Ita. J. Sports Reh. Po.

Italian Journal of
Sports Rehabilitation and Posturology

A New Integrated Approach in the Postural Evaluation of an U16 Elite Soccer Player: A Case Report.

Gabriele Grassadonia[1,2,3,4], Luca Sacchetta[5], Viviana Rosati[6] and Nicoletta Locuratolo[7].

[1] *UCAM - Research Center for High Performance Sport, Catholic University of Murcia, Murcia, Spain.*
[2] *UPSS - International Departement of Academy of Motor Arts, Popolar University of Sport Sciences, Rome, Italy.*
[3] *UPM - Departement of Medical Sciences, Popular University of Milan, Milan, Italy.*
[4] *MIU - Miami International University, Miami, USA.*
[5] *I ndipendent Researcher.*
[6] *D.A.I. Neuroscience/Mental Health, AOU Umberto I Polyclinic Hospital of Rome, Italy.*
[7] *Sapienza University of Rome, Department of Human Neurosciences, Rome, Italy.*

Abstract

Acute distal abdominal oblique tear confirmed by ultrasound and radiograph imaging, rare soccer injury, suitable for study in the postural field. Following an original protocol, never described in sport, relatively still little addressed even in the clinical setting, the subject underwent an integrated postural assessment based on the study of postural changes in different tests with and without receptor stimuli and on tests with different rates of dynamism. A U16 elite soccer player of Italian Championship, evaluate with innovative and multifactorial tests, which overcomes the drawback of a partial and incomplete observation of postural abnormalities/changes arising from the use of single or multiple receptor stimulation, as commonly occur in diagnostic routine tests. The corrections examined regard static and dynamic tests, such as rasterstereography, podalic morphometry, stabilometry, baropodometry and sprint running test with GPS-IMU, showing different outcomes to different stimuli, that indicate the importance of having a multimodal postural approach. Moreover, a major comprehensive postural evaluation, closely related to specific sports situations, can target the correct therapeutic approach in a more specific way, bringing out different behaviours and motor adaptations, defining a "roadmap" which aims to individualize training practices to optimize locomotor strategies, seeking as far as possible to prevent injuries or to recover better from them.

Keywords: *posture, injury, return to sport, return to play, rehabilitation, motor control.*

Citation. *Grassadonia G, Sacchetta L, Rosati V, Locuratolo N. A New Integrated Approach in the Postural Evaluation of an U16 Elite Soccer Player: A Case Report. Ita. J. Sports Reh. Po. 2023; 10 (29); 6;(2): 2810 -2828 IBSN 007- 11119-55; IBSN 007- 11119-55; CGI J OAJI 0.201 ; Published Online. Corresponding Author : Grassadonia G, email: gabriele.grassadonia@gmail.com*

Introduction

Since the first study by Deutsch F. in 1952,[7] posturology has remained relatively unexplored, despite the study of human posture is an integral part of functional disorders and their symptoms. The analyses carried out have taken into consideration the use of stimulation of one or more receptors, as well as a dynamic evaluation, more linked to specific sports situations, with the aim of facilitating and making more precise and correct the therapeutic approach to be subsequently used, with the ambitious hypothesis of highlighting the different motor behaviours and adaptations that could be the cause of the injury mechanisms (often neglected to the detriment of the study of the effect). This a new paradigm of an integrated approach in the postural evaluation. The choice to also assess high dynamism, such as the evaluation of the lower limb force production capacity during the sprint, because is one of the fundamental characteristics in soccer and could also be interesting in situations of ''return to sport'',[23] as it provides complementary information in addition to the normal functional evaluations, in line with the sporting reality, to be compared with more common clinical and therapeutic examinations. By effectively applying lower limb force in a horizontal direction, speed increases indicate mechanical effectiveness.[1,25] In line with our recent work which suggests that other mechanisms are involved in determining metabolic demands during non-stationary locomotion, and that the recruitment ratio of quadriceps and hamstrings muscles changes as speed increases, but the neuromuscular activation is however highly subjective, it can vary from subject to subject, denoting also a certain degree of economy, which results from these first data highly individual.[11] It could also be hypothetically linked to the role in team sports.[14] In this original research the relevance of an innovative multifactorial postural assessment, which overcomes the inconvenience of partial and incomplete information on the observation of postural changes, is discussed.

Background and Case Presentation

Unfrequently described in soccer players are injury of the external and internal abdominal oblique muscles that work together to control trunk rotation and lateral trunk flexion; thus, the main hypothesis of this case study description is however mainly focused to draw attention to the importance of a global postural evaluation with the aim of identifying the dysfunction in its entirety, defining a targeted and effective rehabilitation approach. The subject was a 15 years-old (1.79 m and 59.5±2.12 Kg, with BMI 18.57±0.66) U16 elite soccer player of Italian Championship, that suffered, during training in a pre-season competition, a strong left parietal pain. After clinical suspect, ultrasound exam was performed on muscle of the abdomen, reporting injury on the distal third of the external left oblique muscle of the abdomen after an ultrasound instrumental examination. The mechanism of this rare injury, without contact during training in a pre-season competition, it was a twisting-rotational movement during a friendly match.

Materials and Methods

Procedures and Study Design

This study was conducted at University Hospital Policlinico Umberto I, Department of Neurosciences and Mental Health, Rehabilitation Centre, and in Vigor Perconti Sporting Center during competitive season 2018/2019. Data were collected in multiple session. Written informed consent was obtained from parents because the patient was under 18 years of age. Ultrasound and radiographic examinations were performed (see Figure 1 for more details). The instruments used were the GPS Spinitalia - SpinGNSS 50Hz v2 (Rome, Italy), IMU Spinitalia - SpinIMU 100Hz v2 (Rome, Italy) and Formetric 4D rasterstereography (Diers International, Schlangenbad, Germany) with Pedoscan, and Digital Morphometry with 3DPODS Diasu (Rome, Italy). The authors are aware of the variations that can exist in some calculations by varying algorithms and instrumentation on ratio of force, metabolic power, and energy cost (however, these are not the topic of our case study).[26]

Results

Clinical-instrumental examinations

Ultrasound examination were performed two times, in the first time the abdominal wall carried out with a linear probe, where it shows physiological alteration of the distal third of the left external oblique muscle adjacent to the distal insertion on the iliac crest and iliac bone with fibrillar structure, an area diffusely hyper-ecogenic with minimal surrounding fluid layer, consisting of a first degree muscle distraction, at the second time for control examination instead the ultrasound 14 days after the previous one, where the resolution of the altered ecogenicity of the previously injured muscle is observed. In addition, has also been carried out pelvis radiograph imaging under load (acetabular space right ≈204.4 mm and acetabular space left ≈197.3 mm).

Formetric

The main results of the Formetric® Scoliosis Angle detected was: ‘’Base’’ 10° (T1-T12), ''Mouth Correction'' 7° (T1-L1), ''Left Eye Correction'' 6° (T8-L1) and ''Mouth and Left Eye Correction'' 8° (T6-T9). Total sum of rotary degrees from C7 to L4 (both right and left) in "base" 38°, "mouth correction" 36°, "eye correction" 32°, and ‘’mouth and eye correction'' 35°, not showing significative difference, despite quality differences (Figure 1). On the sagittal plane with kyphotic angle 53° and lordotic angle 47° in ‘’Base’’ condition, ''Mouth Correction'' 7° (T1-L1) with kyphotic angle 55° and lordotic angle 47°, ''Left Eye Correction'' 6° (T8-L1) with kyphotic angle 53° and lordotic angle 48°, and ''Mouth and Left Eye Correction'' 8° (T6-T9) with kyphotic angle 55° and lordotic angle 50°. Cervical and lumbar fleche (arrow) of Stagnara in the "Base" condition of 71.3 mm and 59.8 mm respectively, cervical and lumbar fleche of Stagnara in the "Mouth Correction" condition of 69.9 mm and 63.9 mm respectively, cervical and lumbar fleche of Stagnara in the condition ''Left Eye Correction'' respectively of 69 mm and 62.1 mm, and cervical and lumbar fleche of Stagnara in the ''Mouth and Left Eye Correction'' condition of 72.8 mm and 63.4 mm respectively. The pelvic tilt of dimples was evaluated obtaining like as results for ''Base'' condition 21.67°, ''Mouth Correction'' of 20.54°, ''Left Eye Correction'' of 23.62° and ''Mouth and Left Eye Correction'' of 23.02°; and finally was evaluated the pelvic antero-retroversion with ''Base'' condition of 23.46°, ''Mouth Correction'' of 26.36°, ''Left Eye Correction'' of 26.05° and ''Mouth and Left Eye Correction'' of 24.15°. Pelvic torsion (of the hemipelvis) to the right in all conditions with respective inclinations always to the left, ''Base'' 5° torsion with 15 mm inclination, "Mouth Correction" 7° torsion with 18 mm inclination, "Left Eye Correction" 6° torsion with 12 mm inclination, and ''Mouth and Left Eye Correction'' 4° torsion with 9 mm inclination. Further results of appreciable importance obtained with the analysis carried out by Formetric, have been trunk inclination anteroposterior flexion with value for ''Base'' condition of 6.49 mm, ''Mouth Correction'' of 0.18 mm, ''Left Eye Correction'' of 2.92 mm and ''Mouth and Left Eye Correction'' of 4.59 mm; the trunk imbalance in the lateral flexion for the ''Base'' condition of 3 mm to left, ''Mouth Correction'' of 4.5 mm to right, ''Left Eye Correction'' of 4.5 mm to left and ''Mouth and Left Eye Correction'' of 3 mm to left.

Stabilometry

The stabilometry left foot oscillation detected was: ''Base'' 2.4-0.3 cm, ''Mouth Correction'' 1-0.9 cm, ''Left Eye Correction'' 0.6-2.3 cm and ''Mouth Correction and Left Eye'' 1.8- 1.7 cm. While the stabilometry of foot right oscillation detected was: ''Base'' 2.6-0.7 cm, ''Mouth Correction'' 1-0.2 cm, ''Left Eye Correction'' 0.6-0.2 cm and ''Mouth Correction and Left Eye'' 1.5-0.3 cm. The body stabilometry: ''Base'' 2-2.2 cm, ''Mouth Correction'' 0.9-2.3 cm, ''Left Eye Correction'' 0.5-4.8 cm and ''Mouth Correction and Left Eye'' 0.9-2.8 cm.

Baropodometry

The ‘’Base’’ baropodometry value, or without any kind of correction, it was so distributed: 53.9% hindfoot load pressure and forefoot pressure load instead of 46.1%. Pressure load left foot 52.7% and pressure load right foot 47.3%. Pressure load forefoot left 23.5%, load pressure right forefoot 22.6%, hindfoot load pressure left 29.1%, hindfoot load pressure right 24.7%. The ‘’Mouth Correction’’ baropodometry was total rear pressure load 59.2% and total front pressure load 40.8%. Pressure load of only left foot 50%, and pressure load or right foot also 50%. While pressure load or left forefoot was 18.9%, pressure load forefoot right was instead 21.9%, pressure load left hindfoot 31.1%, and pressure load or right hindfoot 28.0%. The ‘’Left Eye Correction’’ baropodometry was 63.6% total rear pressure load, and 36.4% total of pressure load front. Pressure load left foot was 48.8%, and pressure load of right foot 51.2%. Forefoot pressure load left was 17.6%, and forefoot load pressor right was 18.8%, pressure left hindfoot load was 31.2%, and pressure load hindfoot right 32.4%. The double correction, ‘’Mouth Correction and Left Eye’’ baropodometry was total rear load pressure 55.9%, and load pressure forefoot 44.1%. Pressure load left foot 41.9%, while pressure load of right foot 58.1%. Pressure load left forefoot 16.6%, pressure load forefoot right 27.5%, load pressure left hindfoot 25.3%, and load pressure right hindfoot 30.6%. In addition, the podalic morphometry mean difference on left foot is on 12%, while in the right foot is 11.8%, values that indicate a good structural condition. The subject was also tested in dynamic conditions with a walking test (Table 1) where he nevertheless showed a greater pressure both average and maximum of the right foot compared to the left (right foot max pressure 351.57 ± 109.16 and average pressure 85.15 ± 7.4, compared to the left foot max pressure 284.03 ± 50.39 and average pressure 77.58 ± 4.94 g/cm^2) also developing greater force on the right foot (325.56 ± 12.42) than the left foot (302.28 ± 9.24).

GPS-IMU

In addition, regarding the total data obtained in the linear (LR) and shuttle sprints (SR), before and after the injury, detected with GPS-IMU technology, the measurements made show a slight decrease in the times obtained on all tests except the 20+20m SR where had the same time obtained (with an average percentage difference of -3% compared to the first test and a respective standard deviation of ± 3%, with a statistically insignificant p=0.90). The values of energy cost also change, decreasing on average by 6% (s.d. ± 5%) and p=0.57; the metabolic power with a -9% (s.d. ± 8%) and p=0.28; and the GPS speed with a -2% (s.d. ± 4%) and p=0.85; in addition, was investigated the coefficient of correlations on energy cost and duration of three phases of SR (acceleration, deceleration and reacceleration) pre-injury r^2=0.03 and post-injury r^2=0.21, more details in **Table 2**. While the ratio of force (RF) on 30m, reached each 5 metres, pre and post injury, with relative correlations pre-injury r^2=0.88 and post injury r^2=0.14, with statistically significant differences (5-10m p=0.01; 15-20m p=0.02; 25-30m p=0.00). Cohen's d in order (0-5m d=0.22; 5-10m d=0.45; 10-15m d=0.19; 15-20m d=0.41; 20-25m d=0.19; 25-30m d=0.72).

Discussion

Elite athletes involved in sports that require high intensity, multidirectional and multivariable movements, then often can expose to postural problems up to sometimes also become pathologies. The prescription of an exercise or treatment must follow the specific need and should be based on biomechanical factors emerging from tests and any other assessment related to the sport in question.[28] The corrections examined about static tests instead, such as rasterstereography, stabilometry and baropodometry, concerned gauze used as thickness to correct the mouth and a 1400 Gauss magnet for correction of the left eye. Obviously, before having this type of corrective stimulus, the subject had undergone a postural check-up. In a second moment, if it is deemed appropriate to have definitive corrections and not only stimuli, it will be necessary to address the subject to qualified clinical personnel who will take care of resolving any imbalances (e.g. ''bite'' at the dentist, glasses at to oculist etc.). Figures 2 and 3 give us an exhaustive idea of how the receptors influence the function even though the subject has a correct and unchanged structure among the two emilates (see podoscan in Figure 3, *right panel*). It should be noted at this point how the subject is sensitive and reactive to the stimuli provided (probably this is also favoured by the young age). Moreover, it is necessary to consider that these changes occur in acute, and that more than likely the chronic aspects should also be investigated; because it could be hypothesized that to get used to the corrections, especially when they are composed of multiple stimuli, more time may be needed to adapt to the new posture. It is possible that to assimilate more corrective information takes more time, and it is legitimate to ask what could or should be corrected first, if it is better to give precedence or not to a correction, it is certain that the advantage could be to understand the effect of a single correction over time, while the disadvantage is to lose the connection between the correct receptors themselves and thus the improvement of more potential functions that could further refine their function and integration between them, having a synchronous correction, and not asynchronous (in stages, first one and then the other), these preliminary considerations would seem to agree with the brilliant and pioneering intuition of Bricot B.[2] Several specific requests for sport can have an impact on this relationship and the typical example is the specific movements of multi-planar, locomotor and torsion-rotary single-leg actions for many sports (one of these is the soccer as in our case), this is one of major reason to accept a great importance of multivariability of training stimuli to increase ''motor skills'' in younger age.[3,9,10,12,30] An integrated system of complete rehabilitative in its approach, can allow athletes to recover first with optimal results. The data collected indicates RF behaving differently before and after the injury. In fact, being a ratio obtained between two accelerations, horizontal and vertical, in a linear sprint, where it is presumable that the torso during acceleration is tilted and then tends to straighten with increasing speed, the ratio should decrease decreasing as little as possible with increasing distance if we want to express force at high speed. This seems to happen in the pre-injury test, with a good linearity (r^2=0.88) and much less in the post-injury test (r^2=0.14), as can be seen from the graph in Figure 4, where we even find phases in which the ratio becomes negative between the two accelerations before reaching the speed peak (the sign in the equation is commanded by the horizontal vector), or in favour of the vertical one, which the smaller it is, the higher the ratio, and obviously, if it is excessive, it is not profitable from the biomechanical and bioenergetic point of view for the run which has as its main objective the locomotion in the forward (horizontal) direction. In accordance with Nagahara R. et al. 2019,[21] a smaller vertical peak force is probably an indicator for better acceleration in the sprint, and to accelerate as much as possible horizontally, the athlete must develop the maximum possible horizontal force, averaged over each step during the sprint. The ability of an individual to perform this task is given by the mechanical and neuromuscular characteristics,[13] therefore, the ability to maintain a high applied force as the speed of movement increases and the decrease in contact with the ground is of primary importance.[8] However, there remain some doubts and issues regarding the use of this ratio as an effective marker of both proper running biomechanics, assuming that in team sports it is actually parameterizable (in agreement with *Colli R. Unpublished*), and an aid to injury prevention. In our case we wanted to divide the SR into three micro-phases (acceleration phase, deceleration phase and reacceleration phase) and we did not find correlate an increase linear in the energy cost at the three micro-phases. From the indications of our case study, it would seem non-linear the correlation of the time taken to travel the three micro-phases that make up a shuttle run, with the energy cost. So, we could find situations in which have less time spent in one or more of the three phases of the shuttle run, and have an energy cost recalculated, through polynomials, by accelerations as briefly described above, which can have in a completely asynchronous way the duration of the individual phases of the shuttles. The ability to produce horizontal force changes through acceleration provides an overview of the likely morphological and neuro-muscular properties involved,[4,5,6,17,18,19,20,22,31] this ability is a key feature for many sports activities, with decrease the energy cost and for the correct force production vector.[15,16,27] However, it remains interesting to evaluate the parameters obtained by the GPS-IMU in the three micro-phases and not only in the total, in order to have a more detailed and accurate analysis of the SRs. As can be seen in Table 2 described above, it is necessary to reason on each individual test and on each individual phase to get a complete picture of the results obtained. As proposed by Van Hooren B. et al 2019,[29] human locomotion can be conceptualized as the behaviour of a dynamic system, with attractors serving different purposes such as optimizing energy and mechanical efficiency, minimizing mechanical load, maintaining stability, increasing the robustness of the movement to disturbances from internal and external sources. To minimise energy losses during ground contact, a strategy that allows the leg to ''spring-like behaviour'', which allows energy to be stored and released, is important. As described by Roberts T.J. and Azizi E. in 2011,[24] if energy is released faster than it is stored, muscle power can be amplified. A rapid decline in the body's mechanical energy or an appendage can be temporarily stored as elastic deformation energy, followed by the release of this deformation energy to perform work on active muscles, thus functioning as a power attenuator. For these reasons we believe it is important to have a correct management of the phases of return to sport, respecting the correct timing and possibly testing the postural conditions that if neglected can generate injuries. There are two different paths to be considered and pursued, that of understanding both the possible causes of the injury and the methodological indications of proper recovery for return to play.

Conclusions

A multimodal approach like ours has certainly helped us to study and understand more the different motor behaviours and negative adaptations that could be the cause and response at injury mechanisms, but clearly on the other hand this more global approach opens and lends itself to more in-depth studies that will have to be done to understand more, finding new markers that are better explanatory and suitable than those already used. Having a complete and integrated profiling of subject to postural evaluation, especially if they are athletes, should be a practice to recommend to coaches and physical trainers as well as medical-health staff, subsequently defining a "roadmap" which aims to individualize training practices to optimize locomotor strategies, seeking as far as possible to prevent injuries or to recover better from them.

Ita. J. Sports Reh. Po.
Italian Journal of
Sports Rehabilitation and Posturology

Author Contributions

Author contributions was for the conceptualization, G.G. and V.R.; methodology, G.G., L.S., V.R., and N.L.; formal analysis, G.G. and V.R.; investigation, G.G., L.S., V.R., and N.L.; data curation, G.G.; writing-original draft preparation, G.G., V.R. and N.L.; writing-review and editing, G.G., V.R. and N.L.; visualization, G.G., L.S., V.R., and N.L.; supervision, G.G., L.S., V.R., and N.L.; project administration, G.G., L.S., V.R., and N.L.

Conflict of Interest and Funding

The authors declare to be free from financial and other relationships with people and/or organizations that could influence the content of the author's work in any way, thus declaring that he has no form of conflict of interest.

Examination on Ethics

The experiment complied with the ethics criteria of institutions reviewing ethics of experiment on human body or local "Ethics Committee on Clinical Experiments" and Declaration of Helsinki.

References

1. Alcaraz PE, Elvira JL, Palao JM. Kinematic, strength, and stiffness adaptations after a short-term sled towing training in athletes. Scand J Med Sci Sports. 2014 Apr;24(2):279-90. doi: 10.1111/j.1600-0838.2012.01488.x. Epub 2012 Jun 5. PMID: 22672673.
2. Bricot. B. Total Postural Reprogramming. 1nd ed. Book Editor: Dux Lucis Books, 1996.
3. Carini F, Mazzola M, Fici C, Palmeri S, Messina M, Damiani P, Tomasello G. Posture and posturology, anatomical and physiological profiles: overview and current state of art. Acta Biomed. 2017 Apr 28;88(1):11-16. doi: 10.23750/abm.v88i1.5309. PMID: 28467328; PMCID: PMC6166197.
4. Cormie P, McGuigan MR, Newton RU. Developing maximal neuromuscular power: Part 1--biological basis of maximal power production. Sports Med. 2011 Jan 1;41(1):17-38. doi: 10.2165/11537690-000000000-00000. PMID: 21142282.
5. Di Prampero PE, Fusi S, Sepulcri L, Morin JB, Belli A, Antonutto G. Sprint running: a new energetic approach. J Exp Biol. 2005 Jul;208(Pt 14):2809-16. doi: 10.1242/jeb.01700. PMID: 16000549.
6. Di Prampero PE, Osgnach C. Metabolic Power in Team Sports - Part 1: An Update. Int J Sports Med. 2018 Jul;39(8):581-587. doi: 10.1055/a-0592-7660. Epub 2018 Jun 14. PMID: 29902808.
7. Deutsch F. Analytic posturology. Psychoanal Q. 1952 Apr;21(2):196-214. PMID: 14930156.
8. Hicks DS, Schuster JG, Samozino P, Morin JB. Improving mechanical effectiveness during sprint acceleration: practical recommendations and guidelines. Strength Cond J., 2019 Issn Print: 1524-1602. DOI: 10.1519/SSC.0000000000000519.
9. Edwards WH. Motor Learning and Control: From Theory to Practice. 1nd ed. Book Editors: Wadsworth, Cengage Learning, 2010.
10. Eriksrud O, Ghelem A, Cabri J. Isokinetic strength training of kinetic chain exercises of a professional tennis player with a minor partial internal abdominal oblique muscle tear - A case report. Phys Ther Sport. 2019 Jul;38:23-29. doi: 10.1016/j.ptsp.2019.04.012. Epub 2019 Apr 20. PMID: 31039484.

11. Grassadonia G, Monte A. The energy cost of non-steady locomotion (sprint and shuttles) is not related with the active muscle volume [Conventional Poster]. Combined Scientific Meeting: 25th ECSS Congress October 28-30 2020; Sevilla, Spain. DOI: 10.13140/RG.2.2.19048.29445
12. Janda V. Muscle Function Testing. 1nd ed. Book Editors: Butterworths, 1983.
13. Jiménez-Reyes P, Samozino P, Morin JB. Optimized training for jumping performance using the force-velocity imbalance: Individual adaptation kinetics. PLoS One. 2019 May 15;14(5):e0216681. doi: 10.1371/journal.pone.0216681. PMID: 31091259; PMCID: PMC6519828.
14. Licciardi A, Grassadonia G, Monte A, Ardigò LP. Match metabolic power over different playing phases in a young professional soccer team. J Sports Med Phys Fitness. 2020 Aug;60(8):1170-1171. doi: 10.23736/S0022-4707.20.10879-X. PMID: 32955845.
15. Macadam P, Mishra M, Feser EH, Uthoff AM, Cronin JB, Zois J, Nagahara R, Tinwala F. Force-velocity profile changes with forearm wearable resistance during standing start sprinting. Eur J Sport Sci. 2020 Aug;20(7):915-919. doi: 10.1080/17461391.2019.1686070. Epub 2019 Nov 11. Erratum in: Eur J Sport Sci. 2022 Jun;22(6):951. PMID: 31650888.
16. Macadam P, Nuell S, Cronin JB, Uthoff AM, Nagahara R, Neville J, Graham SP, Tinwala F. Thigh positioned wearable resistance affects step frequency not step length during 50 m sprint-running. Eur J Sport Sci. 2020 May;20(4):444-451. doi: 10.1080/17461391.2019.1641557. Epub 2019 Jul 25. Erratum in: Eur J Sport Sci. 2022 Jun;22(6):952. PMID: 31282306.
17. Minetti AE, Pavei G. Update and extension of the 'equivalent slope' of speed-changing level locomotion in humans: a computational model for shuttle running. J Exp Biol. 2018 Aug 1;221(Pt 15):jeb182303. doi: 10.1242/jeb.182303. PMID: 29895678.
18. Minetti AE, Moia C, Roi GS, Susta D, Ferretti G. Energy cost of walking and running at extreme uphill and downhill slopes. J Appl Physiol (1985). 2002 Sep;93(3):1039-46. doi: 10.1152/japplphysiol.01177.2001. PMID: 12183501.
19. Morin JB, Samozino P. Biomechanics of Training and Testing Innovative Concepts and Simple Field Methods. 1nd ed. Book Editors Springers, 2018.

20. Morin JB, Edouard P, Samozino P. Technical ability of force application as a determinant factor of sprint performance. Med Sci Sports Exerc. 2011 Sep;43(9):1680-8. doi: 10.1249/MSS.0b013e318216ea37. PMID: 21364480.
21. Nagahara R, Kanehisa H, Matsuo A, Fukunaga T. Are peak ground reaction forces related to better sprint acceleration performance? Sports Biomech. 2021 Apr;20(3):360-369. doi: 10.1080/14763141.2018.1560494. Epub 2019 Jan 24. PMID: 30676878.
22. Osgnach C, Di Prampero PE. Metabolic Power in Team Sports - Part 2: Aerobic and Anaerobic Energy Yields. Int J Sports Med. 2018 Jul;39(8):588-595. doi: 10.1055/a-0592-7219. Epub 2018 Jun 14. PMID: 29902809.
23. Rambaud A, Pavoine A, Morin JB, Rossi J, Edouard P, Samozino P. Evaluation of sprinting force production capacities in athletes at 6th month after anterior cruciate ligament reconstruction: a pilot study [Poster]. Combined Scientific Meeting: 3rd World Congress of Sports Physical Therapy October 4-5 2019; Vancouver, Canada.
24. Roberts TJ, Azizi E. Flexible mechanisms: the diverse roles of biological springs in vertebrate movement. J Exp Biol. 2011 Feb 1;214(Pt 3):353-61. doi: 10.1242/jeb.038588. PMID: 21228194; PMCID: PMC3020146.
25. Samozino P, Rabita G, Dorel S, Slawinski J, Peyrot N, Saez de Villarreal E, Morin JB. A simple method for measuring power, force, velocity properties, and mechanical effectiveness in sprint running. Scand J Med Sci Sports. 2016 Jun;26(6):648-58. doi: 10.1111/sms.12490. Epub 2015 May 21. PMID: 25996964.
26. Savoia C, Padulo J, Colli R, Marra E, McRobert A, Chester N, Azzone V, Pullinger SA, Doran DA. The Validity of an Updated Metabolic Power Algorithm Based upon di Prampero's Theoretical Model in Elite Soccer Players. Int J Environ Res Public Health. 2020 Dec 20;17(24):9554. doi: 10.3390/ijerph17249554. PMID: 33419381; PMCID: PMC7766422.

27. Schuster J, McMaster T, Samozino P, Lacey S, Winkelman N. Mechanical determinants of sprinting performance in elite women's Rugby Sevens; 2018, Journal of Australian Strength & Conditioning, 26(5):16-19.
28. Short SM, Anloague PA, Strack DS. Rehabilitation and Return to Sport Following Surgical Repair of the Rectus Abdominis and Adductor Longus in a Professional Basketball Player: A Case Report. J Orthop Sports Phys Ther. 2016 Aug;46(8):697-706. doi: 10.2519/jospt.2016.6352. Epub 2016 Jul 3. PMID: 27374014.
29. Van Hooren B, Meijer K, McCrum C. Attractive Gait Training: Applying Dynamical Systems Theory to the Improvement of Locomotor Performance Across the Lifespan. Front Physiol. 2019 Jan 18;9:1934. doi: 10.3389/fphys.2018.01934. PMID: 30713503; PMCID: PMC6346699.
30. Wilczyński J, Bieniek K. Correlations of somatic traits and postural defects in girls and boys aged 10-12. Acta Bioeng Biomech. 2019;21(1):79-86. PMID: 31197275.
31. Zamparo P, Pavei G, Monte A, Nardello F, Otsu T, Numazu N, Fujii N, Minetti AE. Mechanical work in shuttle running as a function of speed and distance: Implications for power and efficiency. Hum Mov Sci. 2019 Jun 13;66:487-496. doi: 10.1016/j.humov.2019.06.005. Epub ahead of print. PMID: 31203018.

Appendix

Figure 1 - *Left Panel: ultrasound examination of the abdominal wall carried out with a linear probe, where it shows physiological alteration of the distal third of the left external oblique muscle adjacent to the distal insertion on the iliac crest and iliac bone with fibrillar structure, an area diffusely hyper-ecogenic with minimal surrounding fluid layer, consisting of a first degree muscle distraction. Central Panel: pelvis radiograph imaging under load (acetabular space right ≈204.4 mm and acetabular space left ≈197.3 mm). Right Panel: control ultrasound 14 days after the previous one, where the resolution of the altered ecogenicity of the previously injured muscle is observed.*

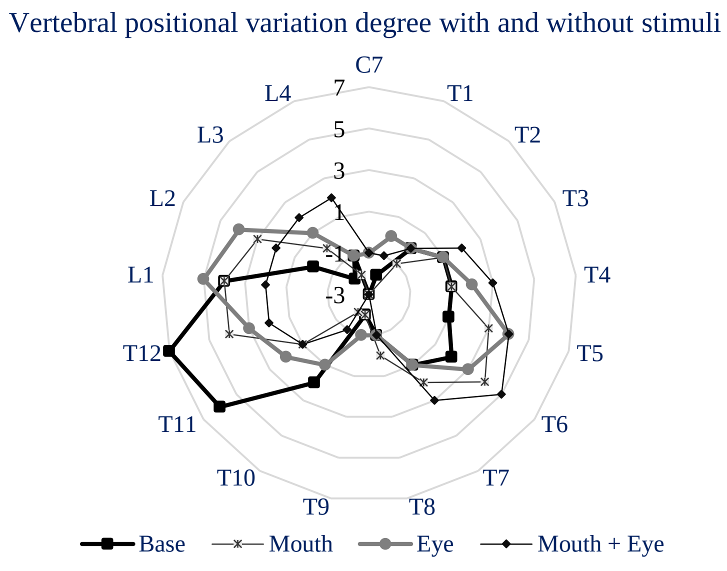


Figure 2 - *Kiviat chart with variables selected and comparised, ranking criteria segnaled with the negative sign '' - '' for the vertebral rotations to the left side, while with the positive sign '' + '' to the right. Total sum of rotary degrees from C7 to L4 (both right and left) in "base" 38°, "mouth correction" 36°, "eye correction" 32°, and ‘’mouth and eye correction'' 35°; not showing significative difference, despite obvious quality differences.*

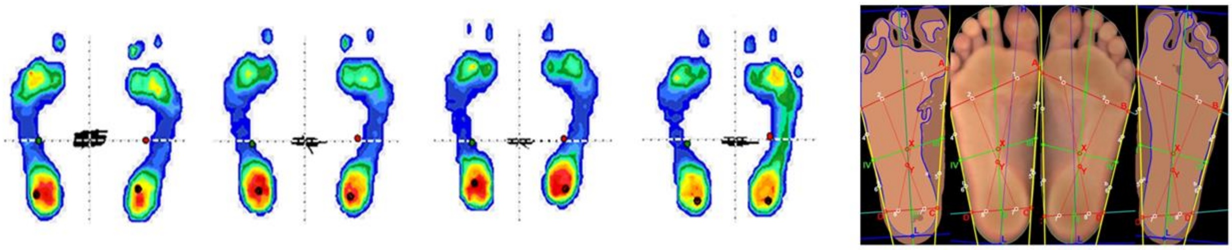


Figure 3 *- Left Panel: Baropodometry and Stabilometry in bipodal position with 4 different conditions from left to right: ''base'', only ''mouth correction'', only ''eye correction'' and both ''mouth and eye correction''. Right Panel: Podalic morphometry. In centrally images the plantar morphometry and laterally in contact morphometry. Podalic morphometry mean difference on left foot is on 12%, while in the right foot is 11.8%, values that indicate a good structural condition.*

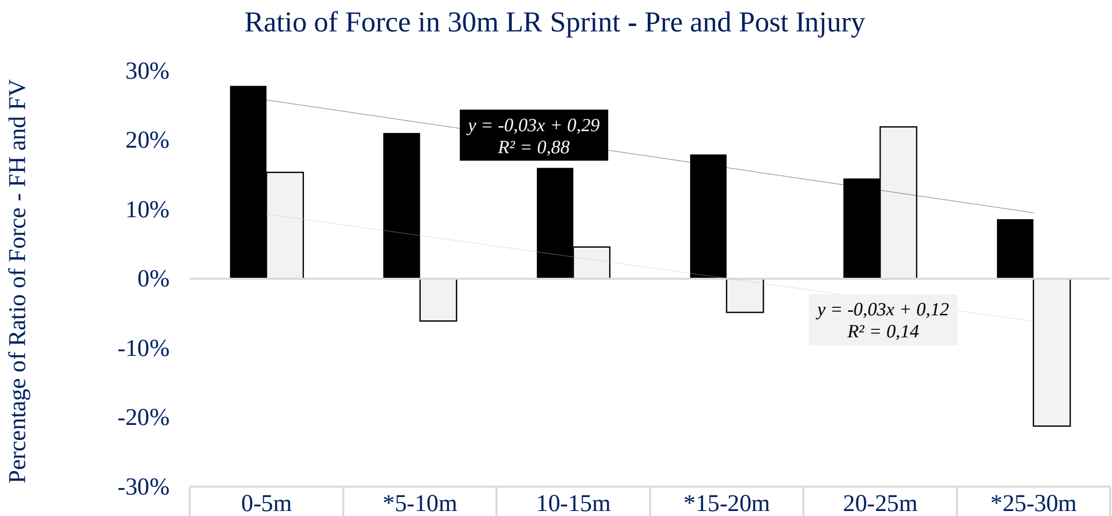
Dynamic Baropodometry	***Left Foot***	***Right Foot***
Max pressure (g/cm²)	*284.03 ± 50.39*	*351.57 ± 109.16*
Average pressure (g/cm²)	*77.58 ± 4.94*	*85.15 ± 7.4*
Podalic load (%)	*48.15 ± 3.34*	*51.85 ± 4.49*
Podalic load (Kg)	*30.81 ± 0.94*	*33.19 ± 1.27*
Podalic load (N)	*302.28 ± 9.24*	*325.56 ± 12.42*
Podalic surface (cm²)	*175.22 ± 6.26*	*172.04 ± 6.7*
Surface area (%)	*50.46 ± 1.8*	*49.54 ± 1.93*

Table 1 - *Dynamic Baropodometry values of the walked.*

Pre-Injury	Duration	V-IMU	V-GPS	W/Kg *	C	Post-Injury	Duration	V-IMU	V-GPS	W/Kg *	C
0-30m LR	4.72	22.90	23.70	58.00	8.81	0-30m LR	5.06	21.33	21.60	44.80	7.47
0-5m	1.34	13.40	15.10	68.00	16.21	0-5m	1.40	12.89	13.40	53.00	14.24
5-10m	0.78	23.14	27.80	62.30	8.07	5-10m	0.82	21.91	26.50	49.40	6.71
10-15m	0.69	26.02	32.10	54.60	6.12	10-15m	0.73	24.76	30.40	44.50	5.27
15-20m	0.64	28.14	37.00	49.30	4.80	15-20m	0.69	26.10	34.30	37.40	3.93
20-25m	0.61	29.31	38.20	47.00	4.43	20-25m	0.68	26.34	32.50	42.00	4.65
25-30m	0.60	29.79	39.00	52.70	4.86	25-30m	0.69	26.21	34.40	36.80	3.85
	Duration	V-IMU	V-GPS	W/Kg §	C §		Duration	V-IMU	V-GPS	W/Kg §	C §
5+5m SR	3.29	10.95	11.30	38.10	12.14	5+5m SR	3.33	10.82	11.30	37.80	12.04
Phase 1	0.94	10.79	12.10	40.50	12.05	Phase 1	1.13	9.58	10.90	35.20	11.63
Phase 2	0.60	9.42	11.70	35.70	10.98	Phase 2	0.63	9.38	11.10	45.30	14.69
Phase 3	1.75	11.68	12.80	38.40	10.80	Phase 3	1.58	12.44	13.80	40.50	10.57
	Duration	V-IMU	V-GPS	W/Kg	C		Duration	V-IMU	V-GPS	W/Kg	C
10+10m SR	4.82	14.93	15.10	52.40	12.49	10+10m SR	4.95	14.55	14.70	47.90	11.73
Phase 1	1.51	14.61	15.40	50.20	11.74	Phase 1	1.68	14.08	14.80	48.20	11.72
Phase 2	0.99	13.21	14.60	40.90	10.08	Phase 2	0.98	12.93	14.30	40.60	10.22
Phase 3	2.32	16.02	17.20	56.10	11.74	Phase 3	2.29	15.67	17.00	49.40	10.46
	Duration	V-IMU	V-GPS	W/Kg	C		Duration	V-IMU	V-GPS	W/Kg	C
15+15m SR	6.24	17.30	17.50	53.90	11.09	15+15m SR	6.44	16.77	17.20	51.10	10.70
Phase 1	2.08	17.33	17.70	57.20	11.63	Phase 1	1.92	15.70	16.90	56.50	12.04
Phase 2	1.22	15.37	17.10	44.50	9.37	Phase 2	1.52	15.99	17.90	38.10	7.66
Phase 3	2.94	18.22	19.20	53.40	10.01	Phase 3	3.00	17.93	18.70	51.50	9.91
	Duration	V-IMU	V-GPS	W/Kg	C		Duration	V-IMU	V-GPS	W/Kg	C
20+20m SR	7.93	18.15	18.30	51.00	10.03	20+20m SR	7.93	18.17	18.50	48.30	9.40
Phase 1	2.60	18.06	18.60	56.70	10.97	Phase 1	2.36	17.86	19.30	57.30	10.69
Phase 2	1.54	16.88	18.70	41.40	7.97	Phase 2	1.66	17.82	19.00	38.80	7.35
Phase 3	3.78	18.80	19.50	50.50	9.32	Phase 3	3.90	18.57	19.20	44.20	8.29

Table 2 - *Table with all data in LR and SR sprint, in the left column the pre-injury values and in the right column the post-injury values.*

**Significative difference p=0.01 in Metabolic Power (W/Kg) in LR, pre and post injury; §inverse correlation r= -0.94 between Metabolic Power (W/Kg) in 5+5m SR, pre and post injury; §inverse correlation r= -0.15 between C (J/m/Kg) in 5+5m SR, pre and post injury.*



	0-5m	*5-10m	10-15m	*15-20m	20-25m	*25-30m
■ RF-Pre Injury	27,87%	21,07%	16,03%	17,98%	14,49%	8,62%
□ RF-Post Injury	15,36%	-6,11%	4,57%	-4,86%	21,93%	-21,24%

Figure 4 - *Ratio of Force, horizontal and vertical force, in 30m on LR each 5 metres, pre and post injury, with relative correlations.*

**Statistically significant differences.*