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LOWER EXTREMITIES MUSCLE CONTRIBUTIONS TO HORIZONTAL AND VERTICAL ACCELERATION OF THE CENTER OF MASS DURING THE FIRST STANCE PHASE IN SPRINTING OF SOCCER PLAYER

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ABSTRACT

Introduction: Sprinting is one of the most important activities in soccer that affects the outcome performance of players. The acceleration ability of the first stance phase was suggested to play a key role in sprinting performance of soccer players. The purpose of this study was to identify how lower limb muscles contributed to the acceleration of the center of mass (COM) and to determine primary muscles during the first stance phase of sprinting in soccer players to develop training program in minimizing injury risk or in strengthening key muscle groups enhancing the effectiveness of rehabilitation for athletes before return to competition.

Methods: Five female soccer players sprinted for 5 meters, at a Laboratory room. Vicon system and force plates were used to collect maker trajectories and ground reaction forces. The contribution of each muscle was calculated by an analysis tool in Opensim.

Results: Gastrocnemius and soleus muscles contributed the highest (24.6% and 25.3%, respectively) to the total forward acceleration of the whole body. Similarly, approximately 37% of the total upward acceleration of the COM was induced by the soleus, while 36.1% was induced by the gastrocnemius. Hip extensors induced nearly 22.2% of the total forward acceleration, while the quadriceps contributed around 10% of the total upward acceleration.

Conclusion: Gastrocnemius and Soleus play key roles in acceleration performance, and this muscle group should be highly focused on training and treatment for sprinting motion of soccer players. Similarly, Hamstrings and gluteus muscles are also considered to enhance acceleration performance.

Keywords: Acceleration, muscle contribution, sprinting.

1. INTRODUCTION

1.1. Sprinting in soccer

In sports generally and football particularly, running speed is one of the important physical capacities for the outcome performance of players. Specifically, better sprinting was reported to be crucial in allowing players to move faster and gain advantage on their opponents, which can influence the results. Thus, sprinting speed is one of the most necessary factors that can enhance player performance in many sports [1]. Namely, sprinting enables players to escape from their opponents and/or to reach a free zone to shoot on the goals or to give a decisive pass in attacking and defeating their opponents in defending [2]. In addition, sprinting was used as one of the key physiological activities to identify and predict talent of soccer players [3]. Outcome results of the first 10 meters in the 40-meter sprinting test can be used to evaluate present performance of players in actual playing conditions [4]. From these reports, the improvement of sprinting performance would contribute to the enhancement of soccer player performance.

1.2. Improving sprinting performance in soccer players

According to studies, a sprinting motion can be separated into three distinct phases, if considering the horizontal velocity of players. Those phases are acceleration, achievement and maintenance of highest velocity, and deceleration phases.

In soccer players, more than 90% of sprinting during a soccer match is short sprinting, with average time of sprinting under 5 seconds, and mean distance shorter

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than 20 meters [3]. Likewise, some studies showed that the first 5 meters in acceleration of short sprinting is very important for good performance in sports. Moreover, the stance phase of the first step after starting is one of the keys in acceleration performance of soccer players [4,5].

To enhance sprint acceleration, players must maximize horizontal acceleration within the shortest time and distance. Increasing step length and frequency is essential for boosting horizontal acceleration. A key strategy is generating strong forward propulsive impulse during the stance phase to drive the body forward rapidly. Improving upward acceleration—by increasing vertical impulse to reduce ground contact time—also contributes to better acceleration [1,6]. Hence, developing forward and upward acceleration during the first stance phase can effectively improve sprinting performance in soccer players.

1.3. The role of muscle strength and power in the acceleration performance

Researchers found strong correlation between short sprinting performance and lower extremity muscle strength, thus increasing muscle strength may improve short sprint performance [1,2].

Understanding muscle contribution during the acceleration process would help in developing effective training programs and increasing the efficiency of exercises to minimize recovery duration [7,8]. Specifically, players and coaches may have better evidence to decide consistent exercises that may increase effectiveness of training programs, and for the therapist to provide more effective treatments that may reduce the time of recovery.

Determining muscle function in the acceleration phase using only experimental data such as EMG, kinematics, or kinetics, is inadequate in quantifying the details of muscle function. Thus, the dynamic simulation method was developed and used to investigate the role of individual muscles in the movement. The dynamic simulation provides estimates of muscle and joint forces. This method also can be used to identify cause-effect relationships in the movement [9]. This method was used to analyze muscle functions in running [8], sprinting with block starting technique [6,7].

1.4. Purpose

There were two purposes of the current study. The first purpose was to identify how individual muscles of lower extremities contribute to anteroposterior and vertical acceleration of COM during starting and the first stance phase in sprinting of the soccer player. The second purpose was to determine the primary muscles that produce forward propulsive impulse and support the body during the first stance phase of sprinting in soccer players, then we may suggest key muscles for enhancement sprinting performance.

2. METHOD

2.1. Participants

Five female soccer players, with no history of lower limb injuries of the soccer team in our university, were recruited to participate in this study (age, 20 ± 0.9 years; height, 159 ± 3.4 cm; weight, 51.9 ± 4.2 kg). Subjects gave their written consent to participate. This study conformed to the recommendations of the Declaration of Helsinki and had been approved by the University Ethics Committee in Niigata University of Health and Welfare, with Institutional Review Board approval number 1866-210730.

2.2. Procedures

The experiment took place in the Biomechanics Laboratory room of Niigata University of Health and Welfare in autumn. Inside the Lab room, an air conditioner was used to keep the temperature around 25ºC.

The participants used Under Armour training clothes and their indoor soccer shoes. Each participant underwent three short sprinting (5 meters) three times on a walkway that was 10 meters. Participants sprinted with maximal effort for each time after 5 minutes of warming up and rested for five minutes after each trial. They started at a standing position and the split starting technique was used (Figure 1). The toe of the front foot was placed at the starting line. The rear foot was placed after the front foot, with the distance depending on the participant. The instruction was to start sprinting as fast as possible after an LED light signal, which is put at the end of the walkway, turns green. Starting location was defined as the first stance of sprinting recorded on the ground force plate. The onset of sprinting was the forward movement of the rear foot, so the rear foot was the leading foot.

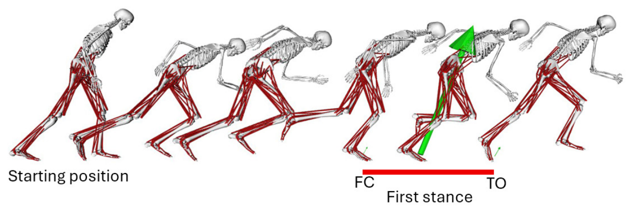

Figure 1.

Snapshots from a simulation of the first stance phase in sprinting of soccer players represent the timing of the first stance phase. The first stance phase starts at foot of stance leg contact with ground (FC) and ends at toe-off when this foot leaves ground (TO). Each red line in the model represents each muscle of lower extremities and torso. The green arrow indicates the representing vector of ground reaction forces during the first stance phase.

2.3. Devices

Motion capture system: Vicon Nexus system (Vicon Motion Systems Ltd, UK) with 12 cameras were used to measure kinematic data with the sampling rate of 250 [Hz]. Full-body maker trajectories, GRF data were recorded for the first stance. The first stance was the stance phase of the first step after starting. Figure 1 showed the timing of the first stance. This was defined as the contact phase between leading foot and ground from initial contact to when the same foot leaves ground. 57 markers were placed on the body of the participant to collect motion of the full body. The marker set was defined as described in a previous study (35). GRF was measured by 6 force plates (Advanced Mechanical Technology, Inc) embedded in the track at the sampling frequency of 1000 [Hz]. Both systems were recorded synchronously using the Vicon system.

2.4. Data processing

Computer simulations of the first stance of sprinting were performed in Opensim 3.3 software to estimate the contribution of each muscle to the acceleration of the center of mass. A generic full-body musculoskeletal model was used with 12 segments, 29 degree-of-freedom (DOF), 92 muscle-tendon actuators [8].

The generic full-body model was scaled to match each subject's anthropometry based on relative distances between pair makers placed on anatomical landmarks of individual subjects. Virtual markers on the model were adjusted locations to represent real markers on the subject's anatomical landmarks from the motion capture system. Inverse kinematic (IK) formulation was used to determine generalized coordinate values of the model (joint angles and translations). Inverse kinematic was solved using a least-squares approach to minimize the difference between real marker locations in the experiment and virtual marker locations on the model through each time frame. Residual Reduction Algorithm (RRA) was applied to make the model's generalized coordinates more dynamically consistent with kinetic data from experiment by adjusting the joint kinematics and model mass properties. Computed muscle control (CMC) was used to estimate a set of muscle excitations that provide kinematics feedback to control model position during movement. Afterwards, the contribution of individual muscles to anteroposterior and vertical acceleration of the center of mass was computed by using Induced Acceleration Analysis (IAA). The muscle excitations from CMC were used to compute these contributions.

Muscle contributions were calculated by percentage of the acceleration induced by each muscle compared to the total acceleration of the center of mass during the first stance for each interested direction. The first stance was identified from first contact between foot and ground to toe-off. We just considered muscles which contributed more than 3% of the total acceleration of the center of mass, and only stance leg muscles were calculated. Mean and standard deviation of the muscle contributions were calculated from all participants.

3. RESULTS

During the first stance, average contact time between foot and ground was 0.21 ± 0.01 s. Mean average horizontal velocity of COM was 3.2 ± 0.18 m/s. Mean average anteroposterior and vertical acceleration of COM were 4.2 ± 0.5 m/s^2 and 1.4 ± 1.3 m/s^2 respectively.

3.1. Muscle contributions to forward acceleration

For the first stance phase, the contribution of soleus and gastrocnemius medialis muscles to forward acceleration of COM were highest, at approximately 24.6 ± 3.4 % and 25.3 ± 4.7 % respectively, followed by gastrocnemius lateralis, with 9.7 ± 2.5 % of the total forward acceleration. There were substantial contributions to forward acceleration from hamstrings muscles. Specifically, the contribution of biceps femoris accounted for 7.4 ± 1.6 % of the total, the figures for semimembranosus and semitendinosus were 5.4 ± 1.1 % and 3.2 ± 0.9 % respectively of the total. Total contributions of gluteus muscles (gluteus maximus, gluteus medius and gluteus minimus) to forward acceleration were minor, with 6.2 ± 0.8 % of the total (Figure 2). In contrast, rectus femoris and the vastus only contributed to backward acceleration of COM. There was 10.2 ± 7.7 % of the total backward acceleration induced by the rectus femoris muscle, while the vastus induced 38.9 ± 9.8 % of the total backward acceleration of COM.

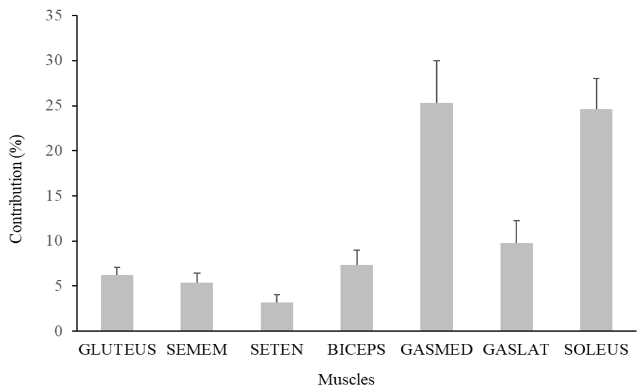

Figure 2.

Mean lower limb muscle contributions to forward acceleration of the center of mass during the first stance phase in sprinting of female soccer players. The Y axis indicates the relative contribution with the unit is %. Muscles presented are: Gluteus muscles including maximus, medius and minimus (GLUTEUS), Semimembranosus (SEMEM), Semitendinosus (SETEN), Biceps femoris (BICEPS), Gastrocnemius medialis (GASMED), Gastrocnemius lateralis (GASLAT) and Soleus muscle (SOLEUS). Error bars represent one standard deviation.

3.2. Muscle contributions to upward acceleration

In the vertical direction, the contribution of the soleus muscle to upward acceleration of COM was highest, at 36.2 ± 5.3% of the total. The second largest contribution is from gastrocnemius medialis, with 26.2 ± 4.3 % of the total upward acceleration, while just 10.1 ± 2.7 % of the total was induced by gastrocnemius lateralis. There were no contributions of the hamstrings to upward acceleration of COM. Similarly, the contribution of gluteus muscles was very small, with under 1 % of the total. In this direction, the rectus femoris and vastus muscles contributed a minority to upward acceleration, with 3.5 ± 1.5 % and 6.5 ± 2.2 % of the total COM's upward acceleration. In the ankle, the contribution of tibialis posterior muscle to upward acceleration also accounted for 5.4 ± 0.7 % of COM (Figure 3).

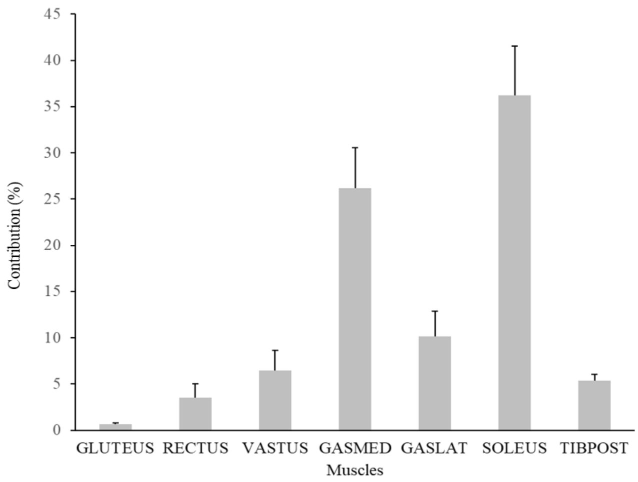

Figure 3.

Mean lower limb muscle contributions to upward acceleration of the center of mass during the first stance phase in sprinting of female soccer players. The Y axis indicates the relative contribution with the unit is %. Muscles presented are: Gluteus muscles including maximus, medius and minimus (GLUTEUS), Rectus femoris (RECTUS), Vastus (VASTUS), Gastrocnemius medialis (GASMED) Gastrocnemius lateralis (GASLAT) and Soleus muscle (SOLEUS). Error bars represent one standard deviation.

4. DISCUSSION

The purpose of this study was to identify lower extremity muscle contributions to anteroposterior and vertical acceleration of the center of mass and determine the primary muscles that play important roles in acceleration performance during the first stance of sprinting in soccer players. The main findings were the soleus and gastrocnemius medialis muscles contributing the largest to forward and upward acceleration. Similarly, gastrocnemius lateralis also plays an important role in acceleration of COM in both directions. For the knee, there was a difference in the contributions between quadriceps and hamstrings muscles to the body acceleration.

In the muscles around the ankle joint, the overall results clarified the role of each muscle in acceleration of COM during the first stance. Our findings indicated that gastrocnemius and soleus muscles are the most important muscles in providing acceleration of the body during the first stance phase. To accelerate the body moving forward, the induced acceleration of gastrocnemius muscles was significantly higher than the soleus muscle, whereas the contribution of both muscles was nearly equal in accelerating the body moving upward. This result was similar to a previous report that studied the key role of gastrocnemius and soleus muscles in forward acceleration of the body during the stance phase of running and the first stance phase of long-distance sprinting [7,8]. However, the current study clearly defined the differences in the contribution between gastrocnemius medialis and lateralis that have not been clear in previous studies. Moreover, gastrocnemius medialis is the main contributor, with the contribution to acceleration being substantially larger than gastrocnemius lateralis, and this result was in line with a previous report about the role of gastrocnemius medialis in providing positive work for acceleration phase. In addition, the result of this study showed the role of the tibialis posterior muscle in providing support during the first stance phase.

This finding is different from studies that investigated the role of muscles during the first stance phase with sprinting from blocks, which reported small contributions of this muscle [7]. Our report is also consistent with the results in a study on the contribution to forward propulsive and vertical impulses that showed gastrocnemius and soleus are key muscles in producing impulses to move the body in the initial sprinting [6]. Therefore, gastrocnemius medialis and soleus should be focused on in training to improve forward and upward acceleration of the body during the first stance, which can lead to enhancement of short sprinting performance in soccer players. Similarly, the gastrocnemius lateralis also needs to be considered to develop forward and upward acceleration abilities, while the tibialis posterior is necessary for upward acceleration ability. Thus, improvement of the ankle plantarflexors may lead to increased stride length, stride frequency, and may reduce the contact time between the foot and the floor that was reported as the important factor in improving acceleration ability. In recovering time after injuries, this study suggests that a strong recovery of the ankle plantar flexor muscle group may help soccer players to quickly recover sprinting performance. Our suggestions are similar to previous studies that suggested that ankle plantarflexion muscle strength and power training may provide the increase in acceleration ability in sprinting.

During the first stance phase, large contributions of hamstrings muscles to forward acceleration were found from this study, and this result is in line with available reports about the role of the hamstrings in producing horizontal forces to push the body forward in sprinting using block starting technique [6,7]. Furthermore, this study thoroughly explores the contribution of each component of the hamstrings muscles that have not been clear in previous studies, with the total contribution of semimembranosus and semitendinosus muscles being nearly equal to the biceps femoris muscles. This is different to studies that showed the function of these muscles in running and sprinting using block start technique, which only reported the role of the biceps femoris [7,8]. As a result, we believe that the semimembranosus and semitendinosus muscles should be considered as the main contributor to the function of the hamstrings. Meanwhile, the minor contribution to forward acceleration of gluteus muscles was similar with previous studies on sprinting with block start [6,7].

The induced upward acceleration of both hip extensor muscle groups was nearly zero. This result is inconsistent with results from studies on running that showed the important role of these muscles in supporting the body [8], but in line with studies on sprinting with block start technique [6,7]. These clarify that in improving forward acceleration ability, soccer players should focus on developing the strength and power generated by these muscles to increase stride length, and frequency similar to previous suggestions in increasing initial running speed [1]. In addition, increasing hamstrings muscle strength was suggested to develop horizontal force production that can improve acceleration performance under fatigue conditions in soccer players. For Gluteus muscles, although this muscle moderately contributes to forward acceleration, strengthening of this muscle was reported to play an important role in preventing hamstrings injuries during acceleration phase of sprinting. Therefore, hip extensor muscles may need to be focused on in training to enhance acceleration performance and prevent injuries in sprinting.

On the other hand, the contribution of quadriceps was to act as the body's brakes in the horizontal direction during the first stance. The function of quadriceps is similar to the stance phase of running [8], but is different with sprinting with block starting technique that shows large contribution of this muscle to forward acceleration [7]. In the vertical direction, the contribution of quadriceps muscle is significantly lower than previous studies on running and sprinting with block starting technique. This difference may be caused by the body position and the range of leg joint motion between the two starting techniques. In standing start technique, the quadriceps muscle activity may need to control the forward momentum of the body after starting to prevent the body from falling forward too much. Thus, the activity in the first stance phase and effects on acceleration ability of this muscle in the first stance phase may be carefully considered in further research.

5. CONCLUSION

In conclusion, this study identified the specific function of individual lower extremity muscles in the accelerating body during the first stance phase of sprinting in soccer players. Gastrocnemius and soleus are the largest contributors to the acceleration of the whole body in the first stance phase, so these muscles should be given more focus on in training and treatment that may increase the efficiency of training or the treatment program for sprinting motion. The hip extensor muscles play secondary roles in acceleration ability during the first stance phase, but these muscles also play a role in maximizing forward acceleration of the whole body. Likewise, although the quadriceps only contribute a minority to upward acceleration, this muscle may play an important role in braking to control body position.

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