International Journal of Kinesiology & Sports Science
ISSN: 2202-946X
www.ijkss.aiac.org.au

The Influence of Time-dependent Surface Properties on Sprint Running Performance between Male and Female Athletes

Michael Hales*, John David Johnson[2]

[1]Department of Health Promotion & Physical Education, Kennesaw State University, 590 Cobb Avenue, Kennesaw, Georgia 30144 USA
[2]Department of Exercise Science & Sport Management, Kennesaw State University, 590 Cobb Avenue, Kennesaw, Georgia 30144 USA

***Corresponding Author:** Michael Hales, E-mail: mhales@kennesaw.edu

ARTICLE INFO

Article history
Received: August 15, 2020
Accepted: October 20, 2020
Published: October 31, 2020
Volume: 8 Issue: 4

Conflicts of interest: None.
Funding: None.

ABSTRACT

Background: The body of research on field based player-surface interaction consists of some contradictory findings and the comparison of male and female physiological responses on different surfaces is limited. **Objective:** The study investigates the influence of surface properties on sprint running before and after completing a muscle fatiguing intervention. **Methodology:** Muscle activity was recorded using surface electromyography (EMG). The vastus medialis (VM), biceps femoris (BF), medial head of the gastrocnemius (MG), and the tibialis anterior (TA) sites were selected for analysis. The mechanical properties (MPs) of each field were shown to be different using ASTM F-3189 protocol. **Results:** A statistically significant three-way repeated measures ANOVA interaction between field properties, sprint trial and muscle groups was determined, $F(3,36) = 10.82$, $p = .006$, $\eta_\rho^2 = .474$. Further analyses revealed an interaction effect between field properties and sprint trial, $F(1,12) = 26.57$, $p = .001$, $\eta_\rho^2 = .689$, between muscle groups and field properties $F(1,12) = 8.78$, $p = .012$, $\eta_\rho^2 = .422$ and between muscle group and sprint trial $F(1,12) = 7.29$, $p = .019$, $\eta_\rho^2 = .378$. In addition, pre-intervention mean sprint time was less on the field possessing more energy return by 9.1%. Post-intervention sprint test results show a significant difference for BF peak muscle activity on the field displaying greater force attenuation. **Conclusion:** Both pre and post intervention sprint results suggest time-dependent properties associated with a sport field could potentially influence muscle activation patterns differently for males and females.

Key words: Surface Properties, Surface Electromyography, Running, Athletes, Hamstring Muscles, Quadriceps Muscles

INTRODUCTION

Each time the foot contacts the ground during a competitive event the MPs of the playing surface has the potential to influence both biomechanical measures and physiological responses. This suggests the interaction between the athlete and a specific combination of energy storing materials and structural design of a playing surface could produce unique human performance outcomes. In other words, presumably the player-surface interface produces an identifier such as a 'finger print' – metaphorically. If athlete development professionals are able to predict how the body is going to respond when playing on a surface with specific properties, the appropriate athlete preparation protocol could potentially be implemented. The creation of a database with player-surface information could be a useful tool for player development centering on performance enhancement and surface-induced injury prevention. The interaction between the foot and the playing surface which is of most interest due to its influence on performance and injury potential occurs during skills which exhibit large accelerations. Our hypothesis states the MPs of a surface, determined by commercially available instrumentation, has an influence on human performance which makes examining the time-dependent properties of a playing surface a necessity for establishing whether or not a relationship exists between sport surfaces and human factors. It can no longer be assumed that an athlete's performance or surface-induced injury is simply related to the surface type – for example synthetic turf versus natural grass. Classifying sport surfaces based on type or composition must be reconsidered because it has been shown that synthetic turf systems or natural grass fields do not always demonstrate the same mechanical parameters from either an intra-classification or inter-classification perspective. This is supported by the findings from recent studies, which examined random samples of synthetic turf fields, quantified differences for selected properties when compared across samples (Sanchez-Sanchez et al., 2018; Villacanas et al., 2017; Sanchez-Sanchez et al., 2016; Sanchez-Sanchez et al., 2014a).

For analyzing athletic performance, there are several biomechanical and physiological factors to consider when

Published by Australian International Academic Centre PTY.LTD.

http://dx.doi.org/10.7575/aiac.ijkss.v.8n.4p.42

investigating sport specific activities exhibiting explosive unidirectional or multidirectional movements on a playing surface. Factors such as muscle activation patterns, foot – ground contact time, loading rate, ground reaction force, energy restitution, surface deformation, viscoelasticity, kinetics and kinematics provide the foundation for quantifying performance enhancement and surface-induced injury causation. When investigating the player – surface interaction and its influence on human performance we should not only rely on surface type but include the MPs of the playing surface as well. The importance of our study and others that have examined human movement patterns while performing on playing surfaces with known mechanical values is to determine the relationship between the MPs of the surface and biomechanical and physiological responses (Hales & Johnson, 2019; Lopez-Fernandez et al. 2018). In particular, the relevance of a surface's ability to store and return energy, inputted by the performer, back to the performer is of great interest due to its ability to influence performance and surface-induced soft tissue injuries. The interrelationship between the athlete and the playing surface has been well established and this provides support for considering both components when attempting to determine a cause and effect relationship. The evolution of surface testing instrumentation offers a better opportunity to easily incorporate surface testing during the same human data collection session. By incorporating instrumentation commonly used to examine sports field properties provides an opportunity to not only validate the testing devices but also identify a correlative relationship between a playing surface and human factors. Lastly, this is important because without a defined athlete – surface relationship the surface measuring device values really have no applicable meaning.

Sport performance differences between male and female athletes have been reported using various performance indicators and conditions. However, to our knowledge physiological measures between sexes before and after engaging in a sport specific agility course on surfaces possessing different MPs has not been investigated. Previous studies have shown muscle fatigue influences males and females differently during isometric contractions but sex differences are diminished during high-intensity dynamic activities (Senefeld et al., 2013; Hicks et al., 2001; Semmler et al., 1999; Hicks & McCartney, 1996). Others have indicated that the specific type of activity, muscle group involved, and age can influence the magnitude of muscle fatigue between males and females. (Enoka & Duchateau, 2008; Hunter et al., 2004). These groups conclude task specificity muscle fatigue is due to sex-related differences within the neuromuscular system. This suggests males and females adopt different neuromuscular strategies to compensate for muscle fatigue and by examining the electrical signal generated during a muscle contraction an alteration in muscle recruitment and patterning could be identified.

In order to analyze the effect of a playing surface on human performance we chose to evaluate myoelectric activity using surface electromyography (sEMG) and 30 meter sprint times. Surface EMG provides invaluable information on muscle activation amplitude and the timing or patterning of muscle activity relative to the sprinting gait cycle phases (Howard et al., 2018; Mastalerz et al., 2012; Kyrolainen et al., 2005; Nummela et al., 1994; Mero & Komi, 1987). These outcome measures can provide a better understanding of the role the MPs of a surface have on the myoelectric activation patterns between sexes. In this study, we examined the influence of a sports field MPs on muscle electrical activity. Our analysis focused on identifying neuromuscular and physiological response differences between male and female athletes while performing a sprint before and after completing a high-intensity bout of sport specific running and agility skills.

METHODOLOGY

Participants

Seven male and 6 female athletes signed a consent form before participating in the Kennesaw State University Internal Review Board approved research study. The test protocol was designed to analyze sprint running performance before and after a bout of high-intensity sport specific exercises so a high level of fitness was mandatory. The participants could only be included in the study if they were at minimum two years post injury and were not currently using orthotics or any type of joint supportive device. In addition to meeting a stringent qualification criterion, the participants completed a physical fitness questionnaire to ensure their safety. The participants were instructed to follow the prescribed pre-test nutritional guidelines beginning 48 hours prior to testing. The athletes were instructed to fast 2 hours prior to testing and not to participate in any type of strenuous activity 48 hours prior to testing (Hales & Johnson, 2019).

Study Design

The study follows a quasi-experimental design. Two outdoor athletic fields demonstrating different MPs were selected to assess the physiological responses and sprint times. The participants were randomly assigned to either Group 1 or Group 2. The test protocol began on Field X for Group 1 and Group 2 tested on Field Y. Four days later, Group 1 was tested on Field Y and Group 2 performed on Field X. Myoelectric activity was selected as a dependent variable to measure the vastus medialis (VM), biceps femoris (BF), gastrocnemius medial head (MG), and tibialis anterior (TA) during each sprint trial. Sprint times (dependent variable) were recorded for the pre and post neuromuscular fatigue protocol. The agility test course used for pre-exhaustion was adopted from a previous study (Hales & Johnson, 2019). The ASTM Standard F3189 Specification F1936 was used to measure three mechanical variables associated with sports fields: 1) force reduction is a measure of impact reduction percentage when compared to a standard concrete surface; 2) vertical deformation measures vertical displacement of the object impacting the surface; and 3) restitution of energy is a measure of energy percentage returned from a surface to the performer.

Procedures

Test preparation protocol

At the beginning of the test session, the participant was given a properly fitted multipurpose training shoe (Men's Ultimate Turf Trainer; *Under Armour, Baltimore, MD, USA*). Next, the lead-practitioner attached the surface EMG electrodes to the properly measured skin locations coinciding with the muscles of the lower extremity under investigation. To ensure maximizing signal strength, the lead practitioner prepped the electrode sites by shaving, lightly abrading, and wiping with alcohol. The electrodes were secured in place with pre-wrap and athletic tape. This was followed by the participant performing a predetermined set of agility and running skills at a low-intensity pace for 5 minutes. This provided the opportunity for the participant to warm-up while familiarizing themselves with the agility course. Lastly, the participant performed a maximum voluntary isometric contraction (MVIC) protocol targeting the VM, BF, MG, and TA muscles. (Hales & Johnson, 2019).

Exercise protocol

The muscle fatigue intervention consisted of performing 4 consecutive agility course trials with a 60-second rest between each trial. The participants performed the test protocol on each field, 7 days apart. Each athlete was tested at the same time of day to minimize any effect on performance due to potential temperature and humidity differences between test days. (Hales & Johnson, 2019). Each testing protocol included a 30 meter sprint trial performed prior to the fatigue intervention and another 30 meter sprint trial conducted immediately following the last agility based trial.

Instrumentation

Four digital (120 fps@1080 p) cameras (Hero4, *GoPro, San Mateo, CA, USA*) were positioned in the same location for each data collection session to record the agility course and two cameras were positioned perpendicular to the start and finish lines to record the 30-m sprint trials. The cameras were synchronized using a GoPro Wi-Fi remote and video editing software (*Adobe Premiere Pro, San Jose, CA, USA*) was used to ensure timing accuracy since we initiated and completed all data collection events when the first body part crossed the start and finish lines. Myoelectric activity of the VM, BF, MG, and TA was recorded using bipolar surface electrodes with a direct transmission system (1000 Hz) incorporated with myo Research software (*Noraxon USA, Inc., Scottsdale, AZ, USA*). EMG data was filtered using a fourth-order Butterworth band pass (high pass with 20 Hz cutoff and low pass with 500 Hz cutoff) processed with 20 ms root mean square smoothing window algorithms and MATLAB R2017a (MathWorks, Inc., *Natick, MA, USA*) was used for EMG signal analysis and processing (Hales & Johnson, 2019). A protocol specified by the American Standards for Testing and Materials (ASTM) was used to analyze mechanical properties of the athletic fields. The Advanced Artificial Athlete recorded force reduction (FR; in percentage), standard vertical deformation (stV; in millimeters), and energy restitution (ER; in percentage) (*Labosport France, Le Mans, France*). The field test procedure (ASTM-1936) was performed in each quadrant of the test areas prior to data collection. The instrument was calibrated according to the manufacturer's guidelines. Baseline measurements were conducted by dropping the spring dampened system onto concrete three times consecutively.

Statistical Analysis

Group means and SDs were used to determine physiological and temporal differences influenced by sport field MPs. An alpha level of .05 (n = 13) was adopted to minimize any type I statistical errors. A three -way repeated-measures analysis of variance (ANOVA) examined muscle activation pattern (VM, BF, MG, and TA) differences while sprinting on the different test fields. Data sets were analyzed using Shapiro-Wilk's test for normality. The sample design consisted of one between-subject independent variable (field type) and two within-subject independent variables (muscle group × sprint trial). Between-subject parameter estimates compared the treatment (field type) effect on muscle activation patterns. For the sample design, within-subjects effects (trial), between subjects effects (field), and between-subjects interaction effects (field type × trial) were examined. A Mann-Whitney U calculation determined differences between males (N = 7) and females (N = 6) for the dependent variables. Follow-up pairwise comparison tests were performed, where appropriate. Data were analyzed with the statistic software SPSS v 27.0.

RESULTS

Participant Characteristics

Participants' physical characteristics (mean +SD): age = 20±1.1 yrs, weight = 82.2±13.9 kg, and height = 1.8±0.3 m, were recorded prior to testing. The participants were collegiate level athletes competing in soccer (F = 3 and M = 4) and lacrosse (F = 3 and M = 3).

Test Field Conditions

Environmental conditions

The test fields are referenced as either Field X or Field Y distinguished by their MP. Ambient temperature for Field X data collection was 22.3°C (3.1°C) and 23.6°C (2.5°C) for Field Y. Relative humidity for Field X testing was 58.3% (3.3%) and 61.4% (3.9%) for Field Y during data collection. No significant difference was determined for ambient temperature or relative humidity.

Surface mechanical properties

The AAA device was checked for accuracy by following the manufacturer's calibration protocol prior to data collection. The intraclass correlation coefficient (ICC) results for the concrete drop-test determined instrument reliability was excellent

(> 0.99). The test-retest reliability test comparing the field properties from session to session concluded both Field X (ICC > 0.79) and Field Y (ICC > 0.85) were excellent. ER mean for Field X was lower (28.23% [2.14]%) than the ER for Field Y (41.63% [1.98%]), t(3) = 11.14, p = .011, d = 6.49. The calculated t test, t(3) = 3.82, p = .023, d = 3.06, for force reduction on Field X (50.53% [1.78%]) and Field Y (54.91% [1.08%]) show a significant difference. Mean vertical deformation was also less for Field X (5.68 [0.42] mm) compared with Field Y (7.13 [0.26] mm), t(3) = 5.75, p = .02, d = 4.23. International field performance standards are presented in Table 1.

Table 1. International sport field performance standards

	Field standards		
	IRB	**FIFA (one star)**	**FIFA (consistency)**
FR-%	55 – 70	55 – 70	< 10%
VD-mm	5.5 – 10	4 – 9	< 15%
ER-%	20 – 50	_	_

International Rugby Board (IRB)[5] *and Fédération Internationale de Football Association (FIFA)*[6] *standards. FIFA consistency describes the acceptable range between test sites on the field.* Abbreviations: ER, energy restitution; FIFA, Fédération Internationale de Football Association; FR, force reduction; IRB, International Rugby Board; VD, vertical deformation. Note: FIFA consistency describes the acceptable range between test sites on the field.

Surface Properties Effect

A significant three-way interaction between field properties, sprint trials and muscle groups was calculated, $F(3,36) = 10.82$, p = .006, $\eta_p^2 = .474$. Follow-up analyses identified statistical significance in two-way interactions and main effects. A two-way repeated-measures ANOVA revealed an interaction effect between field properties and sprint trial, $F(1,12) = 26.57$, p = .001, $\eta_p^2 = .689$, for mean muscle activity from the group of muscles under investigation. A two-way repeated-measures ANOVA showed an interaction effect between muscle groups and field properties $F(1,12) = 8.78$, p = .012, $\eta_p^2 = .422$ and also between muscle groups and sprint trials $F(1,12) = 7.29$, p = .019, $\eta_p^2 = .378$. Further analysis showed significant main effect difference between muscle groups $F(3,36) = 45.39$, p = .001, $\eta_p^2 = .791$. Figure 1 shows muscle activity differences for the participants performing a sprint on fields with different MP prior to the muscle fatiguing intervention.

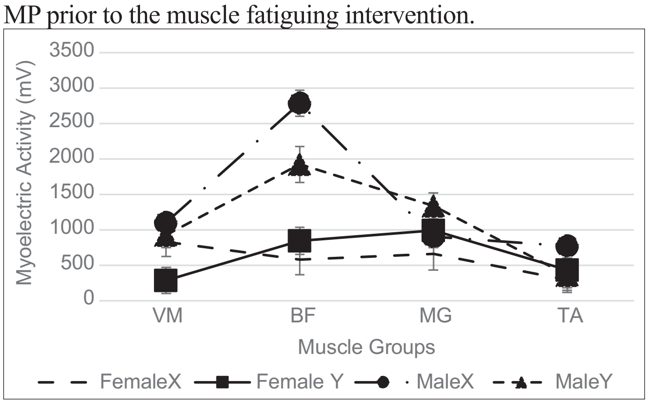

Figure 1. Comparison of mean and (SD) peak muscle activation for the male and female groups on different playing surfaces

Muscle Fatigue Factor

MVICs were recorded prior to each field data collection session. The maximum muscle contractions were compared to examine test-retest reliability from session to session. The ICC for MVIC electromyogram recordings were good (0.71 - 0.88) to excellent (> 0.89) and SEMs were moderate to good (< 10%) for session to session comparisons. Table 2 presents peak means and SDs percentages of muscle activity relative to the maximum recorded values for the sprint test. Comparing peak muscle group activity means between pre-intervention sprint trials and post-intervention sprint trials across the different fields shows a significant difference $F(3, 36) = 3.54$, p = .016, $\eta_p^2 = .053$. Further analyses were conducted to identify specific differences between individual muscle groups. A post hoc analysis for post-fatigue sprinting on field X depicts a significant difference for the BF $t(12) = 3.56$, p = .004 and TA $t(12) = 2.39$, p = .034, peak muscle activation. A post hoc analysis for post-fatigue sprinting on field Y shows significant differences for MG $t(12) = 9.13$, p < .001 peak muscle activation.

Sex Differences

A three-way repeated measures ANOVA revealed a significant interaction effect for the group of male participants $F(3,18) = 11.21$, p = .015, $\eta_p^2 = .651$. Post hoc analyses for the pre-fatigue intervention sprint trials for males determined significance for VM $t(6) = 5.29$, p = .002; BF $t(6) = 10.76$, p < .001; MG $t(6) = 6.89$, p < .001; and TA $t(6) = 11.37$, p < .001 on field X. For field Y, the VM $t(6) = 5.11$, p = .002; BF $t(6) = 5.25$, p = .001; MG $t(6) = 19.02$, p = .001; and TA $t(6) = 8.51$, p = .001 show significance. The post hoc analysis (Figure 2) for pre-fatigue intervention sprint trials for the group of females indicate significance for VM $t(5) = 8.27$, p < .001 when running on field X. Muscle groups VM $t(5) = 2.61$, *p* = .048; BF $t(5) = 4.74$, p = .005; and MG $t(5) = 4.09$, p = .01 show significance on field Y.

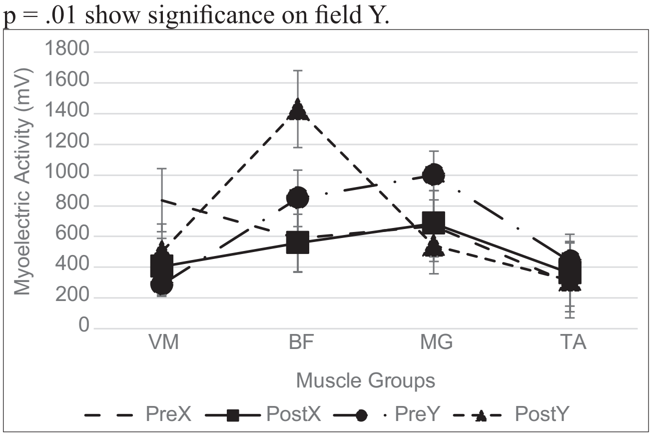

Figure 2. Comparison of pre-fatigue intervention and post-fatigue intervention means and (SD) peak muscle activity for the group of female athletes

Additional pre-fatigue analyses were conducted focusing on sex differences for each test field. The Mann- Whitney U calculation for post-intervention sprint identified a significant difference for VM (U = 32.00, p = .05) and BF (U = 42.00, p = .003) on field X; and BF (U = 4.00, p = .015) and TA (U = 42.00, p = .003) showed a significant difference on field Y. A follow-up analysis identified muscle activation differences between test fields for each group of males and females. The nonparametric calculations for pre-intervention sprint determined significance for VM (U = 38.00, p = .003), BF (U = 42.00, p = .003), and TA (U = 38.00, p = .002) on field X; and VM (U = 42.85, p = .001), BF (U = 37.99.02, p = .002), and MG (U = 41.36, p = .002) showed significance on field Y depicted in Figure 3.

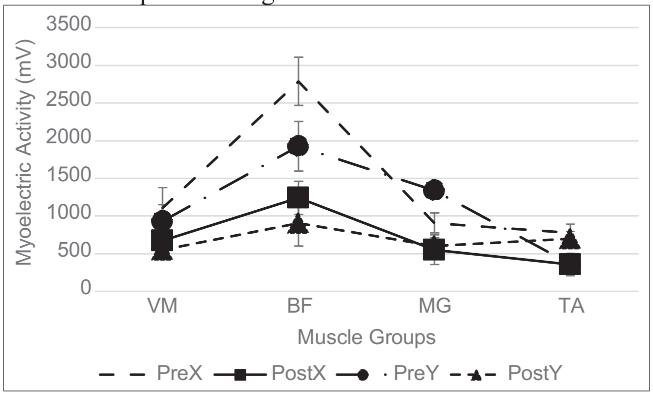

Figure 3. Comparison of Pre-fatigue Intervention and Post-fatigue Intervention Means and (SD) Peak Muscle Activity for the Group of Male Athletes

Sprint Running Times

A repeated-measures ANOVA determined an interaction effect between field properties and sprint trial, $F(1,12) = 7.08$, p = .02, $\eta_p^2 = .346$. The mean pre-fatigue test 30-m sprint time was slower on Field X than Field Y, $t(12) = 19.634$, p = .01, $d = 1.44$. The follow-up analysis, $t(12) = 13.23$, p = .01, $d = 1.76$, also revealed the 30-m mean post-fatigue test time on Field X was slower than the sprint time on Field Y. The pre-fatigue and post-fatigue test times were analyzed independently to identify any differences associated with the time-dependent field properties in Table 3. Pre-fatigue analysis on Field X and Field Y showed a difference between sexes (U = 28.00, p < .001) and (U = 4.50, p = .014), respectively. Male and female sprint times following the fatigue intervention were also different for both fields, (*Field X*, U = 1.50, p < .001; and *Field Y*, U = 2.00, p < .001).

Table 3. Comparison of male and female sprint time means (SD) for pre-fatigue and post-fatigue conditions

Test field	Sprint time: Pre-fatigue Male	Pre-fatigue Female	Post-fatigue Male	Post-fatigue Female
X	4.62 (0.07)	4.95 (0.14)	5.17 (0.12)	5.44 (0.09)
Y	4.28 (0.12)	4.51 (0.14)	4.68 (0.09)	5.02 (0.08)

DISCUSSION

The study identified a viable means for investigating and quantifying the athlete-surface interaction for a group of college athletes while sprinting short distances before and after implementing a series of high-intensity sport specific activities. The results provide supportive evidence for our hypothesis stating that time-dependent properties associated with a sports field elicit different myoelectric activation patterns for males and females under both pre-fatigue and post-fatigue conditions. Sprint times were also used as an additional performance indicator. For our analysis, the test fields MPs were determined to be significantly different, and both male and female athletes ran 10% and 11% faster, respectively, on the field which yielded greater ER-%. These pre-fatigue sprint times suggest the mechanical properties associated with a sports field can influence running speeds. The participants were not intentionally fatigued prior to the initial sprint test and a standardized warm-up and flexibility protocol was followed, we feel confident the pre-fatigue sprint condition was a valid means for determining the influence of a sport field's MP on performance. Previous studies have used sprint times to determine performance differences between field types. A study involving young soccer players used sprints as a performance indicator and found the children (12 years) were significantly faster on AT compared to NG in both dribbling and non-dribbling trials, while the adolescents (14 years) were only significantly faster on AT without the inclusion of dribbling (Kanaras et al., 2014). Another study analyzing a group of rugby players performing sprints on NG and AT reported significantly different sprint times on the different surfaces (Choi et al., 2015). In contrast, a study investigating a group of American football players performing a 40 yard dash on NG and AT found no significant difference in sprint times on different fields (Gains et al., 2010). These early studies which assessed the influence of sport fields on sprinting were categorized solely by surface type so comparing these findings to studies which measure playing surface MPs must be done with considerable caution. More recent studies in this area investigating physiological responses involving sprint running have done so on surfaces with known MPs. One study which analyzed the testing fields using sprint times as an indicator for performance found mean sprint times were influenced by ER-% (Sanchez-Sanchez et al., 2014a). Another study analyzed running performance on AT and NG surfaces where the fields demonstrated similar mechanical behavior. The investigators concluded the fields did not differ enough to cause different physiological and neuromuscular responses. Under this circumstance playing on AT should cause similar neuromuscular responses to NG (Lopez-Fernandez et al., 2018). Running which involves straight-head or multi-directional accelerations is an easily implemented performance indicator with practical application and should be included in future athlete-surface research studies. However, combining sprint and agility times with other instrumentation capable of examining biomechanical and physiological responses could provide a more complete understanding of the relationship between surface MPs, performance enhancement and surface-related soft tissue injury.

The study included two important components making it unique compared to other investigations in this area. These include the objective analysis of the sports fields and controlling footwear. Firstly, the test fields were analyzed using ASTM Standard 3189 test protocol which determined significant differences between fields based on the selected variables: force reduction (FR-%), standard vertical deformation (stVD-mm), and energy restitution (ER-%).

Field-Y demonstrated 32% greater ER-% than field-X, both stVD-mm and FR-% were also significantly greater for field-Y indicating a more resilient surface. Studies analyzing surface stiffness and the role it plays in human energy expenditure and energy returned back to the performer have reported differences based on surface stiffness (Kerdok et al., 2002; Nigg & Yeadon, 1987). Another study showed excessive field rigidity actually elicits an increase in running times (Sanchez-Sanchez et al., 2014b). A group investigating physiological responses for a group of athletes performing sprints and sport specific activities on surfaces possessing different MPs were able to report correlative arguments regarding the influence of surface properties on human performance (Lopez-Fernandez et al., 2018). Studies of this nature provide evidence that a surface possesses properties which have the potential to either enhance or inhibit human performance. More importantly, these studies demonstrate the importance of analyzing the interaction between the athlete and the playing surface. Secondly, controlling footwear is another consideration when evaluating the athlete-surface interface. Several studies support the notion that the interaction between footwear and the playing surface can influence human outcome measures for field based activities which entail large accelerations or abrupt changes in acceleration (Willwacher et al., 2014; Wannop et al., 2009; Heidt et al., 1996; Andreasson et al., 1986). The footwear-surface interface is important to consider when assessing performance on sports field because of the role friction plays during high speed movements (Schrier et al., 2014; Severn et al., 2011; Potthast et al., 2010). Traction during running can enhance speed development, whereas, slippage will inhibit performance. The findings from one study suggests the average college football player would attain approximately the same straight-head sprint speed on the new generation AT as achieved on NG but demonstrated players change-of-direction speed was faster on AT (Gains et al., 2010). These differences could be attributed to the variety of footwear worn by the participants since a standardized shoe was not used.. A similar study investigating surface-footwear traction performance reported significant variability in slalom run times and attributed those differences to the various stud types or stud geometrical shape. (Sterzing et al., 2009). Our decision to control footwear was influenced by previous research which demonstrated inconsistent outcomes when footwear was not controlled. The athletic shoe we chose offered a separate male and female version which had multi-surface compatibility. One of the most important factors to consider when analyzing the athlete-surface relationship is identifying an appropriate mechanism for quantifying performance. Our selection of instrumentation was partly based on the fact that previous studies support the use of sEMG while incorporating a similar methodology as the one used in our study (Hewett et al., 2005; Jonhagen et al., 1996). Our findings revealed male and female athletes demonstrated significantly different sEMG patterns during the sprint trials. During the pre-fatigue sprint trial, the BF showed the greatest difference between sexes by 79% followed by TA at 60% on field-X while VM and BF showed significant difference on field-Y by 73% and 50%, respectively. The male athletes demonstrated the greatest muscle electrical activity for each of the selected muscle group across test fields during the initial sprint trial. There was a high correlation between the sEMG recordings during the sprint and MCVCs. Even though it is necessary to be cautious when examining surface electromyogram data, it seems to be valid for analyzing the surface effect in neuromuscular activity during running activities (Fauth et al., 2010). We followed a stringent preparation procedure which produced consistent electrode site locations based on anthropometric measurements. Additional care securing the electrodes to the skin was taken so the high-speed movements would not cause electrode detachment and minimize artifact due to electrode movement. A limitation of our sEMG analysis and regardless the care taken to ensure consistency, the differences in muscle electrical activity reported could be due to co-activation of adjacent muscle or due to a person's unique fiber-type arrangement instead of the influence of the playing surface. Besides sEMG, other types of instrumentation have been used to quantify the athlete-surface interrelationship. One such study utilizing tensiomyography (TMG) quantified muscular response in the lower extremity for a group of amateur soccer players after completing a sport specific running protocol and found no significant difference whether performing on artificial turf or natural grass (Lopez-Fernandez et al., 2018). Several other studies analyzed blood lactate changes following a bout of sport specific activities (Stone et al., 2016; Hughes et al., 2013) also reported no differences in performance between field types. Another study analyzing blood biomarkers found significant differences in running performance on different surfaces (Ammar et al., 2018). Blood specimen studies provide useful insight into blood-substrate differences after sprinting on AT and NG, unfortunately, the influence of the MPs of the testing fields could not be correlated with the blood-substrate concentration since the test fields were not examined. Other studies using sprint times as a performance indicator on different surfaces (Hales & Johnson, 2019; Choi et al., 2015; Kanaras et al., 2014; Chan et al., 2014 Gains et al., 2010) reported MPs did influence sprint speed. The increasing number of research studies in this area and the varying test protocols have produced information focusing on the athlete-surface relationship which is contradictory in many instances.

Our research study included a sprint test on the different fields following a series of high-intensity agility drills to analyze lower extremity myoelectric activity while in a state of neuromuscular fatigue. A study using a 30 meter sprint as a performance indicator found a 16% difference in mean sprint times by a group of soccer players after performing a muscle fatiguing activity (Sanchez-Sanchez et al., 2014b). We found a similar sprint time reduction in our study, sprint performance for the male group was 11% slower following the agility course, whereas, females showed a 9% decrease in speed on the surface with less ER-%.Numerous studies have reported the effect of neuromuscular fatigue on high-intensity running activities (Lopez-Fernandez et al., 2018; Ammar et al., 2018; Chan et al., 2014). We adopted a similar method to determine if the MPs of the selected sports fields could influence neuromuscular fatigue. Following the initial sprint trial, athletes completed a sport specific activity course at maximum effort to induce a state of muscle fatigue. The athletes HR and VO2 were recorded using a portable gas exchange system while performing the agility course protocol. Within 60 seconds of completing four bouts of the course, athletes performed a sprint on the test field. We were confident the athletes were putting forth maximum effort during the sport specific drills since HR mean was 80% (+4.1) and peak HR was 90% (+5.2) of mean HRmax, mean VO2 was 82% (+5.6) of the measured maximum oxygen consumption mean, and mean RER was > 1.1. These physiological parameters and the sEMG frequency domains were used to conclude neuromuscular fatigue was achieved by the group of participant. Our analysis revealed greater difference in sprint times for field-Y which produced less ER-% and demonstrated greater FR-%. These findings suggest the athletes displayed more neuromuscular fatigue after performing the sport specific drills on the softer surface. This supports the idea that the MPs of a surface can influence the rate and magnitude of mechanical work placed on the musculoskeletal system thus being a precursor to muscle fatigue. During the post-fatigue sprint trial, the results show females produced 51% less BF muscle activity following a bout of high-intensity of sport specific sprint and agility drills. This particular finding has a great deal of practical significance since a role of the hamstring muscle group acts to stabilize the knee joint during running activities. If the hamstring muscle is fatigued and unable to provide the needed stability it could result in a greater potential for knee injuries. Research indicates females experience greater incidences of knee injuries than males when participating in field sports (Voskanian, 2013; Ireland, 2002; Malinzak et al., 2001; Arendt et al., 1999). Previous research has shown fatigability differences between male and female participants (Hicks et al., 2001; Hunter, 2009; Yoon et al., 2007) suggesting males are more susceptible to a more dramatic reduction in performance when fatigued. The sprint speed decrease was slightly less for both male and female participants on the field exhibiting greater ER-%. The sprint time decreases are statistically different as well as practicality different considering the sprint distance was 30 meters. The sprint time difference between pre-fatigue and post-fatigue conditions were similar for both groups, however, the electromyogram data showed quite different muscle electrical activity patterns between sexes. This suggests the male and female participants in our study adapted to the different surfaces using different neuromuscular strategies. These findings are relevant because the probability of a musculoskeletal injury occurring is more likely to occur when the neuromuscular system is fatigued (Enoka & Duchateau, 2008; Malinzak et al., 2001; Kallenberg et al., 2007; Chappell et al., 2005). Our data set suggests the combined effect of a field's MPs and muscle fatigue effects sprint performance differently than the pre-fatigue situation.

CONCLUSION

The selected sport fields, which differed based on their mechanical properties, influenced muscle activation patterns associated with sprint running. The myoelectric activity was significantly different between the male and female performers while sprinting under both pre and post neuromuscular fatigue conditions. Sport fields should not be simply classified by their composition or type. Coaches need to understand MPs can differ between heterogeneous sports fields as well as many homogeneous sport field systems. This suggest competition preparation, or team practices, should be conducted on a playing surface with the same MPs represented by the competition or game field.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the support of the Office of the Vice President of Research (OVPR) at Kennesaw State University for awarding the grant which funded the research project. The findings from this investigation do not constitute endorsement of any products assessed by the authors or the journal. The experiments comply with the current laws of the country in which they were performed. The authors have no conflict of interest to declare.

REFERENCES

Ammar, A., Bailey, S.J., Hammouda, O., Trabelsi, K., Merzigui, N., El Abed, K. et al. (2018) Effects of playing surface on physical, physiological, and perceptual responses to a repeated-sprint ability test: Natural grass versus artificial turf. *International Journal of Sports Physiology and Performance,* 14, 1219-1226. doi: 10.1123/ijspp.2018-0766

Andreasson, G., Lindenberger, U., Renstrom, P., & Peterson, L. (1986). Torque developed at simulated sliding between sport shoes and an artificial turf. *American Journal of Sport Medicine*, 14(3), 225-230. https://doi.org/10.1177/036354658601400308

Arendt, E.A., Agel, J., & Dick, R. (1999). Anterior cruciate ligament injury patterns among collegiate men and women. *Journal of Athletic Training*, 34(2), 86-92. PMID: 16558564 PMCID: PMC1322895

Chan, C.K., Yung, S.H., Liu, M.W., & Chan, K.M. (2014). The change in lower limb kinematic and EMG activity of sprinting after soccer-specific fatigue among female soccer players. *British Journal of Sports Medicine,* 48, 578. doi: 10.1136/bjsports-2014-093494.50

Chappell, J.D., Herman, D.C., Knight, B.S., Kirkendall, D.T., Garrett, W.E., & Yu, B. (2005). Effect of fatigue on knee kinetics and kinematics in stop- jump tasks. *American Journal of Sports Medicine,* 33(7), 1022-1029. doi.org/10.1177/036354604273047

Choi, S.M., Sum, K.W.R., & Leung, F.L.E. (2015). Comparison between natural turf and artificial turf on agility performance of rugby union players. *Advances in Physical Education,* 5, 273-281. doi.org/10.4236/ape.2015.54032

Enoka, R.M., & Duchateau, J.(2008). Muscle fatigue: What, why and how it influences muscle function. *Journal of Physiology*, 586(1), 11-23. doi.org/10.1113/physiol.2007.139477

Fauth, M,, Petushek, E., Feldmann, C., Hsu, B., Garceau, L., G., Lutsch, B. et al. (2010). Reliability of surface electromyography during maximal voluntary isometric contractions, jump landings, and cutting. *Journal of Strength and Conditioning Research*, 24(4), 1131-1137. doi.org/10.1519/JSC.0b013e3181cc235326.

Gains, G., Swedenhjelm, A., Mayhew, J., Bird, H., & Houser J. (2010). Comparison of speed and agility performance of college football players on field turf and natural grass. *Journal of Strength and Conditioning Research,* 24(10), 2613-2617. doi: 10.1519/JSC.0b013e3181eccdf8

Hales, M.E., & Johnson, J.D. (2019). Sport field properties influence muscle recruitment patterns and metabolic response. *International Journal of Sport Physiology and Performance*, 14(1), 83-90. doi.org/10.1123/ijspp.2018-0004

Heidt, R.S., Dormer S.G., Cawley P.W., Scranton, P.E., Losse, G., & Howard, M. (1996). Differences in friction and torsional resistance in athletic shoe-turf surface interfaces. *American Journal of Sports Medicine*, 24(6), 834-842. doi:10.1177/036354659602400621.

Hewett, T.E., Zazulak, B.T., Myer G.D., & Ford K.R. (2005). A review of electromyographic activation levels, timing differences, and increased anterior cruciate ligament injury incidence in female athletes. *British Journal of Sports Medicine* 39(6), 347-350. doi: 10.1136/bjsm.2005.018572

Hicks, A.L., Kent-Braun, J., & Ditor, D.S. (2001). Sex differences in human skeletal muscle fatigue. *Exercise and Sport Science Review*, 29(3), 109-112. doi: 10.1097/00003677-200107000-00004

Hicks, A.L., & McCartney, N. (1996). Gender differences in isometric contractile properties and fatigability in elderly human muscle, *Canadian Journal of Applied Physiology*, 21(6), 441-54. https://doi.org/10.1139/h96-039

Howard, R., Conway, R., & Harrison A. (2018). Muscle activity in sprinting: a review. *Sports Biomechanics,* 17(1), 1-17. doi:10.1080/14763141.2016.1252790

Hughes, M.G., Birdsey, L, Meyers, R., Newcombe, D., Oliver, J.L., Smith, P.M., et al. (2013). Effects of playing surface on physiological responses and performance variables in a controlled football simulation. *Journal of Sports Science*, 31(8), 878-886. https://doi.org/10.1080/02640414.2012.757340

Hunter, S.K. (2009). Sex differences and mechanisms of task-specific muscle fatigue. *Exercise and Sport Science Review*, 37(3), 113-122. doi: 10.1097/JES.0b013e3181aa63e2

Hunter, S.K., Critchlow, A., & Enoka, R.M. (2004). Influence of aging on sex differences in muscle fatigability. *Journal of Applied Physiology*, 97(5), 1723-1732. https://doi.org/10.1152/japplphysiol.00460.2004

Ireland, M.L. (2002). The female ACL: why is it more prone to injury? *Orthopedic Clinician North America*, 33(4), 637-651. doi: 10.1016/S0030-5898(02)00028-7

Jonhagen, S., Ericson, M.O., Nemeth, G., & Eriksson E. (1996). Amplitude and timing of electromyographic activity during sprinting. *Scandanavian Journal of Medicine and Science in Sports,* 6(1), 15- 21. https://doi.org/10.1152/japplphysiol.00460.2004

Kallenberg, L.A.., Schulte, E., Disselhorst-Klug, C., Hermens, H.J. (2007). Myoelectric manifestations of fatigue at low contraction levels in subjects with and without chronic pain. *Journal of Electromyography and Kinesiology*, 17(3), 264-274. doi: 10.1016/j.jelekin.2006.04.004

Kanaras, V., Metaxas, T., Mandroukas, A., Gissis, I., Zafeiridis, A., Riganas, C.S. et al. (2014). The effect of natural and artificial grass on sprinting performance in young soccer players. *American Journal of Sport Science,* 2(1), 1-4. doi: 10.11648/j.ajss.20140201.11

Kerdok, A.E., Biewener, A.A., McMahon, T.A., Weyand, P.G., & Herr, H.M. (2002). Energetics and mechanics of human running on surfaces of different stiffnesses. *Journal of Applied Physiology*, 92(2), 469-478. https://doi.org/10.1152/japplphysiol.01164.2000

Kyröläinen, H., Avela, J., & Komi, P. V. (2005). Changes in muscle activity with increasing running speed. *Journal of Sports Sciences,* 23(10)*,* 1101-1109. doi: 10.1080/02640410400021575

Lopez-Fernandez, J., Garcia-Unanue, J., Sanchez-Sanchez, J., Leon, M., Hernando, E., & Gallardo, L., (2018). Neuromuscular responses and physiological patterns during a soccer simulation protocol. Artificial turf versus natural grass. *Journal of Sports Medicine and Physical Fitness*, 58(11), 1602-1610. doi: 10.23736/S0022- 4707.17.07768-4

Mastalerz, A., Gwarek, L., Sadowski, J., & Szczepanski, T. (2012). The influence of the run intensity on bioelectrical activity of selected human leg muscles. *Acta of Bioengineering and Biomechanics,* 14(2)*,* 101-107. doi: 10.5277/abb120213

Malinzak, R.A., Colby, S.M., Kirkendall, D.T., Yu, B., & Garrett, W.E. (2001). A comparison of knee joint motion patterns between men and women in selected athletic tasks. *Clinical Biomechanics*, 16(5), 438-445. doi: 10.1016/S0268-0033(01)00019-5

Mero, A., & Komi, P. V. (1987). Electromyographic activity in sprinting at speeds ranging from sub-maximal to supra-maximal. *Medicine and Science in Sports and Exercise,* 19(3)*,* 266-274. PMID: 3600241

Nigg, B.M. & Yeadon, M.R. (1987). Biomechanical aspects of playing surfaces. *Journal of Sports Science*, 5(2), 117-145. https://doi.org/10.1080/02640418708729771

Nummela, A., Rusko, H., & Mero, A. (1994). EMG activities and ground reaction forces during fatigued and non-fatigued sprinting. *Medicine and Science in Sports and Exercise,* 26(5)*,* 605-609.

Potthast, W., Verhelst, R., Hughes, M., Stone, K., & De Clercq, D. (2010). Football-specific evaluation of player-surface interaction on different football turf systems. *Sports Technology*, 3(1), 5-12. https://doi.org/10.1080/19346190.2010.504278

Sánchez-Sánchez, J., Haxaire, P., García-Unanue, J., Felipe, J.L., Gallardo, A.M. & Gallardo, L. (2018). Determination of mechanical properties of artificial turf football pitches according to structural components. *Proceedings of the Institution of Mechanical Engineers, Part P: Journal of Sports Engineering and Technology*, 232(2), 131-139. https://doi.org/10.1177/1754337117717803

Sanchez-Sanchez, J., Garcia-Unanue, J., Felipe, J.L., Jiménez-Reyes, P., Viejo-Romero, D., Gomez-Lopez, M., et al. (2016). Physical and physiological responses of amateur football players on third-generation artificial turf systems during simulated game situations. *Journal of Strength and Conditioning Research*, 30(11), 3165-3177. doi:10.1519/JSC.0000000000001415

Sánchez-Sánchez, J., Felipe, J.L., Burillo, P., del Corral, J. & Gallardo, L. (2014a). Effect of the structural components of support on the loss of mechanical properties of football fields of artificial turf. *Proceedings of the Institution of Mechanical Engineers Part P Journal of Sports Engineering and Technology,* 228(3), 155-164. doi:10.1177/1754337114527276.

Sanchez-Sanchez, J., Garcıa-Unanue, J., Jimenez-Reyes, P., Gallardo, A., Burillo P., Felipe, J.L., et al. (2014b). Influence of the mechanical properties of third-generation artificial turf systems on soccer players' physiological and physical performance and their perceptions. *Journal of Sports Medicine and Physical Fitness,* 9(10), e111368. doi:10.1371/0111368

Schrier, N.M., Wannop, J.W., Lewinson, R.T., Worobets, J., & Stefanyshyn, D. (2014). Shoe traction and surface compliance affect performance of soccer related movements. *Footwear Science*, 6(2), 69-80. https://doi.org/10.1080/19424280.2014.886302

Semmler, J.G., Kutzscher, D.V., & Enoka, R.M. (1999). Gender differences in the fatigability of human skeletal muscle. *Journal of Neurophysiology*, 82(6), 3590-3593. https://doi.org/10.1152/jn.1999.82.6.3590

Senefeld, J., Yoon, T., Bement, M.H., & Hunter, S.K. (2013). Fatigue and recovery from dynamic contractions in men and women differ for arm and leg muscles. *Muscle Nerve*, 48(3), 436-439. https://dx.doi.org/10.1002%2Fmus.23836

Severn, K.A., Fleming, P.R., Clarke, J.D., & Carré, M.J. (2011). Science of synthetic turf surfaces: investigating traction behaviour. *Proceedings of the Institution of Mechanical Engineers, Part P: Journal of Sports Engineering and Technology,* 225(3), 147-158. doi:10.1177/1754337111408980

Sterzing, T., Muller, C., Hennig, E., & Milani, T.L. (2009). Actual and perceived running performance in soccer shoes: A series of eight studies. *Footwear Science*, 1(1), 5-17. doi: 10.1080/19424280902915350

Stone, K.J., Hughes, M.G., Stembridge, M.R., Meyers, R.W., Newcombe, D.J., & Oliver, J.L. (2016). The influence of playing surface on physiological and performance responses during and after soccer simulation. *European Journal of Sport Science*, 16(1), 42-49. doi: 10.1080/17461391.2014.984768

Villacañas, V., Sánchez-Sánchez, J., García-Unanue, J., López, J., & Gallardo, L. (2017). The influence of various types of artificial turfs on football fields and their effects on the thermal profile of surfaces. *Proceedings of the Institution of Mechanical Engineers, Part P: Journal of Sports Engineering and Technology,* 231(1), 21- 32. doi:10.1177/1754337115624819

Voskanian, N. (2013). ACL Injury prevention in female athletes: review of the literature and practical considerations in implementing an ACL prevention program. *Current Review Musculoskeletal Medicine,* 6(2), 158-163. doi: 10.1007/s12178-013-9158-y

Wannop, J.W., Luo, G., & Stefanyshyn, D. (2009). Wear influence traction properties in Canadian high school football. *Footwear Science*, 1(3), 121-127. https://doi.org/10.1080/19424280903410062

Willwacher, S., Regniet, L., Fischer, K.M., Oberlander, K.D., & Bruggemanna, G.P. (2014). The effect of shoes, surface conditions and sex on leg geometry at touchdown in habitually shod runners. *Footwear Science*, 6(3), 129-138. doi:10.1080/19424280.2014.896952.

Yoon, T., Schlinder, D.B., Griffith, E.E., & Hunter S.K. (2007). Mechanisms of fatigue differ after low- and high-force fatiguing contractions in men and women. *Muscle Nerve*, 36(4), 515-524. https://doi.org/10.1002/mus.20844