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KICKING PERFORMANCE FOR SOCCER PLAYERS WITH BIOMECHANICAL INSTRUMENTATION

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Abstract. *The kicking motion was evaluated with kinetic and kinematic experimental data. It is known that single-leg balance ability predicts a better kicking performance on the other leg. The current experiment explored it during an instep soccer kick. Four skilled junior soccer players kicked a soccer ball into a frontal target which was 9 meters away from them. Their kicking performance was measured in terms of kinetic data, ground reaction force and center of pressure (COP) for the supporting leg and the kinematic data, the supporting leg's knee angle, and the acceleration level of the kicking leg. It was found that the peak ground reaction force matched the slowdown instant of the kicking leg, while the COP velocity of the supporting leg was kept constant. However, the acceleration data showed that each player adopts a different way to kick the ball, and the media-lateral displacement of the COP showed no correlation with the balance skill.*

Keywords: *instep soccer kick, kicking performance, ground reaction force, center of pressure, acceleration level*

1. INTRODUCTION

The ability to accurately kick in soccer is an important attribute during the competition. In the analysis field of sports motion, the behavior of joint overload and the effects of motor performance in the learning process are examples of areas of knowledge that relate to the diagnosis of the sport, Barbieri (2007). There are several types of kicks performed according to different situations of a soccer game. In set-pieces or penalty kicks for example, kicks can be classified according to the region of the foot that strikes the ball with the force employed at the moment, and with the height at which the ball is kicked, Cunha et al, (2001). The kick in soccer is basically characterized by two types of foot positioning (dominant) in relation to the ball. The first one is the kick with the medial part of the foot, side-foot kick, and the second one is using the dorsum of the foot, which is more often studied in biomechanics due to its applicability and efficiency. According to Barfield (1998), kicking is still going to be a topic that will need a lot of discussion and research in the biomechanics because it will continue to have a large number of situations that are not fully resolved. The attributes considered as being important to have an efficient kick are: the balance ability on the supporting leg according to the ball speed, position and attack angle; adoptability of the neuromuscular system and the mechanical interrelationships of skilled behavior; and the protection against possible injury arising from the game.

One of the most widely used methods of measurement to assess the efficiency of the kick is by means of the parameters of the sensory-motor system and, as this system has a direct relation with the functional performance in daily activities and sports, it is necessary to perform a sensory-motor testing. The balance control during the kick is more important in physical therapy and athletic training procedures. The commonly employed methods to analyze the capacity of the sensory-motor system during the kicking movement is by means of postural control, analyzing oscillations of the COP on the supporting leg, or through the variation of the center of mass (COM), among others, Schmidt et al. (2003) and Rosa (2010). In an attempt to quantify the performance of the kick, Rosa analyzed the level of body sway during a kick performed with one leg posture, with the side-foot kick, and the ball was thrown by a vertical shooting device. Professional indoor soccer players showed relatively small sway movements during the kicking performances. In the study of Amorim (2012), it was sought to correlate the oscillation of COP with the level of lower limb muscle activation in order to analyze the postural balance during the kick using the aforementioned Rosa's protocol. The study of surface electromyography (EMG) revealed an atypical of gluteus medius muscle activation of the lower limb for postural control in the kick. In short, the study of postural control during the execution of the kick not only contributes to the understanding of this sportive gesture balancing body movement, but also provides a wider perspective for an effective training of players. Tracy et al. (2012) analyzed the correlation between the accuracy of the kick with swaying ability through COP, during an interval of 0 to 30 seconds, with 38 undergraduate students comparing with the preferable or non-preferable supporting leg, concluding that there is a strong correlation between the accuracy of the kick and the oscillation level of COP, mainly with the preferential supporting leg. However, the study of Gstöttner (2009) with 21 amateur soccer players had showed no significant difference between the preferred

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and the non-preferred supporting legs when they were evaluated in the static tests of COP during 20 and 30 seconds along with latency times of the lower limb muscle by EMG. The study of static tests implies that COP does not reveal the performance ability of the players on the kick. It is important to reveal the results of trials conducted by Matsuda (2008) indicated that soccer players present better stabilities of COP when compared to other types of sports, such as swimming and basketball.

On the other hand, the start of the kicking movement is important because subsequent corrections are difficult where an inappropriate initial motion compromises the ideal positioning for the ball contact to get the accurately kicking. An instant of the ball contact, together with the joints position, are sets the kicking performance. Thus, the position of the joints at the moment of contact with the ball is of fundamental importance for the final result of the kick accuracy. Researchers argue that the critical points of the kick with the dorsum of the foot are: the positioning of the supporting limb, its balance, and the body positioning for the contact with the ball.

In this sense, it is essential to assess the biomechanical parameters applied during the kick with the dorsum of the foot in amateur athletes in order to improve motor performance, correct flaws that are not detected by the qualitative analysis, and reduce injuries resulting from performance failures of the motor gesture, specially related to posture at the moment of kicking. The aim of this study was to develop an effective system of biomechanical measures applied to the performance analysis of the functional kick of outdoor soccer players and, in this way, analyze dynamic equilibrium behaviors before and during the kick through kinematic and kinetic data.

2. MATERIALS AND METHODS

2.1 Experimental Sample

For the practical application of this research, four players were selected: two junior athletes from Resende Soccer Club, State of São Paulo, aged between 18 and 19 years old, and two juvenile athletes aged between 16 and 17 years old, with a mean ± standard deviation age, body weight and height of 17.5 ± 1.29 years old, 69.0 ± 4.02 kg, and 178.75 ± 5.85 cm, respectively. As a criterion for inclusion, it was considered: right-handers to dominant leg, apparently healthy, no record of joint/ligament injuries and with practical experience in outdoor soccer of at least five years, and with four to five times of weekly training prepared by the technical committee which is responsible for the team's management. As a criterion of exclusion: volunteer athletes could not be in the process of recovering from any type of joint/ligament injury. After being informed about the procedures and objectives of the study, each player signed an informed consent form.

2.2 Trials

The participants were instructed to try to hit a target, with dimensions of (2m x 2 m), located at 9 meters away and 1.5 m height from them. Each volunteer performed three kicks using the dorsum of the foot with an approximate interval of 3 minutes between the executions. Each shooting was divided into three phases: a) <u>Pre-kick Phase</u>: the volunteer approached the ball using 2 or 3 steps and tries to stabilize himself on the force platform with the supporting leg; b): <u>Kick phase</u>: with supporting leg stabilized, the volunteer had prepared the kick with his dominant leg, observing the frontal target until he actually has contact with the ball, and finally performed the functional kick; c) <u>Post-kick phase</u>: after the kicking, he tried to keep as balanced as he can, according to Fig. 1.

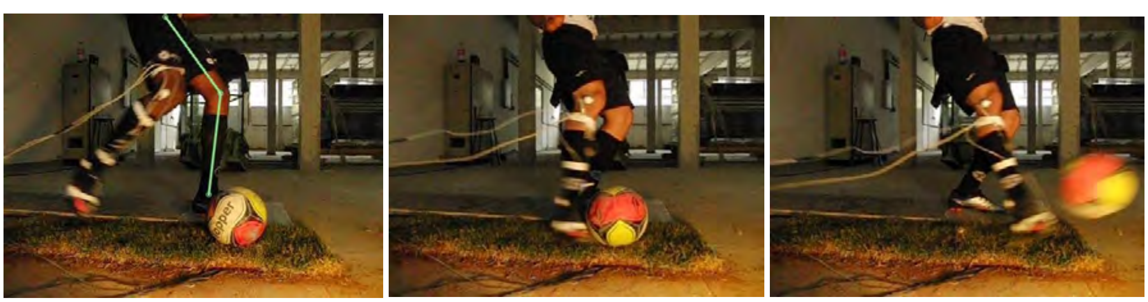

Figure 1. Phases of kicking movements: pre-kick, kick and post-kick.

Lower limb movements for the execution of the kick were filmed with a high-speed camera. In this research, all kicks were recorded by a: Casio Exilim FH-20 EX, with frequency of 210 Hz with a resolution of 480 x 360 pixels. The images served to distinguish the three defined phases, pre-kick, kick and post-kick. The same images were used to determine the speed of the ball in the post-kick and also the knee angles on the kick step. After capturing the images, the files stored in (.MEG) format and divided in each frame using the KINOVEA ® to determine five phases in the kick step, defined in the following ways: 1st) when the volunteer touches the heel on the platform; 2nd) when the volunteer

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supports the left foot of the calcaneus to the metatarsal; 3rd) when the volunteer performs the maximum flexion of the knee of the kicking limb; 4th) the moment when the volunteer approaches the kicking limb, touching the ball and flexing the supporting limb; 5th) when the foot loses contact with the ball. The knee angle and ball speeds were determined with specific software described in MATLAB - MathWorks.

For the acquisition of contact forces data of the supporting foot, it was used a force and balance platform that was developed in a biomechanics laboratory. With the force platform which is used as stabilometer, the ground reaction forces (GRF) were gathered and, variations of COP were recorded. The force platform used in this research was developed according to International Standards of Measurement, and has the following specifications: load capacity of 3600 N (consisting of 4 load cells); Load cells with a capacity of 900 N, sensitivity of 2mV/V, 4340 steel body (using 4 pieces); 4 Strain Gauges (model J2A-06-SO38-350) with gain factor 2, from manufacturer MM; base built with an aluminum plate 5052 with 10 mm thickness, sized 500 x 500 mm. The 4 load cells were set in the corners of the platform and supported by 4 feet articulated by spherical steel at its base to avoid the influence of horizontal forces during the data collection. The signal capture of 4 load cells was performed using a HBM Spider8 conditioner, with specific CATMAN software, at an acquisition frequency of 200 Hz.

The calibration of the force platform was made with statically known weights. Initially, each individual load cell was evaluated with 200N, presenting a sensitivity of 449.01 ± 5.41 N/mV, with correlation coefficient R^2 = 0.9998, in the range of 0 to 794, 90N. The platform assessment was performed with 4 load cells set in the corners, indicated as CH0, CH1, CH2, and CH3 in Figure 2. The calibration procedure of the platform was made with 4 distinct points, P1, P2, P3 and P4, placed 100 mm away from the center of the platform, with loads of 373,6N and 794,9N. Four repetitions were performed in each of the points, which resulted in a maximum deviation of 0.005 mV/V of sensitivity in the load cell that is equivalent to 0.25% positioning error.

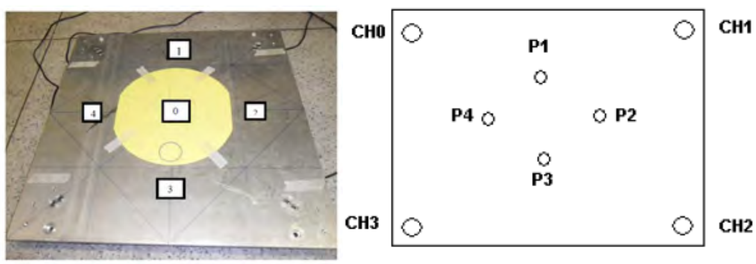

Figure 2. Force platform view and position of load cells CH1, CH2, CH3, and CH4.

An evaluation of the force intensity of the kick, it was used a capacitive accelerometer, SILICON DESIGNS, Inc., model: 2210-025, ranging from 0 to 25 g, with frequency of 0-1,000 Hz, sensitivity in a differential mode 160mV/g, in a single-ended mode 80 MV/g, and output voltage of 2.5V. The accelerometer was attached to the foot, neighbor of the ankle joint, and the acceleration measures were recorded in the direction of the kick, i.e. in an anteroposterior direction. For the calibration of the accelerometer, it was used an exciter of Sound & Vibration Measuring Instruments with 152,9Hz of frequency that presents an acceleration level of 9.81 m/s^2 (+ 1g) for voltage of 2, 64V, checked by an oscilloscope Tektronix, model TDS 1002, 60 MHz. The accelerometer signals were captured by Spider8, ensuring the synchronization of the platform with the acceleration signals. As for the synchronization with the images of the camera, a frame from the sequence of images was manually selected at the moment the heel touches the ground as reference framework.

3. RESULTS

Through a kinematic analysis, it was obtained data from knee angles on the kick phase, and the ball speeds on the post-kick one. Either the knee angles or the speeds of the ball showed small differences between the players ensuring a uniform kicking behavior among the players.

In table 1, there are mean and respective standard deviations of knee angles, and extracted ball speeds by 5 sequence image frames with intervals of 4.76 ms. Ac, max and Dc, max of the dominant foot are, respectively, the values of maximum acceleration and maximum deceleration of the kicking leg, and tac,norm and tdc,norm are normalized times when the maximum accelerations and decelerations occurred. The normalization of time was obtained with respect to the total time of the kick, i.e. the sum of the time intervals of pre-kick, kick and post-kick. GRF,peak-norm and trf,peak-norm indicate respectively the maximum soil reaction divided by the body weight of each player and the normalized time at the instant of the maximum reaction occurred.

The posture of accurate kicking related with the knee angle and the ball speed immediately after the contact with the dominant foot was quite near for all volunteers, presenting performances of uniform kicks acquired by years of training of the selected volunteers. However, the peaks values of acceleration, deceleration and reaction forces showed different behavior, indicating different strategies has taken by player in kicking performance. However, the maximum decelerations were observed in the moment of the loss contact with the ball.

Table 1. Experimental results for kicking movements with four soccer players.

Player	**Knee angle (°)**	**Ball Velocity (m/s)**	**Ac,max (m/s²)**	**tac,norm (-)**	**Dc,max (m/s²)**	**tdc,norm (-)**	**GRF,peak-norm (-)**	**trf,peak-norm (-)**
A	137.5±3.6	21.9±1.5	5.6	0.57	8.6	1.0	1.82	0.27
B	129.3±4.8	21.1±1.2	2.7	0.27	5.6	1.0	1.75	0.70
C	139.8±2.3	22.9±0.5	1.9	0.39	7.8	1.0	2.11	0.67
D	136.8±7.7	22.0±2.2	4.0	0.60	4.5	1.0	1.65	0.18

The acceleration and deceleration behavior of the foot during the three dominant kicking phases are presented in Fig. 3 with an average of three kicks for each volunteer. The time is normalized in Fig. 4, considering the initial time as the moment the support leg touches the force platform, and the final time when the ball loses contact with the dominant foot. It is expected that, on the final phase of approximation, there is a deceleration to control the correct kicking posture, and to get the exact location of the position of the ball to hit the target. Volunteers (B) and (C) showed low acceleration in the step of approximation, and volunteers A and D had higher accelerations showing better kicking skills, once all computed kicks successfully hit the target. On the deceleration phases, specifically with negative acceleration values, volunteers A and D showed reduced contact time with the ball, implying a good motor control of the kicking sway.

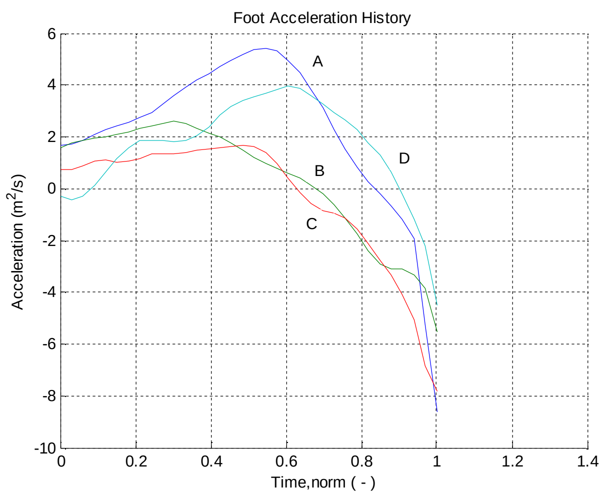

Figure 3. Behavior of tibial acceleration for the dominant foot in normalized time with 4 subjects (A,B,C and D).

Figure 4 presents the GRF variations recorded in the force platform where the two peaks can be observed, being that the first one is related the moment the heel of the support leg touches the ground, and the second one at the time of discharge by the metatarsal region of the contacting foot. Volunteers A and D presented a higher peak at the 1st one, and volunteers (B) and (C) at the 2nd one. The occurrences of the 1st peak on the normalized time varied for each player in the range of 0.1 to 0.25. However, on the 2nd one, all players had the same peak moments on normalized times. These results show that each player uses a similar supporting foot balance strategy, i.e. even with different striking ways of the supporting leg, they try to reach a balance at the kicking moment by adjusting the kicking position or controlling the inner muscle forces of the lower limb.

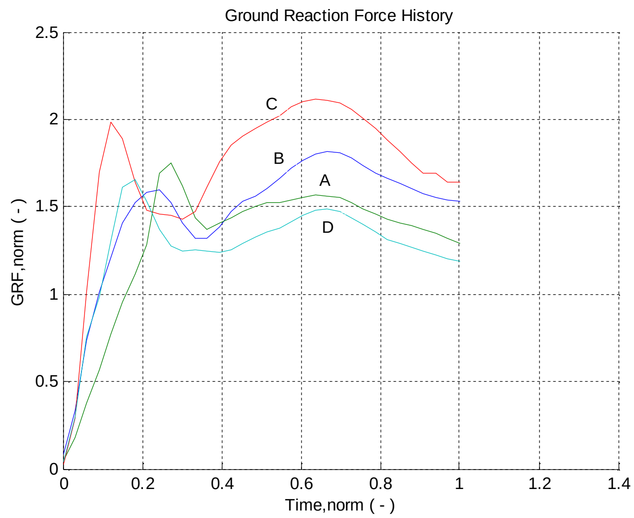

Figure 4. Behavior of normalized ground reaction force (GRF,norm) of the supported foot on normalized time with 4 subjects (A,B,C and D).

As for the stability of the support leg, it can be observed through the maximum variation and average values of the reaction forces after heel contact, especially when the reaction force reaches its 1st GRF peak. Table 2 presents the respective normalized GRF with maximum (MA), mean (MED), and standard deviation (SD) for players disregarding the values before the 1st. peak. Volunteers A and D demonstrated to be more skilled in kicking by the analysis of acceleration and deceleration. They also had a relative stability by the GRF variation level, and voluntary C with minor variation of acceleration in the approximation phase presenting a greater variation of GRF, thus featuring worse kicking performance. This tendency remains in the analysis of COP in a medial-lateral direction (CPx-MA) where volunteer C presents greater variation among the volunteers, and the values of CPx-Ma, in table 2, are average values of maximum displacement of COP in lateral direction to 3 kicking attempts, except for volunteer B who features only 2 attempts.

Table 2. Maximum variation, mean and standard deviation of normalized GRF after heel contact.

PLAYER	GRF,norm-MA	GRF,norm-MED	GRF,norm-SD	CPx-MA (mm)
A	0.5	1.60	0.14	34.6
B	0.46	1.48	0.11	32.7
C	0.68	1.82	0.22	72.0
D	0.41	1.35	0.12	35.4

As for the COP behavior, its changing speed in relation to its location can be observed through a phase diagram shown in Fig. 5. It is observed in the initial phase of the kick with greater speed and at the final phase of the kick with less speed for all players. It is important to highlight that players A, B and D presented a nearly null speed at the end of the kick phase, which ensures stability at the moment of the kick. And, in the case of Player C, even at the end of the kick phase, he still presents a significant COP speed causing instability at the moment of the kick. Therefore, the stability analysis of the kick with the GRF parameter and COP has the same tendencies, and associating to the analysis of acceleration and deceleration of the dominant foot, kicking foot, a precise behavior of the motor control of players during the performance of the kick can be assessed.

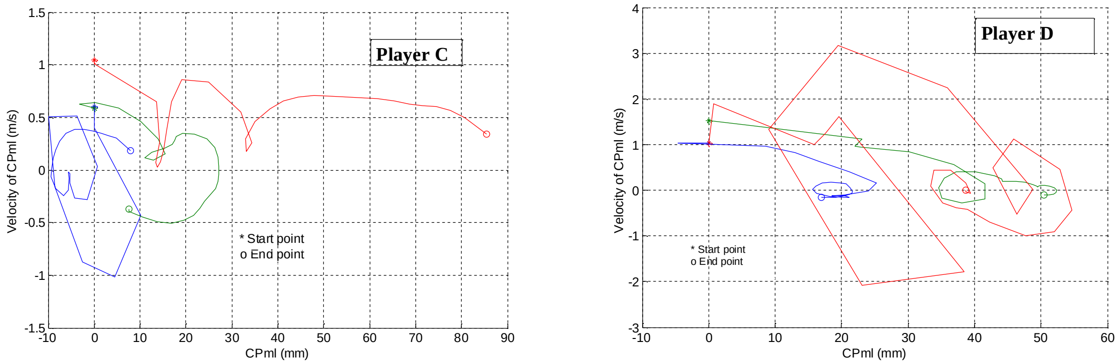

Figure 5. Phase diagram of COP in a mediolateral direction with the supporting foot, COP Vs Velocity of COP.

4. DISCUSSIONS

The knee angle of the supporting leg studied in this work is a parameter that was considered as important in stabilizing posture when performing a kick. However, a study related to this angle generally refers to the kicking leg, and the dominant leg to obtain the kicking power, Levanon and Dapena (1998), Teixeira (2004). In the study of Wickstrom (1975), it is listed only a qualitative observation of an inversion of the knee angle of the kicking leg in relation to the supporting leg, not commenting on the posture stability during the kick. In this study, an accurate kick was performed to hit a distant target which was 9 m away from the players where the stabilization of the knee angle of the supporting leg showed an important factor to get a kick hit with few variations, 137.9° to 129.3° on average, even with different anthropometry for each subject.

On the ball speed, it is important to highlight that the tendency is that youth players present lower speed when compared to professional players. This fact is due to the influence of the development of muscular strength of lower limbs. Isokawa and Lees (1998) found the ball's speed ranging between 20 to 30 m/s for adult players using their dominant limb, without specifying which part of the foot was in contact with the ball. With the non-dominant limb, the speed had a reduction of 10 to 15% when compared to the use of the dominant limb. In studies of Levanon and Dapena, it was found a ball speed of 22.5 ± 1.8 m/s immediately after the impact, and the instant the ball loses contact with the medial part of the foot was at 28.6 ± 2.2 m/s for adult players. The latter, as the dorsum of the foot is an equal condition held this work, showed variations of 21.2±1.2 to 22.9±0.5 m/s. The least values found in this work can be interpreted with the sample of junior players and with the demand to use an accurate kick.

It is well known that the deceleration of the lower limb in moments preceding the kick is caused by a strong antagonist muscles action. Lees and Nolan (1998) cite in their work that the acceleration of the lower limb progressively rises until moments before the foot has an impact with the ball. A thorough study of the acceleration curves on this study indicates that the deceleration starts well before the moment of impact with the ball. On the other hand, Teixeira (1999) observed the kicking standard of five skilled players and found that the higher the demand for precision is, being manipulated by the reduction of the target area, the lower the speed of the kick gets. This proves the hypothesis of a deceleration of the lower limb which is necessary to optimize precision. As for the acceleration studies of Barfield et al. (1998), it was found an average acceleration of 7.8 m/s² ± 0.8 m/s² in the foot's COM displacement for an accurate kick.

Most studies examine the kicking limb, neglecting the study of supporting limb. Nevertheless, this limb has a relevant importance during the kicking performance. In addition to supporting the body, the positioning of the supporting limb affects the precision of the movement, Barbieri et al., (2009). To improve the efficiency of the kick, it is necessary to pay attention to the supporting limb to accomplish correct movements of the kicking limb, Carey et al., (2001). In this work, through variations in the GRF of the supporting limb, it is analyzed the dynamic behavior that was not discussed by the observation of the knee angle. Previous studies, Rodano and Tavana (1993) apud Moreira *et al.* (2004), reported by measuring gait analysis that, the GRF has a maximum value of 1 to 1.2 of body weight (BW) and, on running, this value increases in 3 to 5 of BW. The maximum magnitude of the GRF produced by the supporting leg on the moment of kicking is currently of the order of 3.2 of BW. Average values of (2.69 and 1.24 of BW) are reached for vertical and horizontal components of the GRF, respectively. The average value of the GRF on the moment of the foot hits the ball was 2.04 of BW. A study conducted by Isokawa and Lees with young athletes presented values of 1362 to 1454 N for the maximum force of GRF produced on a power kick. These researched data are well similar to those in the present work. It was observed that our results showed similar patterns of GRF peak when the player supports his body on the force platform, and the kicking limb is taken backwards. This is characterized as a preparatory phase in the stabilization for the execution of the kick, in which the supporting foot thoroughly stands on the platform and the kicking leg performs its greatest knee flexion.

The existing literature in the sports handles the postural balance abilities in terms of the COP. Several studies examine the CP through static positions in which the subject has to remain in a standing position for a few minutes.

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Schmidt et al. (2003) concluded that in one leg oscillations, it is evident the difficulty to maintain a lateral stability in relation to the anteroposterior stability because, when standing on just one foot, the supporting area is much more anteroposterior direction than laterally distributed, besides a decrease in all the support area. Almeida et al. (2009) in a study on COP through the static position, it was verified the foot region where the greatest overload was concentrated. In his research, it was analyzed a group of players with less than 20 years of age (n = 7) which showed a tendency of greater weight discharge in the forefoot, midfoot, and heel, respectively for both feet. With respect to practical experience, it was found that athletes with less than 10 years of practice had higher plantar pressure in the forefoot, midfoot, and heel, respectively. In relation to the displacement of the COP, a tendency was found for the four volunteers: they presented a load transfer from the heel to the forefoot, which reflects the results of Almeida to practitioners with less than ten years of experience. In the study of Duarte (2000), it was found a tendency of repetition in the behavior of the COP curve spectrum on the analysis of postural balance. According to Duarte, the COP migration occurs during the balance control at an orthostatic two legs posture which has relatively long duration. In his studies, it was found 3 formats of COP oscillation patterns that repeat themselves in a temporal scale called as *Shifting* (step type), *Fidgeting* (wrist type), and *Drifting* (ramp type). It is important to note that these findings relate to the quiet bipedal orthostatic posture and kept for a long time, that is, at an average oscillation frequency of approximately 2 Hz in a minimum interval of 1 minute. The kicking performance presented in this work is characterized by a high frequency of body oscillation due to a reduced supporting base and task time, in addition to performing a fast and highly coordinated movement for its execution. However, for the precision kicking, the static or nearly static analysis of COP is not suitable measurement since the events happen in a greatly reduced time, about 1 to 1.5 seconds, during the phases of contact with the platform. In the dynamic analysis of COP, Rosa held a motion trial of precision kicking with an interval of 1.20 to 1.27 seconds and observed individuals trajectories of the COP for each volunteer. For the average displacement curves of COM in both axes, it was found coherence and a higher tendency on the intra-subject analysis. In this work, the COP analysis was carried out only in medial-lateral direction, sway movements, imposed on in step kicking where the postural balance depends on lateral oscillations of the supporting foot and, the graphs of phases diagram were adopted to show the balance behavior during the kick. With them, the body balance control of each kick can be seen with clarity because it showed significant differences for each player according to the motion strategy. However, for the final conclusion will be required attended by most players. The authors of this study believe that the analysis system hereby proposed will aid in the work of coaches and physical therapists who work with indoor or outdoor soccer players who currently use qualitative assessments of kicking control very often.

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