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Mechanisms that influence accuracy of the soccer kick

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ABSTRACT

Goal scoring represents the ultimate purpose of soccer and this is achieved when players perform accurate kicks. The purpose of the present study was to compare accurate and inaccurate soccer kicks aiming to top and bottom targets. Twenty-one soccer players performed consecutive kicks against top and bottom targets (0.5 m^2) placed in the center of the goal. The kicking trials were categorized as accurate or inaccurate. The activation of tibialis anterior (TA), rectus femoris (RF), biceps femoris (BF) and gastrocnemius muscle (GAS) of the swinging leg and the ground reaction forces (GRFs) of the support leg were analyzed. The GRFs did not differ between kicking conditions ($P > 0.05$). There was significantly higher TA and BF and lower GAS EMG activity during accurate kicks to the top target ($P < 0.05$) compared with inaccurate kicks. Furthermore, there was a significantly lower TA and RF activation during accurate kicks against the bottom target ($P < 0.05$) compared with inaccurate kicks. Enhancing muscle activation of the TA and BF and reducing GAS activation may assist players to kick accurately against top targets. In contrast, players who display higher TA and RF activation may be less accurate against a bottom target. It was concluded that muscle activation of the kicking leg represents a significant mechanism which largely contributes to soccer kick accuracy.

1. Introduction

The instep soccer kick is considered the most powerful of the kicking techniques (Kellis and Katis, 2007a; Lees and Nolan, 1998), but a powerful kick is not always a successful one because accuracy has a bearing on a kick's success, such as goal scoring. Many factors influence kicking accuracy and inaccuracy ranging from errors from the players' approach, support leg placement characteristics, kicking leg swing motions and kicking foot-to-ball contact characteristics. These factors have been extensively examined biomechanically, mainly under laboratory conditions (Asai et al., 2002; Kellis et al., 2006; Katis and Kellis, 2010; Scurr et al., 2011), while only a few were performed under field conditions (Giagazoglou et al., 2011). Further, most studies examined biomechanics of powerful soccer kicks (De Proft et al., 1988; Kellis et al., 2006), but not the biomechanics of accurate kicks.

The placement of the support leg is of great importance for the performance of a kick, since the support leg is considered responsible for stabilizing the body while the kicking leg swings (Lees et al., 2010). During the kick, the support leg lands next to the ball with the knee flexed to absorb the impact of landing. In this way the speed of the kicking movement is reduced, stabilizing body segments and is thought to have a beneficial effect on kicking performance (Lees et al., 2010). This means that the body may assume different postures depending on the direction of the ball to the target. If this is the case, then differences in ground reaction forces made by the support leg should be expected between kicks which hit the target and those which do not.

Previous studies have examined muscle activation patterns during powerful soccer kicking using electromyography (EMG) (Dorge et al., 1999; Kellis et al., 2004; Brophy et al., 2007; Scurr et al., 2011). Only recently, Scurr et al. (2011) examined the EMG activity of the quadriceps muscles when kicking towards different targets. Particularly, they found differences in the EMG activity of kicking limb muscles when kicks for accuracy aimed at different corners of the goal post. Kicks aimed to the top right corner demonstrated a higher level of quadriceps activation compared to those aiming to the other corners. This study focused on quadriceps muscles activation only, and while quadriceps activation is crucial for kicking power, the activation patterns of other muscles is also of great importance as kicking involves simultaneous movement of several segments around many joints. Despite these limitations, it seems that kicking accuracy largely depends on differential activation of the muscles during the kick in combination with the position of the target. This

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might also be related to game conditions, i.e. when a player performs two kicks using essentially the same technique, but one hits the target and the other does not.

Players have several options when kicking the ball to goal such as to kick it to the top or bottom of the goal. Surprisingly, the biomechanical adjustments taking place when players perform kicks to the top or bottom of the goal have not been investigated in detail. One study, though, has shown that players lean the body away from the ball (backward body lean) and use a lower contact point on the ball when a player kicks the ball to the top of the goal to enable the ball to follow a higher trajectory after release (Prassas et al., 1990). This suggests that in order to position the kicking foot further under the ball there should be a different support leg placement and different activation of lower limb muscles for kicks to the top of the goal compared to the bottom.

Goal scoring represents the ultimate purpose of soccer. This is achieved when players perform accurate kicks. In this respect, identifying the mechanisms, such as support leg-ground interaction and details for the nature of activation of muscle groups around a joint, which lead to an accurate kick, may provide insight into the role support leg and muscles play in successful and unsuccessful kicks.

Therefore, the purpose of the present study was to compare accurate and inaccurate soccer kicks when aiming to top and bottom targets, focusing on the ground reaction forces made by support leg and on the muscle activation patterns of selected lower extremity muscles of the kicking leg.

2. Methods

2.1. Participants

Twenty-one male amateur soccer players (age: 23.7 ± 2.3 yrs, mass: 75.2 ± 6.3 kg, height: 180 ± 2.1 cm) volunteered to participate in the present study. The players were members of two teams participating in the fourth division of the Hellenic Amateur Association League, for the last 4 years. Ten players were strikers, seven were midfielders and four were defenders. Participants had a minimum of 8 years of experience and trained at least three times plus one game per week. All participants passed medical examination within 15 days before the tests and had no injury of their lower limbs, while as was stated they refrain from injury the last 6 months before the measurements. Fifteen players preferred to kick with the right foot and six with the left foot. Participant informed written consent was received prior to the testing procedures. The University Ethics Committee approved the protocol.

2.2. Testing procedure

A 15-min warm-up consisting of jogging, stretching exercises and several familiarization trials was performed. Following the familiarization session each participant performed three maximum instep kicks in order to generate reference EMG data for normalization purposes. All the kicks of the study were performed against a full length goal (7.32 × 2.44 m) using a standard size and inflated ball (FIFA approved) from a distance of 11 m, thus corresponding to the penalty shoot-out.

In the main session, each participant performed 20 consecutive kicking trials. Ten kicks were performed to a top target and ten kicks to a bottom target. All the kicks were performed in a random order. Targets (0.50 m^2) were positioned in the center of the goal, one at the top and the other at the bottom (Fig. 1). A two-step running path, a self-selected approach angle and a self-selected kicking type were used during the kicking trials (Scurr and Hall, 2009). Participants were instructed to kick the ball in order to hit the target "as accurate as possible, as fast as possible". A kick was defined accurate every time the ball hit the target or passed through the target area. A 30 s rest interval between consecutive kicks was provided. The average of all the kicking trials was used for further analysis.

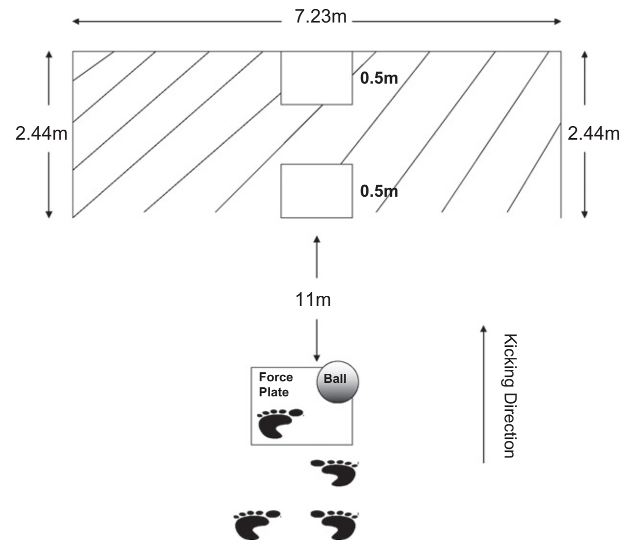

Fig. 1. A schematic illustration of the kicking trials on different targets.

2.3. Ground reaction forces

The vertical, anteroposterior, and mediolateral components of the GRF's during the plant of the support leg were measured using a Kistler piezoelectric force platform (Kistler Type 9281C, Kistler Instruments, Winterthur, Switzerland). The force platform was located beside the ball, in the middle of a 5-m-long pathway and was concealed with plastic turf to avoid disorientation of the player by focusing on stepping inside the force platform when kicking. The force platform was interfaced through Kistler amplifying units (Type 233A) to an Ariel Performance system (Ariel Dynamics Inc., San Diego, CA). The force platform signals were A/D converted at a sampling rate of 1000 Hz and recorded using the analogue converter of the Ariel system. Subsequently, they were analyzed simultaneously with the electromyographic data.

2.4. Electromyography

The EMG activity was recorded using an EMG interface module of the ARIEL system (Ariel Dynamics Inc., San Diego, CA), sampling at 1000 Hz. Bipolar surface electrodes in the form of metallic bars with 1-cm inter-electrode distance interfaced to a 16-channel analogue interface amplifier (Common mode rejection ratio = 100 dB at 50/60 Hz, bandwidth = 8–500 Hz, gain = 400) were placed longitudinally with respect to the underlying muscle fiber arrangement on the center of the muscle bellies of the rectus femoris (RF), the gastrocnemius (GAS), the tibialis anterior (TA) and the biceps femoris (BF) muscle of the kicking leg. The EMG electrode locations were prepared by shaving the skin of each electrode site and cleaning it with alcohol wipes to reduce skin impedance levels. These locations were identified by palpation during a maximal voluntary isometric effort from the seated (RF, GAS and TA) and prone (BF) positions. The electrode arrangement and the location was further monitored by taking several sample measurements with the participant at rest and during several sub-maximal contractions and analyzing the amplitude as well as the frequency content of the signal. The soccer ball was placed on an electronic switch, which upon impact, was simultaneously triggered and sampled with the EMG data as a separate channel.

EMG data were analyzed using Ariel Performance Analysis Software (APAS, Ariel Dynamics Inc., San Diego, CA). The signals were high-pass filtered with a Butterworth fourth-order zero-lag digital filter at a cut-off frequency of 20 Hz and full-wave rectified. The signal was smoothed again, by calculating the moving average (MAV) over 10 ms intervals.

Before the main kicking session, the subjects were asked to perform three "maximum" kicking trials, by asking the subjects to perform kicks as fast and as strong as possible, but without any accuracy constraint. Subsequently, each muscle maximum MAV value during maximal kicks (from ground contact to impact) was used to normalize the corresponding EMG signals obtained during the main testing session.

2.5. Data analysis

The kicking movement was defined from ground contact of the support leg to initial ball impact (kicking phase) (Barfield, 1995). This definition was given since we focused on muscle activation at the final stages of the kick. Total kicking duration was set as 100%. Subsequently, the EMG signal of each muscle and the GRFs were averaged along 10 phase intervals, every 10% from ground contact (0%) to initial ball impact (100%). Moreover, the duration of each kicking condition, muscle EMGs and the GRFs at impact were examined.

2.6. Statistical analysis

Data were checked for normality, using Levene's test. Subsequently, a two-way repeated measures analysis of variance (ANOVA) with two within-subject variables (Target × Accuracy) was used to examine differences between the kicking conditions in GRFs and muscle activation at ball impact. *Post hoc* Tukey tests were applied to examine significant differences between pairs of means.

A three-way analysis of variance (ANOVA) with repeated measures with three within-subject variables (Accuracy × Target × Phase) was used to examine differences in each dependent variable between accurate and non-accurate kicks, at bottom and top targets over 10 data points of the kicking phase. *Post hoc* Tukey tests were applied to examine significant differences between pairs of means. The level of significance was set at $P < 0.05$.

3. Results

The success rate for the low target kicks was 56% and for the top target kicks 51%. The kicking duration during each kicking condition is presented in Table 1. The results indicated non-significant differences in the duration between the kicking conditions ($P > 0.05$).

3.1. Ground reaction forces (GRFs)

The GFRs at ball impact did not differ between the accurate and the inaccurate kicks performed on a top or a bottom target (Table 1; $P > 0.05$). The curves of the vertical, anteroposterior and mediolateral components of the GRFs are presented in Fig. 2. The ANOVA indicated a non-significant effect of the type of kick on vertical (Fig. 2A; $P > 0.05$), anteroposterior (Fig. 2B; $P > 0.05$) and mediolateral (Fig. 2C; $P > 0.05$) GRFs.

3.2. Electromyography (EMG)

The EMG activation levels for TA, RF, BF and GAS muscle at ball impact are presented in Table 2. The results showed significant differences between the kicking conditions ($P < 0.05$).

In particular, the ANOVA results indicated a statistically significant two-way interaction effect (Accuracy × Target) on the activation of TA ($F_{3,80} = 3.250$; $P < 0.026$), BF ($F_{3,80} = 2.839$; $P < 0.043$), RF ($F_{3,80} = 2.887$; $P < 0.041$), and GAS ($F_{3,80} = 2.893$; $P < 0.040$). For top target kicks, *post hoc* analysis indicated significantly higher TA and BF and lower GAS activation (collapsed across phase) during accurate kicks compared with inaccurate ones ($P < 0.05$). For bottom target kicks, *post hoc* Tukey tests showed a significantly lower RF and TA activation (collapsed across phase) during the accurate kicks compared with inaccurate ones ($P < 0.05$).

The TA, RF, BF and GAS muscle activation curves are presented in Figs. 3 and 4. The ANOVA results indicated a statistically significant interaction effect on TA activation (Fig. 3). *Post hoc* analysis indicated a higher activation of TA at the final stages of the top accurate kicks (80–100%) compared to inaccurate kicks. Further, there was a lower TA EMG at the initial (10–20%) and final (100%) phases of the bottom target accurate kicks compared to the inaccurate ones ($P < 0.05$). Similarly, the ANOVA results indicated a significant interaction effect on RF activation (Fig. 4). *Post hoc* analysis indicated that compared to inaccurate, the accurate bottom soccer kicks displayed lower activation at ball impact ($P < 0.05$).

The ANOVA results indicated a significant interaction effect (Accuracy × Target × Phase) on BF (Fig. 4) and GAS (Fig. 3) activation ($P < 0.05$). *Post hoc* analysis indicated that compared to inaccurate, the accurate kicks displayed a higher BF activation (Fig. 4) and a lower GAS (Fig. 3) activation at ball impact (100%) ($P < 0.05$) for top target kicks.

4. Discussion

The main findings of this study were that GRFs made by the support leg did not differ between accurate and inaccurate kicks. However, we found that accurate kicks aiming at a top target showed higher TA and BF activation and lower GAS activation compared to inaccurate kicks. Accurate kicks aimed at a bottom target displayed a lower TA and RF activation compared to inaccurate kicks. To our knowledge, differences in muscle activation patterns between accurate and inaccurate kicks have not been reported.

Table 1
Temporal parameters (ms) and GRF's (N) at impact for each of the kicking condition.

	Top target		Bottom target	
	Accurate	Inaccurate	Accurate	Inaccurate
Duration (ms)	144.7 ± 32.4	138.5 ± 30.7	137.8 ± 24.3	142.8 ± 22.6
GRF's at impact (N)				
Vertical	449.4 ± 296.4	480.5 ± 255.8	405.0 ± 262.9	462.4 ± 242.6
Anteroposterior	125.4 ± 88.2	128.0 ± 74.2	85.6 ± 78.6	81.0 ± 50.6
Mediolateral	331.2 ± 89.5	359.7 ± 92.5	382.6 ± 68.2	370.6 ± 74.5

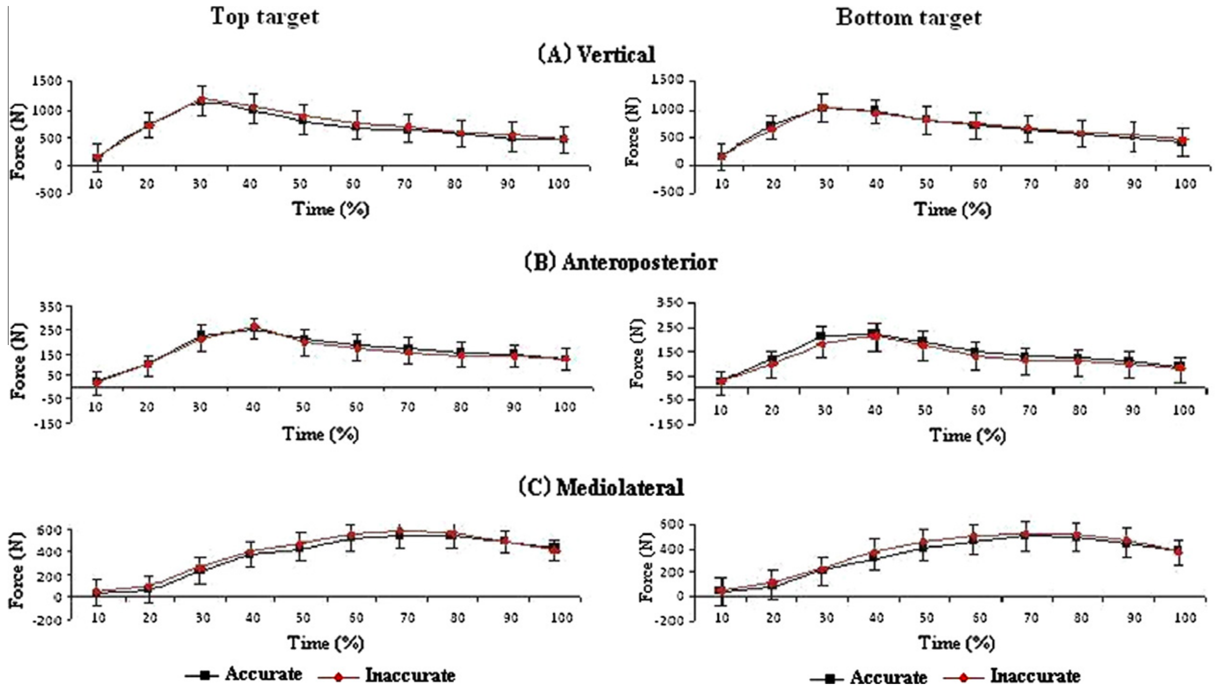

Fig. 2. Ground reaction forces (N) of the support leg during each kicking condition. The top diagrams (2A) indicate the vertical GRF's, the middle diagrams (2B) the anteroposterior GRF's and the bottom diagrams (2C) the mediolateral GRF's. Values are expressed for every 10% from ground contact until ball impact.

Table 2
Activation levels (expressed as percentage of maximum soccer kick) of selected muscles at impact for each of the kicking condition.

	Top target		Bottom target	
	Accurate	Inaccurate	Accurate	Inaccurate
Tibialis anterior (TA)	40.7 ± 35.7	22.2 ± 14.4*	17.8 ± 14.8	31.5 ± 26.9*
Rectus femoris (RF)	49.9 ± 31.9	52.2 ± 32.4	40.1 ± 27.7	60.2 ± 35.6*
Biceps femoris (BF)	54.6 ± 35.1	35.5 ± 23.4*	55.3 ± 29.3	47.3 ± 34.8
Gastrocnemius (GAS)	37.4 ± 24.5	54.7 ± 43.8*	51.4 ± 26.1	54.5 ± 35.8

* Significant differences between accurate and inaccurate kicks.

The duration of the kicks did not differ between the kicking conditions (Table 1), which is in contrast with previous studies (Carre et al., 2002; Teixeira, 1999). However, the present study examined only the kicking phase from ground contact to initial ball impact without taking into consideration the entire kicking movement (pre-support phase). This is because the largest contribution for soccer kick performance takes place during the last stages of the kick (Dorge et al., 1999; Tsaousidis and Zatsiorsky, 1996). Nevertheless, it is still interesting that accuracy as well as the type of target did not influence kick duration.

Non-significant differences in GRFs were observed between the kicking conditions (Fig. 2). Previous studies have examined instep

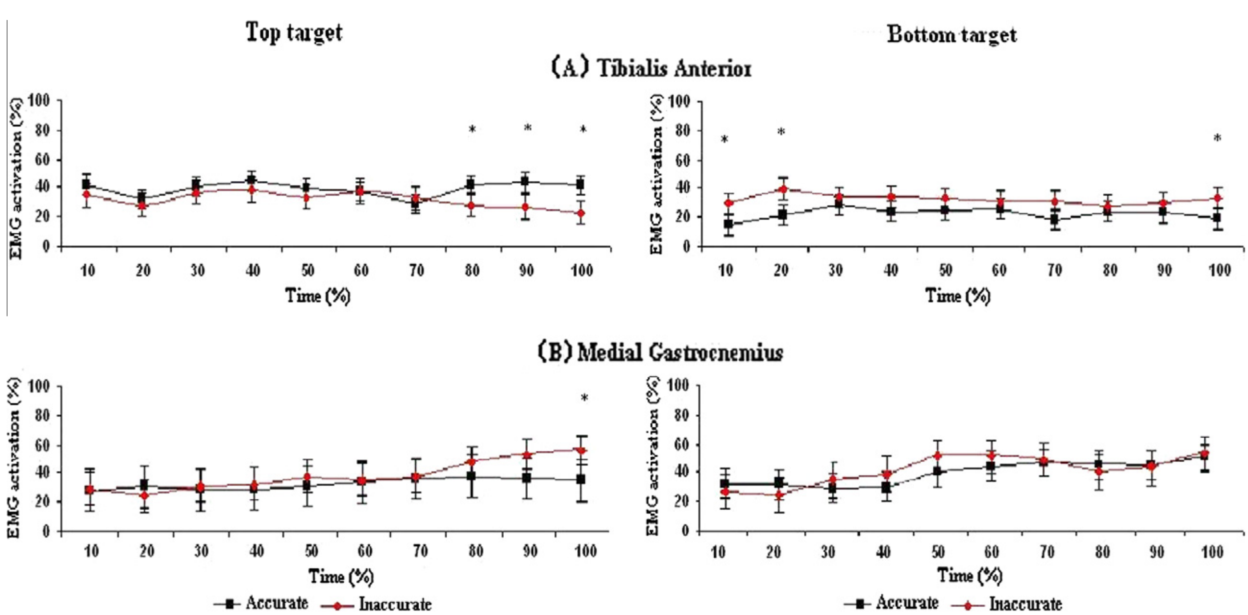

Fig. 3. Activation levels of tibialis anterior and medial gastrocnemius muscle (expressed as percentage of maximum soccer kick) during each kicking condition. Values are expressed for every 10% from ground contact until ball impact (*significant differences between accurate and inaccurate kicks).

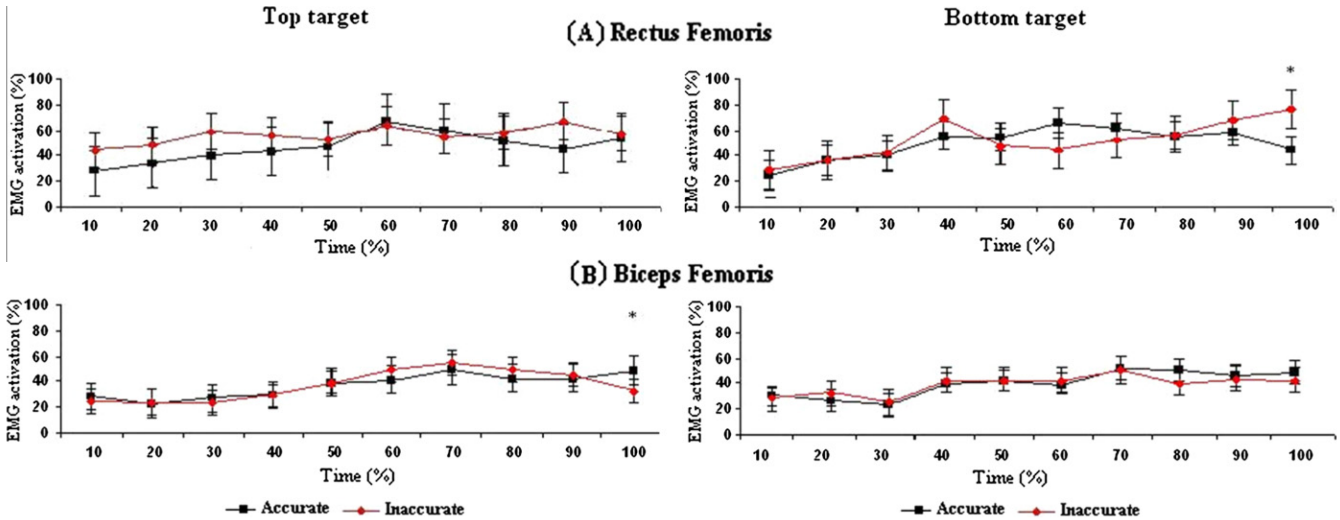

Fig. 4. Activation levels of rectus femoris and biceps femoris muscle (expressed as percentage of maximum soccer kick) during each kicking condition. Values are expressed for every 10% from ground contact until ball impact (*significant differences between accurate and inaccurate kicks).

kicks under fatigue conditions (Kellis et al., 2006) or examined different kicking techniques (Katis and Kellis, 2010) and also failed to find significant differences in GRFs. It seems that players adopt a common way to place the foot next to the ball in order to maintain stability during the kick, which is not affected by external conditions. Our results, therefore indicate, that if the support foot affects kicking accuracy, this is probably not reflected in the level of force exerted by the foot on the ground upon impact neither on the contact duration.

The aim of the player when kicking a ball to a top target is twofold: First, to lift the ball from the ground, thus giving the ball an upward trajectory and second, to direct the ball to the desired target area. To accomplish the first aim, the player should position the swinging foot underneath the ball during foot-ball impact, while the ankle joint should be in a dorsi flexed position to allow a foot-ball impact that would permit to the ball to rise from the ground (Asai et al., 2002; Prassas et al., 1990). A more dorsi-flexed ankle seems to create optimum conditions for a better foot-ball collision leading to a higher trajectory of the ball and therefore better chances for the soccer player to hit the top target.

Different kicking conditions are expected to create different kicking foot's positioning demands relative to the ball, and, as a result, different muscle activation adjustments. The results of the study showed a higher TA activation and a lower GAS activation during accurate kicks compared to inaccurate ones against a top target (Table 2). Practically, this means that the more activated the TA, the more dorsi flexed the ankle, thus enabling a higher trajectory of the ball. In contrast, a higher GAS activation has probably negative effects on the accuracy of the kick on a top target (Fig. 3). Since the GAS muscle is responsible for ankle plantar flexion, an increased activation of this muscle during the kick would lead to a more plantar flexed ankle. In this case, the player would have fewer chances to raise the ball to the proper height to hit the target. Alternately, since GAS is a bi-articular muscle, a higher activation may also contribute to knee joint stabilization as the knee rapidly extends at the final kicking phase. It seems, therefore, that from the muscles surrounding the shank, examined in the present study, the TA is an important contributor for lifting the ball from the ground.

In addition to GAS, accurate top target kicks were accompanied by a higher BF and unaltered RF activation at ball impact compared with inaccurate kicks (Fig. 4). This finding underlies the significant contribution of BF activation to control posture and the motion of the limb and to drive and prepare the lower limb for an optimum ball impact, thus permitting an accurate soccer kick. Because of its anatomical role as a principal knee flexor as well as hip extensor, the BF has two roles: First, a higher BF activation prior to ball impact could be considered as responsible for counteracting the excessive activation of the quadriceps muscle. It does not seem unreasonable to suggest that the final adjustments and its greater activation (Fig. 4) are taking place so that the ball is directed to the desirable target by slowing down the knee extension and the movement of the kick, permitting a more accurate kick. Second, a higher BF activation may indicate a higher effort made by the player to control the hip, as the whole kicking leg moves toward the ball against the top target. It has to be noted, however, that accuracy in the mediolateral direction probably implies the involvement of other ankle muscles such as the peroneii and the soleus muscles and the hip adductors and abductors muscles, not examined in this study.

The aim of the player when kicking a ball to a low height target is not to lift the ball from the ground. The present results showed that muscle activity differs between accurate and inaccurate bottom target soccer kicks (Table 2). In particular, both TA (Fig. 3) and RF activity (Fig. 4) were lower during accurate low target kicks, while no changes in GAS and BF activity were recorded. During lower trajectory soccer kicks, the height of the ball after contact is very low and therefore, a lower TA and RF activity is probably needed. A high RF activity combined with a higher TA activity would result in an increase in height of the ball at release, thus directing the ball to different paths than the desired (bottom) target. Furthermore, the reduction of TA combined with an unaltered GAS activity during successful bottom target kicks indicates a less stiff ankle at ball impact. In addition, lower RF activation indicates a rather lower knee extension velocity and perhaps a smaller ball speed (Kellis and Katis, 2007b). This re-enforces previous suggestions that a faster kick is not necessary a successful one (Kellis and Katis, 2007a; Lees and Nolan, 2002). Furthermore, an additional explanation may be that part of the increase in RF activity during the unsuccessful kick may represent additional effort made by the player to control the hip joint.

The soccer kick is a complex movement being the result of multiple muscle activation. It has been suggested that the central nervous system groups the functioning of muscles, thus, creating muscle synergies to enhance performance with lower energy consumption (Bernstein, 1967; Fautrelle et al., 2010). This is also related to the environmental conditions and the demands of the required movement. If this is the case, one might suggest that accurate kicks are the result of muscle activation strategies which probably differ compared with activation patterns which lead to inaccurate kicks. Within the limitations of this study, it appears that players adjust the activation of specific muscles during the last stages of the kick to direct the ball to the desired target. In contrast, during inaccurate kicks it seems that this fine tuning is absent.

Previous studies underlined the importance of an appropriate technique during soccer kicking trials (Kellis and Katis, 2007a; Lees et al., 2010). This technique includes the proper movement of the soccer player accompanied by the proportional coordination of the segments. It is possible that when a soccer kick does not lead to the desirable result, in our case when the kick does not hit the target, an error of the movement sequence has occurred (Savelsbergh and van der Kamp, 2000). The results of the present study showed that electromyographic changes had an effect on kicking accuracy.

The present results are applicable to young amateur players who participate in systematic training and play one game a week. In theory, accuracy and level of skill may differ in professional players as opposed to amateurs. Moreover, our experiment was performed under laboratory conditions where kicking targets are pre-designed and can only simulate real game conditions. In the present study, we examined activation patterns of four muscles, while many more muscles are activated and may play a role in determining a successful kick. Finally, interpretation of EMG patterns is affected by the method used to normalize raw EMG signal as well as cross talk between muscles. In the present study, we chose to normalize raw data as a percentage of maximum EMG during a kicking trial. While this can allow comparisons between kicks and kicking phases, it does not provide information on the magnitude of activation of each muscle as percentage of maximum voluntary contraction. Cross-talk is a common issue for all studies examining multiple muscle activation using surface EMG, especially during multi-articular movements such as the kick. In the present study, we took all measures to ensure minimal EMG cross talk (i.e. identification of anatomical locations for EMG placement, small inter-electrode distance, stabilization of EMG cables).

Soccer is a 90-min game with more goals scored at the last 15-min of the game (Abt et al., 2002). Therefore, accuracy demands should remain at high levels during the entire duration of the game. Rahnama et al. (2003) showed that muscle strength declines during the game and as a consequence it might be expected that kicking accuracy also decreases during the game. The results of the present study underline the importance of a high BF and TA activation for an accurate kick, mainly for the top target. Coaches use exercises for BF on a regular basis, however, exercises for TA are commonly missing from soccer players' training program. Therefore, programs should aim at training both the BF and TA muscle in order to better tolerate fatigue, in all the phases of the game, especially in the last minutes in which an increase of soccer players' fatigue is observed (Mohr et al., 2005). Moreover, a second aim of the training programs would be to enhance synergies between muscles in order to work in favor of kicking performance.

5. Conclusion

The present study indicated that accurate kicks show different activation patterns of BF, RF, TA and GAS muscles, but similar GRFs compared with inaccurate kicks. Thus, patterns of muscular activation represent one mechanism that influences the accuracy of a kick. In order to perform an accurate kick to a top target, a player must first be able to lift the ball from the ground, thus altering the balance between TA and GAS activation and secondly to counteract the activation of the quadriceps by an increased activation of the BF and GAS. To perform an accurate kick to a bottom target, a player must first be able to keep the ball at ground level by limiting the activation of the TA, and secondly to direct the ball to the desired target by limiting the activation of the RF.

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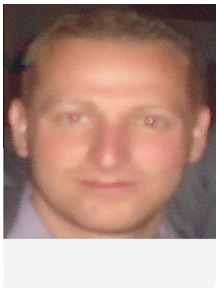

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