INFLUENCE OF COORDINATIVE MOTOR ABILITY ON LOWER LIMB KINEMATICS IN YOUNG FOOTBALL PLAYERS: INJURY PREVENTION THROUGH WEARABLE INERTIAL SENSORS

Stefano Di Paolo[1], Nicola Pizza[2], Stefano Zaffagnini[1,2], Laura Bragonzoni[3]

Department of Biomedical and Neuromotor Sciences, University of Bologna, Bologna, Italy[1]
2nd Orthopaedic and Traumatological Clinic, Rizzoli Orthopaedic Institute, Bologna, Italy[2]
Department of Quality of Life, University of Bologna, Bologna, Italy[3]

The aim of the present study was to evaluate, during ordinary training, the lower limb kinematics in young football players, and to verify if the kinematic patterns are influenced by coordinative motor abilities. Fourteen healthy players (10y ± 2m) were enrolled. Each player performed two activities: a pre-defined path with typical movements of football training and matches; the Harre test to evaluated children's coordinative motor ability. Wearable inertial sensors were used to assess lower limb joint kinematics and accelerations. Based on Harre test, players were divided into two groups, more coordinated and less coordinated. During all tasks performed, less coordinated players showed stiffer kinematic strategies and greater limb asymmetry, which are potential risky patterns for non-contact (e.g. Anterior Cruciate Ligament) injury. Quantitative analysis on the field could contribute to deepening the biomechanical understanding of players' motion and injury risk.

KEYWORDS: wearable sensors, joint kinematics, football, injury prevention

INTRODUCTION: Motor control plays a crucial role in injury prevention strategies in football at all levels. Such an ability is acquired in pre-pubertal period, which is also when children usually approach football. The evaluation of coordinative motor ability mainly relies on functional tests with time or score as main outcome (Chiodera et al.,2007). Recent studies (Watson & Mjaanes, 2019) stated the importance of neuromuscular and biomechanical training already in the youth, in order to reduce the risk of non-contact injuries, e.g. Anterior Cruciate Ligament (ACL) rupture. ACL rupture is, indeed, one of the most invalidating injuries for footballers and sport teams. The "risky" motion patterns in ACL injury are currently under investigation in sports medicine and biomechanics fields, as well as prevention and rehabilitation training programmes.

Prevention strategies in football are increasingly relying on motion capture technologies. Quantitative assessment of players' movement can be a key tool to comprehend complex injury patterns that may seriously affect their health and activities. All the biomechanical aspects, available from such analyses, can be translated into personalized training programs with the goal of injury prevention and safe return to play. Currently, the vast majority of these studies is performed in a laboratory environment, thus introducing biases related to the limited space and to a low automatization of the movement. Wearable inertial sensors give the opportunity to overcome these problems and analyse players' motion directly on the pitch, in trainings or matches. Verheul et al. (2020) recently underlined how quantitative measurements, especially the ones acquired directly in field environment, are essential but still lacking. In particular, the on-field biomechanics of young players has been investigated only in one study (Burboa et al., 2017), and never in relation to motor abilities. Such an analysis could contribute to highlight biomechanical aspects of motor control development.

The purpose of this study was to evaluate, during an ordinary training, the lower limb kinematics in young football players using wearable inertial sensors, and to verify if the kinematic patterns are influenced by coordinative motor abilities.

METHODS: Fourteen healthy young male football players (10 years ± 2 months) were enrolled in the study. Every subject was asked to perform two different motor activities: a pre-defined path, with typical movements performed in football training and matches; the Harre test, to evaluate the coordinative motor ability. The path consisted in 5 tasks (Figure 1, right): a lateral shuffle (LS), a vertical jump (VJ), a low skip (SK), 2 changes of direction (COD) at 90°, one right and one left, and a shot on goal (SH). Children received only few indications on how to perform the path, in order to let them move in the most natural way. Motion data were collected through a set of 7 inertial sensors (Xsens MVN) placed on feet, shanks, thighs and pelvis (Figure 1, left). Joint angles and accelerations of hip, knee and ankle were acquired for all the tasks performed in the path (sampling frequency 100Hz). For the Harre test, the time elapsed was measured. The time elapsed was used to divide the players according to their higher (less time elapsed) or lower (more time elapsed) coordination. The kinematic parameters evaluated were: hip, knee, ankle angles on frontal, transverse and sagittal plane, in terms of ranges and peak values; hip, knee, ankle accelerations (measured at the joint centre) on antero-posterior, medio-lateral and vertical axes, in terms of ranges, positive peaks and negative peaks. The data were evaluated in terms of dominant and non-dominant limbs (13 dominant right, 1 dominant left) and compared between the most coordinated and the least coordinated players. The within-group limb symmetry was also assessed. The three central tasks of the path (VJ, SK, COD), i.e. the most interesting in terms of coordination and limb symmetry, were considered in the final analysis. The two-tailed t-test ($p<0.05$) was used to assess statistically significant differences. A parent/tutor of each player signed an informed consent and agreed to their own son's performance data acquisition and treatment for research purposes. The coach of the team was present and supervised all the data acquisition phase.

Figure 1 – Inertial sensors placement (left); pre-defined path for kinematic data acquisition (right)

RESULTS: Based on the results of the Harre test, the players were divided in two groups ($p=0.0087$): in the Group A ($n=7$) the ones who took more time to complete the test (20.5±2.9 sec), which were considered less coordinated; in the Group B ($n=7$) the ones who took less time to complete the test (16.4±0.9 sec), considered more coordinated.

A significantly higher range of motion (i.e. range of flexion angle) and peak flexion was found in players of Group B compared to Group A for hip joint in dominant and non-dominant limb both in VJ and SK (Table 1). Furthermore, Group B players showed a higher ankle range of motion in dominant limb in VJ and knee peak flexion in non-dominant limb in SK.

Group A players showed a higher range of internal-external hip rotation in both VJ and COD. In the same tasks, Group B showed higher varus peaks compared to Group A.

Moreover, a significant limb asymmetry was found in Group A (Table 2): in SK, in terms of peak external rotation; in COD, in terms of hip abduction-adduction, knee varus-valgus and ankle internal-external rotation. No significant asymmetries were found in Group B.

In terms of accelerations (Table 1), positive peaks and ranges of vertical hip acceleration were found to be higher in Group B for both dominant and non-dominant limb in VJ. In COD, positive peak and range of vertical ankle acceleration and medio-lateral hip acceleration were found to be higher for dominant limb of Group A. Furthermore, in the COD, players of Group A showed higher positive peak and range of knee acceleration and higher peaks of negative medio-lateral ankle acceleration in dominant limb compared to non-dominant ones (Table 2).

Table 1: COORDINATIVE MOTOR ABILITY differences between Group A and Group B for joint angles (top) and accelerations (bottom). For conciseness, only the significant differences ($p < 0.05$) were reported.
Abbreviations: flex=flexion; IE=internal-external; V=vertical; ML=medio-lateral

Task	Angles (°)	Group A	Group B	p-value (diff %)
VJ	Dominant - Hip flex peak	44.0 ± 7.7	59.8 ± 12.8	0.0188 (-36%)
	Dominant- Ankle flex range	17.7 ± 8.5	34.7 ± 18.4	0.0498 (-96%)
	Non Dominant- Hip flex peak	42 ± 8.5	59.2 ± 13.1	0.0152 (-41%)
	Non Dominant- Hip IE range	23.7 ± 6	15.6 ± 6.7	0.0362 (+34%)
	Non Dominant- Knee varus peak	-4.3 ± 2.4	-9.4 ± 2.8	0.0034 (-117%)
SK	Dominant - Hip flex peak	50.4 ± 7.3	64 ± 7.8	0.0059 (-27%)
	Dominant- Hip flex range	45.8 ± 10.1	58.9 ± 9.2	0.0269 (-29%)
	Non Dominant- Knee flex peak	91.3 ± 9.2	102.2 ± 9.5	0.0494 (-12%)
COD	Dominant- Hip IE range	28 ± 4.6	21.5 ± 4.3	0.0188 (+23%)
	Non Dominant- Knee varus peak	-8.1 ± 2.9	-12.9 ± 3.7	0.0192 (-60%)
	Accelerations (m/s^2)			
VJ	Dominant - Hip V peak(+)	39.4 ± 9.9	79.9 ± 30	0.0109 (-103%)
	Dominant - Hip V range	62.8 ± 7.2	119.1 ± 36.7	0.0062 (-90%)
	Non Dominant - Hip V peak(+)	40.7 ± 12.8	71.1 ± 27.5	0.0277 (-75%)
	Non Dominant - Hip V range	69 ± 25.1	117.4 ± 49.5	0.0469 (-70%)
COD	Dominant - Ankle V peak (+)	130.8 ± 23.4	91.8 ± 31.4	0.0227 (+30%)
	Dominant - Ankle V range	219.1 ± 39.3	156.3 ± 53.3	0.0288 (+29%)
	Dominant - Hip ML peak (-)	-141.1 ± 48.6	-78.2 ± 43.3	0.0253 (+45%)
	Dominant - Hip ML range	247.2 ± 58	157.2 ± 67.9	0.0209 (+36%)

Table 2: LIMB SYMMETRY differences between dominant and non-dominant limb for joint angles (top) and accelerations (bottom). For conciseness only the significant differences ($p < 0.05$) were reported.
Abbreviations: ER=external rotation; AA=abduction-adduction; VV=varus-valgus; IE=internal-external; V=vertical; ML=medio-lateral

Task	Angles (°)	Dominant	Non-Dominant	p-value (diff %)
	Group A - Knee ER peak	-4,5 ± 2,2	-7,9 ± 3,1	0,0379 (-77%)
COD	Group A - Hip AA range	27,3 ± 4,4	22,2 ± 2,7	0,0266 (+19%)
	Group A - Knee VV range	23,2 ± 6,7	14,5 ± 3,5	0,0133 (+38%)
	Group A - Ankle IE range	28,5 ± 8,3	19,3 ± 4,4	0,0298 (+32%)
	Accelerations (m/s^2)			
COD	Group A - Knee V peak (+)	119,9 ± 19,8	72,7 ± 20,5	0,0009 (+39%)
	Group A - Knee V range	183,9 ± 36	126,6 ± 37,4	0,0129 (+31%)
	Group A - Ankle ML peak (-)	-165,9 ± 33,9	-111,3 ± 54,2	0,0471 (+33%)

DISCUSSION: The kinematics of young players was evaluated in relation to their coordinative motor abilities, evaluated through the Harre test. Firstly, players with less coordination (Group A) showed a reduced range of motion (flexion angle) in all the lower limb joints, thus looking to adopt a “stiffer” kinematic strategy. A stiffer kinematic strategy is often associated with higher intra-articular stress (Pollard et al., 2010). In rehabilitation programmes after ACL injury, reaching a good range of motion in landings and cut manoeuvres for both hip and knee is a key point. Moreover, the hip strategy is always preferred to the knee strategy to reduce the stress on the knee ligaments (Nguyen et al., 2018).

Secondly, according to the current concepts on non-contact injury biomechanics, players of Group A seemed to be less stable (higher rotations) on transverse and frontal plane compared to players of Group B. In particular, high hip internal-external rotation is associated with dynamic knee valgus, a common pattern in ACL injury. In addition, players of Group B had higher varus peaks, another key point to reach in rehabilitation programmes.

A third crucial point regards limb asymmetry: statistically significant differences were found only in players of Group A, often with higher internal-external and abduction-adduction rotation in the dominant limb. Kinematical asymmetries are often associated to the risk of non-contact ACL injury, either primary or secondary. Higher values on dominant limb were also found in terms of accelerations. Accelerations are still debated as a biomechanical metric, but could be intended as a surrogate for intra-articular stress (the vertical ones) and stability (the antero-posterior and medio-lateral ones). In the present study, these metrics seem to confirm the results obtained through the joint angles analysis.

The present study underlined, even with a small population, significant biomechanical differences between the young players, starting from their motor ability. Players with lower coordination showed some of the typical risky patterns found in ACL injuries: this finding should encourage a stronger use of motor control programmes in footballers. The wearable inertial sensors technology offered a huge amount of significant data and gave the opportunity to deeply analyse players' biomechanics directly on field. Therefore, a further use of this technology in sport biomechanics is highly recommended, given its valuable information and use in "real" environments.

CONCLUSION: This study highlights the biomechanical differences in a population of young football players in relation to the coordinative motor abilities, through the wearable inertial sensor technology, applied directly on field and during an ordinary training. A low motor coordination was associated with potential risky patterns, commonly found in non-contact joint injury. Through an extensive use of wearable sensors, in association with experienced coaches and sport medicine experts, biomechanical motion patterns of football players could be precisely identified and used in personalized training and rehabilitation programmes.

REFERENCES

Burboa, J., Bahamonde, M., Inostroza, M., Lillo, P., Barahona, M., Palet, M., & Hinzpeter, J. (2017). Efecto de un entrenamiento deportivo en el compartimiento angular de la extremidad inferior en niños futbolistas de entre 11 y 12 años. *Acta ortopédica mexicana*, *31*(3), 128-133.

Chiodera, P., Volta, E., Gobbi, G., Milioli, M.A., Mirandola, P., Bonetti, A., Delsignore, R., Bernasconi, S., Anedda, A. and Vitale, M. (2007) Specifically designed physical exercise programs improve children's motor abilities: physical exercise programs in children. *Scandinavian Journal of Medicine & Science in Sports,* 18, 179-187.

Nguyen, A. D., Taylor, J. B., Wimbish, T. G., Keith, J. L., & Ford, K. R. (2018). Preferred Hip Strategy During Landing Reduces Knee Abduction Moment in Collegiate Female Soccer Players. *Journal of sport rehabilitation*, *27*(3), 213-217.

Pollard, CD., Sigward, SM., Powers, CM. (2010). Limited hip and knee flexion during landing is associated with increased frontal plane knee motion and moments. *Clinical Biomechanics*, 25(2),142-146.

Verheul, J., Nedergaard, N. J., Vanrenterghem, J., & Robinson, M. A. (2020). Measuring biomechanical loads in team sports–from lab to field. *Science and Medicine in Football*, 1-7.

Watson, A., & Mjaanes, J. M. (2019). Soccer injuries in children and adolescents. *Pediatrics*, *144*(5).

ACKNOWLEDGEMENTS

The authors would like to thank the Folgore Mirandola football team and its coach for the opportunity to conduct the study on the team players and the support to the data acquisition.