

Postural Sway Characteristics in Static Balance Control of Youth Female Soccer Players

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Purpose: Balance control, particularly in uni-lateral domain, is essential in soccer. Majority of the existing studies examined dynamic balance via clinical tools, and primarily involved male players. Thus, the purpose here was to examine the nature of Center of Pressure (COP) postural sway in youth female players across bipedal and unipedal conditions

Methods: Sixteen pre-adolescent female competitive players (age 12.4 ± 21.40 years) were asked to stand on a force plate in bi-pedal stance with the dominant and non-dominant legs respectively. Three, 10 second trials were carried out for each condition.

Results: As expected, across the four COP measures bi-pedal stance resulted in least sway ($P = .05$). However, the subsequent analysis showed different center of pressure (COP) profiles in the dominant versus non-dominant condition across COP velocity ($P = .003$), path length ($P = .001$) and anterior-posterior (AP) sway ($P = .003$), with sway area revealing no statistical differences ($P = .821$). In addition, the analysis of stabilograms confirmed that in the non-dominant condition the pronounced COP oscillations were of lower amplitude and frequency as compared to the dominant leg.

Conclusions: Overall, postural asymmetry was found as the sway characteristics on both legs differed, with dominant side exhibiting more sway and faster COP oscillations. In line with the inverted pendulum model, this may be due to less than optimal ability to modulate muscle torques generated at the ankle. It is hypothesized that the postural asymmetry between the dominant and non-dominant legs may result from muscular asymmetries that have been often reported in youth soccer players, as a result of their pronounced foot dominance.

Key words: Balance asymmetry; Center of Pressure (COP) measures; Inverted Pendulum Model; Uni-lateral stance; Strength.

Introduction

Soccer combines technical abilities with high degree of speed, endurance, strength, power, agility, as well as balance control. As a result of the training that soccer players undergo, they exhibit balance control that is similar to that evident in gymnasts, and superior to other sports such as basketball¹. Also, balance skills differentiate elite level soccer players from their less competitive counterparts, thus further confirming that this is an important domain of their development as athletes^{2,3}. Balance control, and more specifically uni-lateral balance, is of particular importance when performing technical skills such as shooting, passing, receiving the ball, or dribbling. For example, Chew-Bullock and colleagues⁴ showed that kicking accuracy was predicted better by uni-lateral balance on non-dominant foot as compared to the dominant limb which was used for kicking. Also, uni-lateral balance is one of the key physical determinants of “cutting action” involved in change of direction and agility⁵.

From the biomechanical standpoint, the control mechanisms underlying unperturbed stance, either bi- or unilateral, have been embedded in the single inverted pendulum model.⁶ The key assertion of the model is that the central nervous system (CNS) modulates torque produced at the ankle to control the horizontal position of the COM along the base of support in the sagittal plane. The resulting ankle “stiffness” is sufficient to correct small deviations in the COM position when the sway frequency is low⁷. Methodologically, the effectiveness of the respective control mechanism is often inferred from the characteristics of

COP profiles, which represent the projection of the body COM on the standing surface within the base of support. Changes in COP measures, such as shifts in the COP trajectory or changes in COP velocity, reflect the adjustments and responses implemented by the neuromuscular system to control the body's COM and maintain stability. Parameters derived from the manipulations of torques and forces measured from a force plate (i.e., AMTI®) such as COP path length, velocity, sway area and 95% elliptical plots, are considered to be the gold standard of balance assessments.

The analysis of postural sway in youth players attracted little attention in literature, despite the fact that developmentally their balance control may not be optimal, and they often exhibit a pronounced leg dominance in their technical skills⁸. The majority of the existing studies implemented clinical assessment tools focusing on dynamic balance showing developmental differences among adolescent male soccer players. However, the results pertaining to the differences between the two legs remained equivocal. Lack of differences between the dominant and non-dominant legs were reported in some research⁹⁻¹¹, however other studies involving similar clinical measures revealed the presence of such asymmetries. For example, Breen and colleagues¹², using Balance Error Scoring System (mBESS) and Y-Balance Test, showed significant differences in bi-pedal and uni-pedal conditions among male players between 12 and 18 years of age. The results also indicated that youngest players performed the worst on the single leg stance, and demonstrated more asymmetry in the posterolateral and posteromedial

directions as compared to older athletes. A similar pattern of results was reported by Chtara and colleagues¹³ who examined dynamic balance in adolescent, male players. To our knowledge the only study that examined explicitly bilateral and unilateral static balance in youth players, via COP sway measures, was carried out by Bigoni et al.,⁸. As expected, the bi-pedal stance resulted in smaller amount of sway as compared to the uni-lateral tasks. In addition, the results failed to show statistically significant differences between the dominant and non-dominant legs, however it is worth noting that out of the three variables sway path length and COP velocity approached the expected level of significance. It is likely that large intra-group variability contributed to the lack of statistical differences between the dominant and non-dominant legs.

Thus far there has been no research examining these issues in youth female players. Considering that developmentally boys and girls mature at different rate, and the development of balance control is different during adolescence¹⁴, further research focusing on female, youth players is warranted. Thus, the purpose of this study was to examine the nature of postural sway characteristics in static bi- and uni-lateral stance in youth female soccer players.

Methods

Participants.

Sixteen pre-adolescent (Age 12.42 ± 1.40 years) female players were recruited from local competitive programs via purposive sampling. Once the technical director agreed to take part in the recruitment process, the coaches of the respective teams were contacted by the researcher. All players within the U-11, U-12, and U-13 teams were given the information letter along with the consent forms. If interested, the parents of the players were asked to contact the researcher directly via provided email. The sample consisted of female players between the ages of 11 and 13 years. Players who sustained any significant injuries involving knees or ankles within the last 6 months were excluded from the study. Participants' age, weight, body mass index, height, foot width and length were recorded (Table 1). The study was carried out in accordance with the institutional ethical guidelines and approved by School of Kinesiology Ethics Board. Upon the approval of the study, and prior to its commencement, all participants and their guardians provided written consent.

Table 1. Participants' Demographics and Anthropometric Data

Participant (#)	Age (yrs.)	Weight (kg)	BMI	Height (cm)	Foot Length (cm)	Foot Width (cm)
1	14.62	67.15	23.55	173.30	249.22	95.84
2	10.72	28.24	12.10	152.76	213.33	85.41
3	12.61	49.63	18.75	163.14	225.07	82.42
4	11.58	69.57	10.60	152.23	223.22	86.78
5	12.93	38.90	16.22	155.28	234.44	92.85
6	12.12	40.12	18.61	147.50	238.90	92.22
7	12.48	55.34	20.33	165.73	245.44	88.90
8	11.72	67.56	24.87	165.14	238.70	91.31
9	14.25	52.61	19.63	163.4	212.23	79.82
10	12.68	43.72	17.43	157.66	230.96	82.33
11	11.86	40.19	16.66	158.97	226.75	81.60
12	11.50	48.16	19.01	158.80	224.26	89.02
13	12.63	53.02	21.86	163.72	201.14	82.49
14	14.38	65.10	22.52	170.54	223.66	91.47
15	11.91	35.74	17.02	143.85	209.63	79.83
16	13.22	41.34	18.27	150.12	213.98	81.25
Mean	12.43	48.12	18.33	158.81	225.62	86.45
SD	1.42	12.22	3.63	8.21	13.52	5.22

Experimental Design

The study was descriptive in nature and it implemented a quasi-experimental design, with a single group. To examine the differences in balance control, a repeated measure design was implemented with balance condition (both, dominant, and nondominant foot) as an independent variable. The testing was completed in one session, and it was carried out individually. Due to the length of each testing, the entire team completed their session within three days. Prior to testing, morphological measurements were completed (Table 1), and leg dominance was established by asking the player to take a penalty shot. The leg used was considered as the dominant. The balance testing session commenced with one practise trial per condition, each lasting 5 seconds. As unilateral balance is more demanding the tasks involving dominant and non-dominant leg were implemented first, and they were counter-balanced across the participants. The bi-pedal condition was carried out last. Each participant was required to complete three 10 seconds trials per condition. The participants were asked to maintain their balance while remaining as motionless as possible, while looking at a target located shoulder height 5 meters in front of the participant. The participants were asked to keep their arms on their hips.

Methodology

To derive the sway characteristics, an AMTI® force platform connected to an AMTI® OR6 amplifier (Advanced Mechanical Technology, Inc, US, Colorado) was used. The maximal gain on the amplifier was set to 4000 with a low pass filter of 10.5 Hz. The force platform data was collected at a sampling rate of 100 Hz. The AMTI® BioDaq Analysis package (Advanced Mechanical Technology Inc. US, Colorado) was used to capture the force and torque data and compute the Center of Pressure (COP) data measures. The primary measures of interests included area of sway (cm^2), path length (cm), COP velocity (cm/s) and anterior-posterior (AP) sway (cm)¹⁵. The 95% area of sway captured the total area formed by the COP trajectory covered in the AP and mediolateral (ML) directions. The COP path length represented the total distance traveled by COP during the test time. The AP sway reflected the distance between the maximum and minimum COP peak excursions in the AP plane of motion, while the average COP velocity was calculated by dividing the COP path length by total testing time¹⁵. Across all the measures, a smaller value represented more effective control. The nature of the potential balance asymmetry was also assessed qualitatively using stabilograms, which captured the COP profiles in terms of the 95% ellipse and force distributions in AP directions. For this qualitative analysis, three participants were selected who were approximately the same age and had similar morphological characteristics.

Statistical analysis.

All data as reported as mean and standard deviation. To examine the differences in balance control AP sway, area of sway, COP velocity and path length were used as dependent variables. A repeated measures ANOVA was implemented for each dependent variable separately, while dependent samples *t*-tests were used as planned comparisons in the case of a significant ANOVA. The effect sizes were calculated for the ANOVA analysis (η^2), as well as for the *t*-test (Cohen's *d*). A posteriori power analysis was reported for each ANOVA. All analyses were carried out using SPSS statistical package software (IBM SPSS Statistics, US) at alpha level set at $P < .05$.

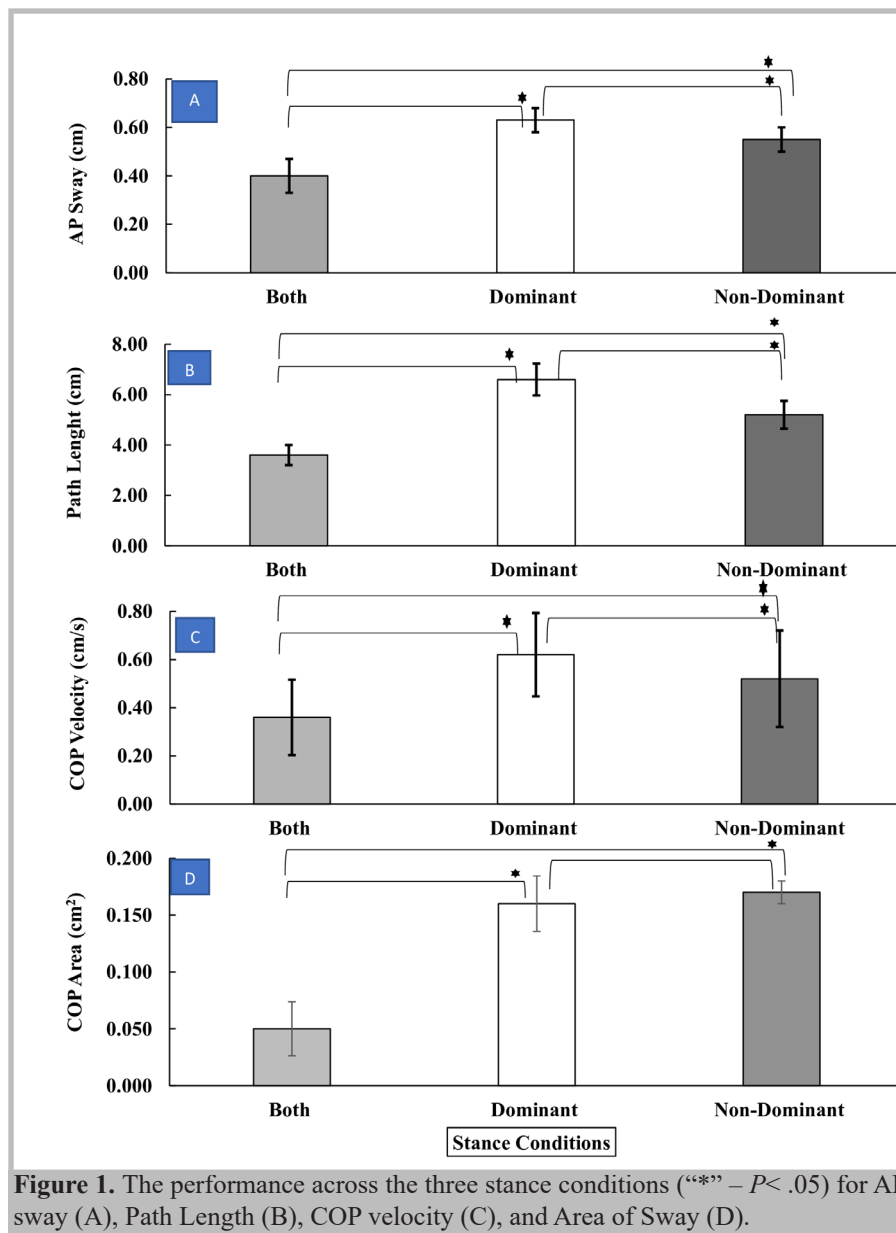
Results

COP Measures.

The ANOVA analyses revealed significant differences for AP sway ($P = .001$, $\eta^2 = .40$), Area of sway ($P = .011$, $\eta^2 = .68$), COP velocity ($P = .001$, $\eta^2 = .81$) and Path length ($P = .001$, $\eta^2 = .79$) (Figure 1). The posteriori power analysis, as captured by the lower-bound estimate values ranged from .81 to .97 across the ANOVA analyses. In terms of AP sway, the least sway was exhibited when standing on both feet when compared to the dominant ($P = .005$, $d = 1.29$) and non-dominant leg ($P = .02$, $d = .93$). In terms of the uni-lateral conditions, more sway was exhibited when standing on the dominant leg ($P = .003$, $d = .55$). The analysis of COP velocity revealed similar pattern of results as standing on both feet resulted in the smallest velocity as compared to the dominant leg ($P = .003$, $d = 3.72$), and non-dominant leg ($P = .001$, $d = 2.81$). Also, standing on non-dominant leg coincided in slower COP sway as compared to the dominant condition ($P = .003$, $d = .65$). The path length variable also revealed significant differences between the bipedal stance and dominant ($P = .001$, $d = 2.90$) and non-dominant legs ($P = .001$, $d = 2.10$). The comparison between the uni-lateral stances showed that less sway was exhibited in the non-dominant condition as compared to the dominant stance ($P = .009$, $d = 2.61$). The analysis of area of sway showed significant differences between both feet condition and dominant leg ($P = .001$, $d = 2.35$), and non-dominant leg ($P = .001$, $d = 2.43$). However, the differences between the two unilateral conditions were not statically significant ($P = .821$, $d = .03$).

COP Stabilograms.

Also, to infer the nature of the differences in COP profiles, between the dominant and non-dominant legs, the area of sway plots along with the corresponding force profiles in the X-axis were compared. The plots were derived from 3 participants of same/similar morphological characteristics, to control for the variability associated with constraints such as height or size of base of support (Figure 2). The analysis of the COP profiles revealed that although the shape and size of the area of sway were comparable for each participant across dominant (Figure 2A, E, I) and non-dominant sides (Figure 2B, F, J), the overall nature of the dispersion of the sway between the dominant (Figure 2C, G, K) and non-dominant sides (Figure 2D, H, L) were different. In line with the outcome measures, it is evident that more sway was generated in the dominant leg condition (Figure 2A, E, I). In terms of the COP profiles, it is evident that the 95 percent elliptical curve rotated and aligned in the direction of the increased sway (x direction) for either the dominant or non-dominant leg. However, the trajectory of the COP displacements inside the elliptical curve for the non-dominant leg was mostly within 95% limit, and it appeared to be within normal limits. On the contrary, for the dominant leg, part of the trajectory of the COP displacements for the elliptical curve exceeded the 95% normal limits in the x direction of the sway. Furthermore, the profiles of the non-dominant leg (Figure 2D, H, L) were less dense, particularly around the middle of the x and y axes, which corresponds with the upright vertical alignment of the COM over the base of support. In line with these COP outcome measures, it is evident that more sway was generated in the dominant leg condition and that greater movement variability beyond the 95% ellipse was higher in the dominant leg. Behaviorally, these outcomes indicated that the corrective adaptations to the location of COM within the base of support for the dominant leg took place closer to the stability limits, as opposed to the corrective mechanisms employed when standing



on the non-dominant leg, which suggested a more controlled and stable posture. Generally, the more abrupt corrective adaptations experienced with the dominant leg coincide with a larger velocity of COP, which may suggest more ballistic postural adjustments and greater instability.

In terms of the corresponding horizontal force profiles, it is evident that more pronounced changes in force occurred in the dominant condition (Figure 2D, H, L). These changes can be observed in the magnitude of the force oscillations, which appeared to have larger peaks on the dominant leg (indicating that the body exerted more force to maintain balance likely due to increased muscle activation and coordination. Furthermore, force fluctuations occurred over wider values for the dominant leg as compared to the non-dominant leg (Figure 2C, G, K) which reflects the differences in weight distribution and neuromuscular control as the body adjusted to counteract the sway and maintain the Center of Mass (COM) within the base of support. Finally, the force profiles appeared to have more irregular oscillations and magnitudes with the dominant leg. These irregularities reflected the dynamic nature of sway and the continuous adjustments made by the body to maintain balance while standing on the dominant leg. This outcome could be attributed to the body's efforts to align itself vertically while standing on the dominant leg, leading to greater variability in force profile.

Discussion

Differences in COP measures.

In terms of bi-pedal stance, it was expected that this condition would result in the least sway. Developmentally, it is assumed that by this age bi-lateral balance control is adult-like in terms of amplitude, frequency and velocity¹⁵⁻¹⁶. The current data revealed a robust pattern across all the measures indicating that bilateral stance coincided with smaller amount of sway and COP velocity. This finding is consistent with previous work¹², which showed that despite the fact that adolescents exhibit growth periods at different times, balance control reaches “maturity” around 13-14 years of age¹⁷. In the uni-lateral stance conditions, the current study revealed differences in COP profiles between the dominant and non-dominant legs across 3 out of 4 measures. The differences were evident in AP sway, path length and velocity, but not in the area of sway. This result is in line with previous work indicating that soccer players have a better standing balance in nondominant one-legged stance⁹. However, in the context of present sample it is difficult to compare these results to previous work as there has been no studies examining COP characteristics of female youth players across the different stances. The only research which examined the comparable age group, but among male players, was carried out by Bigoni and colleagues⁸. In line

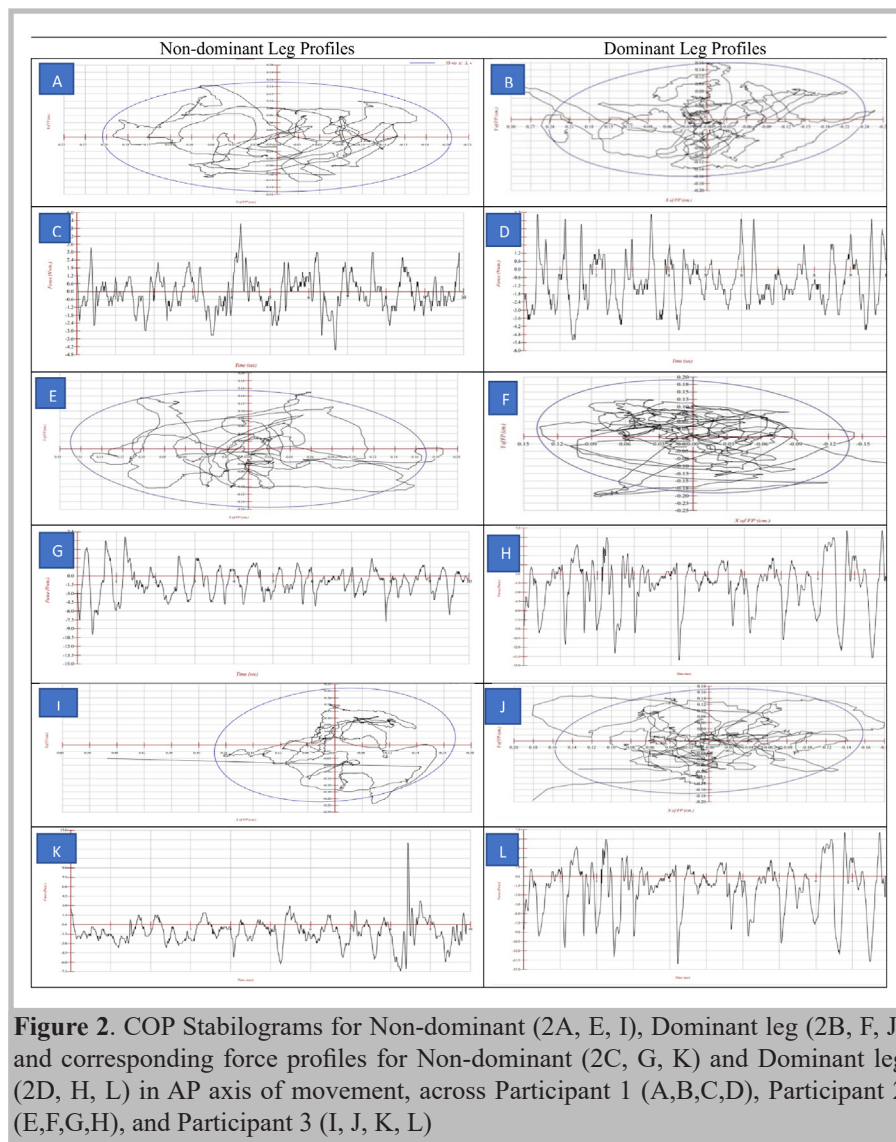


Figure 2. COP Stabilograms for Non-dominant (2A, E, I), Dominant leg (2B, F, J) and corresponding force profiles for Non-dominant (2C, G, K) and Dominant leg (2D, H, L) in AP axis of movement, across Participant 1 (A,B,C,D), Participant 2 (E,F,G,H), and Participant 3 (I, J, K, L)

with the current data, the results showed that descriptively larger path length was exhibited while standing on the dominant foot. This outcome was also true for COP velocity, suggesting that balancing on the dominant leg was less optimal, as this condition resulted in COP displacement, which was occurring at a faster velocity. Both analyses only approached statistical levels of significance ($P = .09$), while the effect sizes were not reported, thus caution is warranted in terms of the possible Type 1 error. Nevertheless, the substantial amount of intra-group variability reported suggested that at least some individuals in the sample were exhibiting such bilateral asymmetries.

The current results provided an in-depth analysis of the characteristics of the emerging postural sway. Among the measures implemented, the results showed lack of statistical differences in sway area, which captures the surface of the 95% confidence ellipse fitted to the sampled ML and AP data. This variable allows making inferences about the estimated size of the surface covered by the excursion of the COP during the test. On the other hand, a measure such as path length provides information about the pattern of the COP excursions, when the recording period is constant. Both measures are influenced by the sum of all the inertial and voluntary forces acting onto the force platform. However, it is evident that the two measures are not redundant, hence they capture the different aspects of postural control. Sway area is more sensitive to the large excursions towards the limits of stability, whilst path length conceptually has been considered as a better indication of the presence of a 'stiffening' strategy¹⁸. Thus, collectively it is

evident that despite the fact that both conditions resulted in comparable magnitude of the COP excursions from the vertical, overall, the non-dominant condition resulted in small degree of sway, hence better overall balance control. In addition, due the fact that path length and AP sway are closely aligned, as both capture back-and-forth oscillations of the COP, both confirmed that less sway was exhibited in the non-dominant condition. In the past path length has been more sensitive over sway area for detecting changes in body sway¹⁹ and to be a better predictor of falls²⁰. Also, rehabilitation research has shown that balance training did not modify sway area, but it resulted in diminished path length, implying enhanced postural control²¹. Thus, in the context of bi-pedal and uni-pedal static balance control, and the inverted pendulum model, it could be assumed that the inferences emerging from overall amount of sway exhibited should be considered as the primary indicator of how well the ankle strategy is implemented to maintain COM close to the vertical. Another important parameter to consider when capturing the nature of emerging postural sway is the mean COP velocity, which can be viewed as the normalized derivative of path length. This variable showed age-related differences, under various sensory conditions²², and it has been considered as a good predictor of falls in older adults²³. Clinically, it is considered as one of the most reliable measures of sway¹⁸, and one of the most accurate indicators of less-than-optimal control of balance²³.

Differences in Stabilograms.

The analysis of COP measures captured the nature of the differences emerging at the level of ground reaction forces.

These analyses suggested that control strategies responsible for maintaining stance in both unilateral conditions were in fact different. The review of the corresponding stabilograms provided an additional insight into how the nervous system's attempts to counteract the changes to COM to prevent falling or staggering. The profiles (Figure 2) appeared to support the inferences emerging from the outcome measures. As evident from the COP displacement profiles, pertaining to the dominant leg, the plots revealed more frequent displacements around the middle of the coordinated system as well as excursions close and past the 95% ellipse. This is in contrast to the profiles pertaining to the non-dominant leg where the oscillations are not as frequent, and only occasionally drift far away from the vertical past the boundary. Also, this may indirectly explain the differences in COP velocity, as more control hence stability, coincides with fewer and slower COP adaptations. In terms of the distribution of the horizontal force, the magnitude of the oscillations in the dominant leg are characterized by large peaks, suggesting that more force had to be exerted to prevent further displacement of the COM from the vertical, and outside of base of support. And, although these large amounts of force are also evident in the non-dominant leg, the frequency of these oscillations is substantially smaller. Thus, not only that more force had to be generated to maintain vertical alignment of the body, while standing on the dominant leg, but these adaptations were also taking place more frequently.

Constraints on Balance Control.

The nature of emerging COP trajectories reflects the status of several cognitive, sensory, motor and morphological constraints. Although this study aimed at describing the postural differences between different stances, it is speculated that one of the potential constraints contributing to the emerging differences is muscular strength. Previous work involving non-athletes showed that postural asymmetries between the dominant and non-dominant leg were in fact attributed to strength asymmetries observed across the two limbs²⁴. This was also confirmed in several studies involving athletic populations, suggesting that the strength of the muscles, particularly around the ankle joints, plays a critical role in postural corrections during single limb standing²⁵. In fact, in rehabilitation / clinical research, reduced ankle strength has been found to contribute to loss of balance, while muscle training around this joint led to improvements in balance recovery²⁶⁻²⁷.

In the context of soccer, the differences in unilateral balance can be attributed to differences in the frequency and intensity of the use of the dominant and non-dominant limbs, which in turn affects the strength, as evident in adult female soccer players²⁸⁻²⁹. The presence of such postural, and muscular asymmetries may be even more prevalent in youth players who often have a distinct preferred sidedness when executing technical skills involving striking the ball, and "cutting" while changing directions^{30, 31}. This has been confirmed in youth male soccer players (14 years of age)³², particularly in isokinetic muscular strength where 72% of the participants showed asymmetric across the dominant and non-dominant legs. Thus, given the impact of strength on unilateral tasks, it is plausible that the balance related asymmetries evident in the present work are at least partially a by-product of muscular asymmetries³³. Here, it should be noted that the assertion is that players use primarily the dominant leg for striking the ball, whereas the non-dominant leg is involved in more balance-related activities during shooting or as a push-off leg when changing the direction. Since, biomechanically the dominant and non-dominant legs exhibit distinct kinematic and kinetic profiles³⁴, it is suggested that the support or planted leg would exhibit different synergistic relations than the non-

dominant leg, which would result in better balance. The results from this research seem to confirm the latter hypothesis.

Practical Applications

There are few important implications that emerged out of this work. From the technical development standpoint, players from an early age should be encouraged to use both feet to strike the ball in order to diminish leg-dominance. This will likely enhance their technical pedigree, and from the motor perspective improve their strength and likely balance by having to plant, pivot, and explode from each foot. In terms of off-field training, uni-lateral low-amplitude plyometric programs focusing on isolated use of each foot could be beneficial. Such training programs involve a combination of bilateral, alternative and unilateral "pogo" jumps, hops and bounding tasks. The emphasis is placed on a greater number of ground contacts, in short duration ballistic actions, which are performed across all planes of movement thus mimicking the load placed on the lower limbs while playing. These programs have been used effectively to improve reactive strength, speed, power and balance in the past⁵. This type of training may be beneficial to youth female players who developmentally tend to have lower levels of muscle strength and power compared to male soccer players due to differences in muscle mass and body composition³⁵. The further enhancement of these domains can also decrease the rate of soccer injuries, particularly among youth female players who tend to have a significantly higher risk of knee and ankle injuries, as compared to males, across different levels of competition and playing surface³⁶.

Conclusions

The inferences emerging from the current data pertaining to the differences between bi-pedal and uni-pedal stances were robust. More specifically, the fact that youth female soccer players exhibited better balance in non-dominant versus dominant leg condition were supported by several COP measures and the corresponding stabilograms. Such balance asymmetries have not been examined previously in youth female athletes, however a similar pattern of results has been evident with youth male players⁸. Due to the small sample size in the current study the emerging inferences warrant caution and require further replication. Also, the potential underlying causes of the emerging differences between the two legs are at this point speculative. Although, previous studies involving adult soccer players showed that strength asymmetries across dominant and non-dominant legs exist, their impact on balance control in youth players remains equivocal.

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