 positions of each half of the court. The first recorder was placed at the side of the court, centre of one half of the court at a distance of 8.5 m which is perpendicular to the court and at a height of 1.2 m. The second recorder was placed on the opposite side of the court, facing the back of the participant, to capture lunge actions performed on the opposite side of the first recorder, for the purpose of reviewing and making sure that the movements were accounted for correctly during data analysis. The video was analysed to quantify the number of lunges by two separate investigators using Sports Code Pro (Sportstec, USA). Lunges, were classified into either a half lunge (the forward movement of the knee which does not exceed the position of the toe) or full lunge (the forward movement of the knee which goes beyond the toe) as outlined by Jonhagen et al. (2009).

Muscle Soreness

The level of muscle soreness was quantified using a 100-mm visual analogue scale (VAS) in which 0 indicated no pain and 100 represented the worst pain imaginable from both legs. Level of perceived pain of the quadriceps femoris, hamstring and gluteus muscles were assessed during a single leg forward lunge using each leg. The participant was required to mark the level of perceived pain on the VAS taking the above mentioned muscles as a whole (Jönhagen et al., 2009).

Statistical Analysis

A one-way analysis of variance (ANOVA) with repeated measures was used to assess changes in the variables measured before and after the matches (CR10, muscle soreness, MVC torque and other neuromuscular parameters). A two-way analysis variance (ANOVA) with repeated measures was used to compare the magnitude of changes of the MVC torque and neuromuscular parameters over time between dominant and non dominant legs (using absolute values), and between knee extensors and knee flexors (using normalised values). Where significant interaction effects were detected, Bonferroni post-hoc tests were performed. Pearson product-moment correlations were used to examine relationships between the number of lunges (total, full) and changes in MVC torque; with a correlation of $r < 0.75$ was considered poor, $r=0.75 - 0.9$ was considered a moderate correlation and $r > 0.9$ was considered as a strong correlation (Cronin et al., 2003). Statistical significance was set at $P<0.05$, and all values are reported as means and standard deviations being conducted using SPSS.

RESULTS

An average number of 194 ± 18 lunges were accounted with a range from $160 - 240$ lunges for all matches. Out of the total number of lunges, 153 ± 12 were half lunges (the forward

movement of the knee which does not exceed the position of the toe) and 41 ± 15 were full lunges (the forward movement of the knee which goes beyond the toe).

Table 1
Changes (mean ± SD) in maximal voluntary isometric contraction (MVC) torque of the knee extensors-KE and knee flexors-KF for the dominant leg prior to exercise (Pre), within 10 min after exercise (Post), 1 hour post-exercise (Post 1 h), significantly difference to Pre.

Dominant Leg						
	KE MVC (Nm)	**Changes (%)**	***P*-value**	**KF MVC (Nm)**	**Changes (%)**	***P*-value**
Pre	278.4 ± 50.8			143.3 ± 36.2		
Post	248.4 ± 43.8	-11 ± 2.5	<0.05	116.5 ± 27.1	-18 ± 8.1	<0.05
Post 1 h	237.6 ± 44.2	-14 ± 3.2	<0.001	119.2 ± 27.3	-16 ± 7.4	<0.05

Table 2
Changes (mean ± SD) in maximal voluntary isometric contraction (MVC) torque of the knee extensors-KE and knee flexors-KF for the non-dominant leg prior to exercise (Pre) and 1 hour post-exercise (Post 1 hour), significantly difference to Pre.

Non-dominant Leg						
	KE MVC (Nm)	**Changes (%)**	***P*-value**	**KE MVC (Nm)**	**Changes (%)**	***P*-value**
Pre	237.6 ± 41.7			122.0 ± 29.2		
Post 1 h	207.6 ± 33.8	-12 ± 4.1	<0.05	107.6 ± 30.1	-12.5 ± 6.2	*Not Sig*

Table 3
Correlation between variables

	Pre – Immediate Post	Pre – 1 hour Post Exercise
Changes in KE MVC Torque & Total Lunges	r = 0.64, p<0.001	r = 0.36, p<0.05
Changes in KE MVC Torque & Total Full Lunges	r = 0.68, p<0.001	r = 0.36, p<0.05

When changes in MVC torque of knee extensors and flexors were compared between dominant and non-dominant legs, a significant interaction effect (p<0.05) was found for both. A post-hoc test showed that a significant difference at 1 hour post-exercise occurred such that the magnitude of decrease was greater for the dominant leg (14.6 ± 3.2 %) than the non-dominant leg (12.4 ± 4.1%) for the knee extensor torque, and for the dominant leg (16.0 ± 7.4 %) than the non-dominant leg (12.5 ± 6.2%) for the knee flexor torque.

Voluntary activation (VA) of the dominant leg was 90.4% at pre-exercise, and decreased (P<0.001) 12% at immediately post-exercise and 8% at 1 h post-exercise respectively, but recovered to pre exercise by 24 hour post-exercise.

Doublet Torque (DT) for the dominant leg was 75.0 ± 5.6 Nm at pre exercise, which was 28 ± 7 % of MVC torque of KE for the same leg. DT decreased 13% at immediately post-exercise (p<0.001), but interestingly recovered to pre exercise at 1 h post-exercise. Both the torque induced by the low (20 Hz) frequency (T20) and high (80 Hz) frequency (T80) electrical stimulation decreased from pre exercise (92.5 ± 18.1 Nm for T20 and 142.8 ± 31.6 Nm for T80, respectively) by 31% and 25%, respectively at immediately post-exercise, and 24% and 16%,

respectively at 1 h post-exercise. Interestingly, both recovered to pre exercise by 24 hour post-exercise (p<0.05). A significant interaction effect was found for changes in torque between T_{20} and T_{80}, and a post-hoc test showed a significantly greater decrease in torque was greater for T_{20} ($31.1 \pm 12.3\%$) than T_{80} ($25.5 \pm 7.9\%$) at immediately post-match, and T_{20} ($24.3 \pm 14.6\%$) than T_{80} ($15.8 \pm 8.0\%$) at 1 h post-exercise. However, the pre exercise ratio was 0.66 ± 0.07, and no significant changes in T_{20}/T_{80} was evident at immediately post-exercise, but a 10% decrease (p<0.05) was observed at 1 h post-exercise, and returned to pre exercise at 24 hour post-exercise. No significant changes in the hand grip strength for dominant (56.6 ± 11.4 *vs.* 56.7 ± 12.9 kg) and non-dominant (49.7 ± 9.6 *vs.* 50.3 ± 8.8 kg) were evident before and after exercise.

VAS for the dominant leg was 2.4 ± 2.1 mm at pre exercise, and increased to 34.4 ± 11.2 mm immediately post-exercise (p<0.001) and further increased to 51.5 ± 11.6 mm at 24 hour post-exercise (p<0.001). Interestingly, VAS for the non-dominant leg was 1.9 ± 1.5 mm at pre exercise, and increased to 18.8 ± 8.6 mm at immediate post-exercise (p<0.001). However, it recovered to pre exercise to 8.3 ± 6.1 mm at 24 hour post-exercise (p<0.001), which was opposite for the dominant leg.

Correlation between variables was performed and the results are presented in Table 3.

DISCUSSION

The main findings were as follows: (i) the number of lunges and full lunges performed during the match was significantly correlated with the magnitude of decrease in knee extensor and knee flexor MVC torque immediately and 1 hour post-exercise; (ii) both knee extensor and flexor MVC torque of the dominant leg (i.e. on the racket side) decreased immediately (-11% and -18%, respectively) and 1 hour (-14% and -16%, respectively) post-exercise, which was accompanied by significant reductions in voluntary activation of the knee extensors, T20 and T80 torque. Peak doublet torque was observed to only decreased at immediate post-exercise while T20/T80 ratio only decreased at 1 h post-match; (iii) knee extensor MVC torque of the non-dominant leg also decreased (-12%) at 1 hour post-exercise. This was accompanied by decreases in voluntary activation (immediately: -12%, 1 hour: -8%) and peak doublet torque (-13%, -4%) of the knee extensors immediately post-exercise, respectively for the dominant leg, but knee flexor MVC torque of the non-dominant leg was unaffected and handgrip strength did not change in either arm; and (iv) muscle soreness increased in both legs immediately post-exercise with a further increase being observed for the dominant leg at 24 hour post-exercise, but the level of pain was moderate. These findings suggested that a 1-hour simulated badminton match, which appears to represent matches that players perform in competitions, induced neuromuscular fatigue although muscle soreness was moderate and that the increasing number of lunges, especially full lunges, contributed to increased fatigue.

MVC peak torque of both the knee extensors and flexors of the dominant leg decreased 11% and 14%, respectively, immediately post-exercise and no recovery was evident after 1 h. This was accompanied by decreases in voluntary activation (immediately: -12%, 1 hour: -8%) and peak doublet torque (-13%, -4%) of the knee extensors immediately post-exercise, respectively for the dominant leg. Interestingly, peak MVC knee extensor torque in the non-dominant leg also decreased (-12%) at 1 hour after the match, although the magnitude of decrease was significantly smaller than that in the dominant leg. This was likely related to the execution of lunges in which the knee extensors of the dominant leg were mainly used, as other movements seemed to be equally performed by both legs. It should be noted that MVC torque and other muscle function variables returned to pre-exercise at 24 hour post-exercise. Although

muscle soreness was present in the dominant leg at 24 hour after the match, it seems likely that muscle damage was minimal.

Girard et al. (2006) reported gradual decreases in knee extensor MVC torque over a 3-h simulated tennis match, resulting in a 13% decrease at the end of the matches that did not recover in the 30 min after the match. Girard et al. (2010) also reported a 16% decrease in knee extensor MVC torque immediately after a 1-h simulated squash match played by elite players. It appears that the magnitude of decrease in the MVC torque in the present study was comparable to those after play in other racket sports (Girard et al., 2006 and 2010).

It should be noted that MVC knee extensor torque decreased further from immediately post to 1 hour post-exercise, and this was accompanied by greater decreases in T_{20} than T_{80}, suggesting low frequency fatigue and thus E-C coupling failure (Girard and Millet, 2008). Interestingly, knee extensor MVC torque did not recover even after 1 hour, which could have resulted from a decrease in motor neurone excitability. Despite the fact that voluntary activation was reported to have reduced significantly across post-exercise and 1 hour post match, which reflected that there were some signs of development of central fatigue, we have no possible distinction between spinal and supraspinal components. In addition, motoneuron pool excitability modulations have been evidenced from the plantar flexors (Girard et al. 2010), thus suggesting that different muscle groups may have contributed differently to the development of central fatigue.

Muscle pain developed immediately after match for the dominant leg only, and the pain increased further at 24 hour post-exercise. It might be that muscle pain was associated with the decreases in MVC torque, as neuromuscular fatigue could be related to a modulation of gain in the spinal loop, which could involve the group III and IV afferents (Gandevia, 2001) which in turn contributed to the cause of central fatigue along with reduction of voluntary activation. Furthermore, Girard and Millet (2008) stated that a decrease in motor neurone excitability in response to metabolic disruption could remain as a potential fatigue factor which would affect the ability to perform the activation of synergistic musculature.

However, if central fatigue was mainly responsible for the MVC torque decrease after match, the handgrip strength of both hands might be expected to also decrease post-exercise, but this was not in this case, which was consistent with previous studies (Girard et al., 2010; Abian-Vicen et al., 2012). Girard et al. (2010) found no changes in handgrip strength after a squash match, and concluded that the loss of cortical excitability intrinsically was probably not the only cause of the central fatigue. Therefore, it appears that the loss of MVC more than 1 hour and decrease in $T_{20}:T_{80}$ indicates a peripheral fatigue most likely associated with a reduced activation of the dihydropyridine-ryanodine receptor complex or sensitivity of calcium within the actomyosin complex.

Furthermore, the number of lunges and full lunges was significantly correlated with the magnitude of decrease in knee extensor MVC torque of the dominant leg at immediately and 1-hour after the match. This suggests that the execution of lunges, especially the full lunges, was an important cause of the fatigue leading to the decreases in the MVC torque. Although there was no significant correlation between the number of lunges and the magnitude of decrease in knee flexor MVC torque in the dominant leg, the reduction of MVC torque for knee flexion was evident. Lees (2003) stated that the braking action when applied in recovery to base after each stroke, apart from the application of lunge could have also contributed in the overall muscle function loss. This could explain the decrease in the knee flexor MVC torque.

Regarding muscle soreness, it is noteworthy that players reported muscle soreness already immediately after the match, and it further increased at 24 hour after match. The magnitude of muscle soreness was greater for the dominant leg than non-dominant leg even though the non-dominant leg show significant difference in muscle soreness at 24 hour post-exercise but has shown to have recovered close to pre-exercise. This may have resulted from non-dominant leg muscles remaining relatively uninvolved in the lunge movements, at least relative to the dominant leg. Most other movement patterns were performed by both leg and therefore indicate the fact that lunges might indeed prove to be the movement which leaded to decrease of knee extensor muscle strength. As discussed above, the recovery of muscle function by 24 hour post-exercise suggests that muscle damage was moderate, probably due to the protective effect that was conferred by regular training and matches. However, it is interesting to note that the players still experienced moderate muscle soreness at 24 hour after match, which is a symptom of muscle damage. It may be that connective tissue surrounding muscle fibres and fascicles (i.e. endomysium, perimysium) was damaged and inflamed during matches, which evoked pain but was not sufficient to cause a prolonged loss of muscle force production (Rampinini et al., 2011). Further study is necessary to investigate the cause of the muscle pain after matches.

CONCLUSION

This was the first study to quantify the number of lunges in relation to a 1 hour simulated singles badminton match. The matches consisted of many lunges with a range of 160 – 240, which appeared to be roughly 15% of the overall movement patterns with full lunges accounting 25% of total number of lunges. MVC knee extensor and flexor torque decreased (10-20%) immediately and 1 h after the match, but recovered by 24 hour post-exercise for the dominant and non-dominant legs. Decreases in voluntary activation, doublet torque, torque induced by 20 Hz and 80 Hz stimulation, and T_{20}/T_{80} ratio was also evident after match, but all returned to the pre-exercise at 24 hour post-exercise. These changes appeared to be associated with the number of lunges, especially full lunges performed in the matches and indicate that peripheral mechanisms at least partly underpinned the loss of force generating capacity. The magnitude of muscle soreness was greater for the dominant leg than non-dominant leg even though the non-dominant leg show significant difference in muscle soreness at 24 hour post-exercise but has shown to have recovered close to pre-exercise. Although mild muscle soreness was evident 24 hour after matches, it appears that muscle damage induced by the matches was moderate since the loss of muscle function was not observed at 24 hour post-exercise. This was likely due to the protective effect that the players obtained from their regular training and experiences in matches. In conclusion, both central and peripheral factors contribute to alterations in neuromuscular fatigue following a 1 hour simulated singles badminton match.

PRACTICAL APPLICATION

It may be necessary for coaches and players to focus on resistance training to strengthen leg muscles especially knee extensors and flexors. The results of the present study revealed an association between the number and type of lunges performed in the matches and decreases in knee extensor strength. It is possible that a large number of full lunges results in a greater loss of knee extensor strength. It may be that the eccentric contractions performed in the lunges induce greater muscle soreness that lasts several days, and might induce muscle damage lasting more than 24 hour. Thus, resistance training incorporating eccentric contractions should be prescribed

to improve knee extensor and flexor muscle strength and thus fatigue resistance. However, without any detailed report of match structure (point duration), no specific analysis of the energy requirement (time spent above a given intensity) or movement patterns (only lunges) it is felt that the main novelty is more about neuromuscular fatigue characteristics. Lastly, a possible use of a handheld dynamometer (force chair) could be considered as it is reliable and valid in the field (Crow et al., 2010).

FUTURE RESEARCH DIRECTIONS
(i) Examination of whether resistance training of the lower extremities (e.g., knee extensors and flexors) helps to prevent DOMS and loss of muscle function.
(ii) To establish a simple method to assess changes in muscle function in relation to fatigue and muscle damage as in the present study, MVC torque was measured using an isokinetic dynamometer which this methodology cannot usually be performed in a practical situation. Thus, measurements that could be performed easily but are reliable and valid should be established.
(iii) Identify the difference between other time points in reference to the nature of the game could provide further information of recovery of muscle activity.

LIMITATIONS
Limitations to the current study include:
(i) Time point (10 min) between exercise cessation and the start of the neuromuscular assessment may have allowed a substantial recovery.
(ii) There is no hydration or pre-body weight measurements were taken.
(iii) VAS for muscle soreness was subjective and not using a previously published technique.
(iv) The nature of the game (being based on playing time) rather than playing to win could influence the effort of the players, and the fact these were simulated games and not matches within a competitive environment (such as a tournament).
(v) Strength and significance of a relationship provide no insight into whether the relationship between two variables is causal.

ACKNOWLEDGEMENT

CONFLICT OF INTEREST
No conflict of interest was declared for all authors.

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