

## The global symmetry index, symmetry index, quality index and kinematics of the gait cycle with the synchronized contribution of the latest generation magnetic-inertial and electromyographic technology. Practical surveys and planning hypotheses for the revision of gesture

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Performed by ARGS, Advanced Research Group in Sport, School of Health and Sport Science, DISB, Urbino University (IT) with K-Sport World, STATS Perform, ITALY.

Published online: May 31, 2022

(Accepted for publication May 15, 2022)

DOI:10.7752/jpes.2022.05158

### Abstract:

The walk is certainly the cornerstone of human mobility. The literature has focused on the qualitative and quantitative analysis of walking and how certain parameters can change after an aerobic fatigue test. Our research proposal is based, in an innovative way in literature, on the analysis of specific parameters of the gait cycle, considered highly significant, such as the global symmetry index, the symmetry index, the quality index of the gait cycle, pelvic kinematics and muscle activation and the differences in these parameters before and after an aerobic fatigue test (resistance of the gesture over time). A total of 27 male athletes, aged (9-11) participated to the study, in which state-of-the-art equipment was used in the field of movement sciences that includes a device that integrates triaxial inertial sensors and a set of synchronized wireless probes, part of fourth generation instruments, still the most advanced on the market, for wireless surface electromyographic analysis. Thanks to these devices it was possible to carry out an evaluation of the subjects directly, with the live acquisition of data during the entire execution of the test protocol, allowing to evaluate the aforementioned parameters, which are considered strategic in pre-adolescent age, both for a more accurate basic construction of the element sure to offer a better planning of work sessions or training sessions at the time and in the future, also in consideration of periods immediately following high workloads, where fatigue affects the precision of gestures in the young athlete with various consequences, including significant ones, which is not always taken into consideration.

**Keywords:** gait cycle, fatigue, GSI (Global symmetry index), innovative validation, IMU/EMG

### Introduction

Walking is a rhythmic succession of movements used by animals with limbs to move on the ground from one place to another and it's the most used way of locomotion by humans to move. In recent decades, the development of new technologies has allowed a more analytical look at the movement of walking and the mechanisms that are associated with it, in order to be able to adapt and improve it for different sports and rehabilitative mobility situations and also for individuals with motor difficulties. due to problems deriving from different skills. Sciences such as biomechanics, which analyzes the behavior of anatomo-physiological structures when subjected to static and dynamic stresses, have allowed us to study the kinematics of the movements of the body segments at different walking speeds, the dynamic study of the reaction forces of the ground and the kinesiological study of the main muscles of the lower limb even in conditions of fatigue. These analyzes are usually carried out inside the laboratory, using particular sets of cameras, operating in the visible or near infrared range together with markers placed on the subject's skin, which represent the most widespread technological solution for estimating human movement. Optoelectronic systems do not provide a direct measurement of the kinematic variables but an estimate of the kinematic trajectories, reconstructing the position that the point assumes instant by instant on the three dimensions, thus representing an instrument of high accuracy, precision and reliability. It was on these premises that the idea of the project was born: to synchronize instruments of different physical applications such as electromyographs and inertial sensors precisely to analyze the main form of locomotion of the human being, walking, in an innovative way. This synchronization allowed us to evaluate various aspects of this motor pattern, such as the symmetry indices, the time values of the gait cycle and the kinematics of the pelvis. The future objective, improved the problem of the solidity of the adherence to the skin and muscles of the probes, which for us was evident and disabling compared to the initial project, certainly more aimed at medium and high level technical dynamic elements, such as gearboxes direction, changes of direction,

speed, is certainly the use of these devices in conditions of maximum dynamics, since we believe that the synchronization of these technologies for the analysis of sports movement performed directly on the field and in increasingly close to the real ones of the game, may constitute a further step, necessary, in qualitative and quantitative terms, of data collection and evaluation of sportsmen of all ages and types, considering however that maximum execution is a useful element if not necessary for a comparative analysis essential to establish the limits of certain movements as well as the real training needs of the same for maximum improvement of performance. The walk, is the form of locomotion that distinguishes the human being from the rest of the animals; more generally, it is a basic motor scheme, or a constitutive element of human motility. The ability to walk is considered a gesture not to be acquired through learning but it is often considered something acquired by birth. It is not always so often that modifications of the same are necessary for specific use of the fabric for certain needs. Through the loss of balance and the subsequent recovery and management of the same, a correct and orderly sequence of movement is implemented, which includes support and oscillation phases of the foot and lower limb in general. The support phase is always followed by an oscillation phase and in both moments there may be characteristic aspects to be observed. The duration of the two phases is different and variable but can be described in a generic form as in the following figure (Fig. 1).

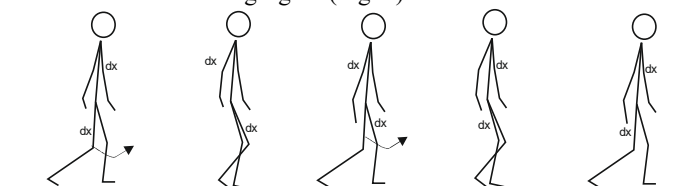


Fig.1; Stages of the step cycle (R.E.Izzo 2022)

It seems clear that the support phase plays a decisive role in the evaluation of the step, being in fact the phase that involves the management of the weight of the subject both for and against the earth's gravity. At this point it is easy to understand that the longer duration of the support phase compared to the oscillation phase is a completely natural thing due to mechanical factors such as friction on the ground and due to neuro-physiological factors such as the search for stability, proprioception and balance required in the single stance phase. The analysis of the different phases and their temporal values, of the kinematics of the pelvis, of the symmetry values, of the timing of muscle activation and their deviation from physiological and normal values is, in our opinion, of fundamental importance, especially speaking of young athletes in the development phase and considering the fact that any imbalances in a relatively "simple" motor pattern such as walking could have more serious effects on more complex motor patterns such as running or its derivatives. There have been numerous studies on gait analysis, both as regards the differences in gait between young and old (Ostrosky et al., 1994), and as regards the precision and repeatability of this motor pattern in young athletes, even with the use of advanced instruments such as accelerometers (Tsivgoulis et al., 2009) or the execution of different tasks during gait (Bove et al., 2007), but to our knowledge in literature are not available works focused on the qualitative and quantitative analysis on walking and how certain parameters can change after a fatigue test; this is precisely one of the two main objectives of our research. Another fundamental aspect to be taken into consideration for a young athlete is the development of the motor skills of balance. Postural balance is the ability to control the position of the body's center of mass within its support base, with great repercussions, as can be easily understood, on the optimal execution of sporting and non-sporting gestures, from a performative point of view. A further aspect that we feel we can detect and of interest in this study is undoubtedly its adjuvant application on motor skills in adult and elderly age, an element that will unequivocally result in regression both for natural causes and for trauma, disease or other. The correct functioning of an individual's postural balance requires an active somato-sensory control system. The different information coming from the three main sensory inputs (proprioceptive, visual and vestibular), as well as from cognitive processes, are integrated and evaluated to generate adequate motor responses, especially of the trunk and lower extremities, which keep the body within its limits of stability. Maintaining postural balance is a fundamental skill of daily life, especially when dealing with a young athlete, for whom correct postural balance is a key component in the execution of complex sports movements, as well as protection against injuries (Izzo et al., 2018). In recent years, balance training has become very popular in addition to the more standard athletic training program in sports such as basketball (Boccolini et al., 2013) although coaches of young athletes often neglect specific balance programs, especially in some sports (for example football) where balance is little considered, but which is fundamental for the execution of complex specific technical movements, crucial for the prevention of injuries. Balance training at certain ages will also be essential for the maturation of sensory-motor skills that could make the difference in a future high-level athlete (Ricotti et al., 2011). In fact, the creation of a mature athlete necessarily passes through the expression of his full potential at every stage of his development. Furthermore, balance and proprioceptivity training, in combination with resistance training, obviously has a positive effect on the ability to express strength in particular in children and adolescents, as well as decreasing the risk of injury, but in a very important manner in elderly people too, although the object is not deeply treated in this study, reducing in a very high percentage risks of a subsequent worst way of life quality. Some surveys carried out on amateur footballers have highlighted differences in balance, even if not significant, between the preferred and non-preferred leg (generally with better values on the

second) (Gstottner et al., 2009), bringing to light another very important aspect, that of asymmetries. The presence of balance asymmetries, but also of strength, in the lower limbs of young athletes who practice various sports is in fact considered a factor of significant technical-tactical choices, which will be limiting during the career as well as an intrinsic risk factor for accidents. In such cases, even in the context of performance it would be important to maintain a balance of symmetry between the right and left sides and to promptly implement strategies aimed at eliminating, or at least limiting, any significant degrees of asymmetry present, moreover the bilateral imbalance would tend to increase with the aging Atkins (et al., 2013). The unstable surfaces are for example an excellent means to improve the intermuscular coordination between the agonist and antagonist muscles, allowing a better control of the joint position and a more uniform weight distribution between the two limbs (Sannicandro et al., 2014). Another factor capable of influencing the ability to balance and therefore expose the young athlete to the risk of injury, we believe is fatigue, understood both as local and global and investigated in numerous studies (Donath et al., 2013, Paillard et al., 2012). In fact, if the athlete is in a state of fatigue, the joints may fail to produce the appropriate neuromuscular responses to protect and maintain joint stability. Thus any change in balance strategy can lead to the risk of injury to both muscle and ligament structures (Adlerton et al., 2003). However, these effects would tend to disappear after a short time (Yaggie et al., 2004). The loss of balance according to Yaggie and Armstrong could be due to cellular waste associated with fatigue conditions that would hinder muscle arousal as well as the afferent stimulation necessary for the somato-sensory receptors necessary for maintaining posture [30]. Several protocols have been used over the years to get the athlete into fatigue conditions: Crowell for example has demonstrated a decrease in postural balance after an exercise protocol consisting of squat jumps, sprints and treadmill running in sports club athletes. male and female (Crowell et al., 2001), the last test common also to the studies of Guidetti (2014) and Bove (2011), albeit with different times. In fact, running tends to disturb postural balance more than walking, also due to a more significant head movement that disturbs the visual information center (Derave et al., 2008). A 2007 study by Mello, seems to mention the intensity of exercise as a key factor in reducing postural balance; they argue that increased postural sway does not occur after exercise with an intensity of less than 60% of maximum heart rate, unless the duration was relatively long. This statement is also supported by the fact that according to the same study, long-distance triathlon and prolonged exercise (> 60 min.) at low intensity, have also increased postural oscillation. Cetin (2008) also analyze the critical role in stabilizing the spine and general core muscle balance, arguing that the addition of exercises that aim to increase core and core strength to the daily routine of sports exercises is a basis for advancing to a higher level of fitness and improving sports performance; thesis also endorsed by Solovjova et al. and Yildizer and Kirazci in their subsequent studies of young athletes and footballers (Solovjova et al., 2014, Yildizer et al., 2017). However, only a few studies have measured the effect of intense aerobic exercise on postural balance among children (or elder people), with a limited number of longitudinal studies (Paillard, 2012). Greiga et al. (2007) in their article argue the importance of aerobic endurance in athletes (in their case football players), being crucial for maintaining postural balance and reducing the risk of musculoskeletal injuries. It has also been shown that hyperventilation and lactic acid accumulation, which may be associated with high-intensity aerobic exercise, immediately increase postural sway in a static position (Zemkova et al., 2014), but we are not aware of any studies of effects of this type of exercise on walking and dynamic balance, aspects that we intend to deepen in our study.

### Means and Method

The aim of the study is to remodel the physical elements of the step, to allow for revision and objective improvement of the same in an optimal performative function. The study used the G-Walk (IMU) and the FREEEMG (electromyograph). The G-Walk sensor (BTS Bioengineering, Milano) was used to analyze the step gait, the instrument is small sized (70x40x18 mm and weight 37g), contains 4 inertial platforms and a GPS. This architecture increases acquisition accuracy by minimizing errors and also allows synchronization with the electromyographic system of the same manufacturer. The system guarantees an operating autonomy of 8 hours and an unlimited range of action thanks to the ability to record data into the internal memory, while wirelessly the available working range is around 15/20 meters. It is absolutely minimally invasive and can be worn with a special belt. The device contains an triaxial accelerometer (1000 Hz), triaxial gyroscope (8000 Hz), a triaxial magnetometer (100 Hz) a GPS receiver (10 Hz) with a Sensor Fusion (200 Hz). (Fig.2)



Fig. 2; G-WALK device, BTS.

The FREEEMG (BTS Bioengineering, Milan) system is an electromyograph equipped with wireless probes for the dynamic analysis of muscle activity. FREEEMG represents the fourth generation of the most advanced technology for surface electromyographic analysis. The accuracy of the signal, the complete absence of cables, the lightness, and the extremely small size of the probes allow us to perform analysis of any type of movement, for each body district, without altering the motor movement of the subject examined. The system communicates

with a PC via USB receivers and can simultaneously manage up to 20 probes. Each probe is equipped an internal memory to guarantee the continuity of the recording even in case of temporary loss of the connection, allowing to carry out acquisitions over great distances and in the open field. The software then processes the information collected, returning the results in graphical form and allowing an immediate comparison with the normality classes. The probes have the dimensions of 16x12mm, a resolution of 16 bits ,and an acquisition frequency of 1 kHz, allowing over six hours of continuous acquisition; they are hooked directly to the pre-gelled electrodes to pick up the signal, without the need for additional fixings.



Fig. 3; FREEEMG electromyography probes, BTS.

The Tests are carried out for the inertial and electromyographic evaluation of walking under standard conditions and, subsequently, under stress conditions. The G-SENSOR device is inserted into the special support band and positioned in the spine at the height between the S1 and S2 vertebrae (sacral vertebrae) below the line that joins the two Venus dimples. The electrodes and probes are placed on the target muscles (anterior tibialis and medial gastrocnemius). Preliminary data (personal and anthropometric data) of the athlete in question are collected for subsequent data normalization and comparison between the subjects.

- Step 1: 15m walk in standard conditions. Description: the athlete positions himself on the starting line in an orthostatic position. At the start he walks in the most natural way possible for 15 meters, following a straight path, at the end of which he stops without making any rotation.
- Step 2: execution of the "suicide" shuttle run, with the aim of fatiguing the athlete thus bringing him into stressful conditions. Description: the athlete positions himself on the starting line in an orthostatic position. At the start he makes a 5m sprint, a change of direction and a subsequent 5m sprint returning to the starting position. Without stopping, he performs the same exercise again but over distances of 10 and 15 meters, concluding the exercise in the starting position (60 meters). The test is repeated 3 times, with 10 seconds of rest between one test and the next.
- Step 3: 15m walk in stressful conditions. Description: step 1 is repeated.

## Results

Below are the results obtained with the analysis of the data relating to the objectives of the study: the global index of symmetry; the symmetry index; the quality of the gait cycle; the single support phase during the gait cycle; the kinematics of the pelvis and muscle activation of the muscles analyzed. Before implementing the test protocol using the inertial device and the electromyographic probe system, data relating to the athletes were collected, data that will then be useful for subsequent considerations and for a comparison between the athletes. The data collected in this first part are date of birth and leg predisposition. After this first phase, we moved on to the actual test phase, in which, thanks to the inertial sensors contained within the G-SENSOR device, it was possible to evaluate five of the six main issues. As a first issue, we wanted to focus our attention on the **global symmetry index** (GSI). The global index of symmetry globally evaluates whether the right limb and the left limb perform the respective gait cycle in a symmetrical way, in terms of the duration of the stance phase and the flight phase. A score of  $75 < \text{GSI} < 100$  is indicative of a high degree of symmetry: the stance phase and the flight phase for both right and left limbs to fall within their respective normal ranges. The values of this index of the athletes analyzed are reported, distinguishing the standard condition in which the first walk was performed from the subsequent stress condition after the shuttle test, in the following table (Table 1).

| Subjects | GLOBAL SYMMETRY INDEX (%) |      | SYMMETRY INDEX (%) |     |
|----------|---------------------------|------|--------------------|-----|
|          | N.C                       | S.C  | N.C                | S.C |
| 1        | 64                        | 65,5 | 4,2                | 4,2 |
| 2        | 35,5                      | 26,2 | 5,6                | 6,1 |
| 3        | 100                       | 9,1  | 1,8                | 9,2 |
| 4        | 100                       | 100  | 1                  | 1,6 |
| 5        | 100                       | 68,8 | 0,6                | 3,9 |
| 6        | 100                       | 100  | 0,7                | 1,7 |
| 7        | 100                       | 100  | 1,4                | 1,6 |
| 8        | 100                       | 67,9 | 0,9                | 4   |
| 9        | 100                       | 100  | 0,6                | 0,4 |
| 10       | 100                       | 83,3 | 1,8                | 3,1 |
| 11       | 90,1                      | 97,5 | 2,7                | 2,2 |
| 12       | 100                       | 98,8 | 0,7                | 2,1 |
| 13       | 93,2                      | 100  | 2,5                | 2   |

|    |      |      |     |     |
|----|------|------|-----|-----|
| 14 | 76   | 63,1 | 3,6 | 4,2 |
| 15 | 100  | 100  | 0,2 | 0,3 |
| 16 | 86,6 | 41,7 | 2,9 | 5,3 |
| 17 | 100  | 85,5 | 0,5 | 3   |
| 18 | 100  | 100  | 0,9 | 1,5 |
| 19 | 100  | 100  | 0,1 | 1,5 |
| 20 | 100  | 65,9 | 0,2 | 4,1 |
| 21 | 100  | 92,9 | 1,2 | 2,5 |
| 22 | 100  | 100  | 0,1 | 1,4 |
| 23 | 100  | 100  | 0,5 | 0,9 |
| 24 | 100  | 65,8 | 0,2 | 4,1 |
| 25 | 100  | 83,3 | 0,7 | 3,1 |
| 26 | 100  | 100  | 0,5 | 1   |
| 27 | 100  | 85,3 | 0,9 | 3   |

Table 1; Results of Global symmetry index (%) and symmetry index of analyzed subjects

The quality index of the gait cycle, the third parameter taken into consideration, evaluates the ability of the subject to divide in a correct and balanced way his right and left gait cycle. Ideally the score of 100 is reached when the stance phase and the flight phase represent exactly 60% and 40% of the gait cycle. The values shown in the following table (Tab. 2) are very important because they help us to better interpret the data of the previous table and to understand to what extent walking is influenced by any asymmetries between the right and left limbs rather than by stress conditions.

| Subjects | STEP CYCLE QUALITY INDEX (%) |          |          |          |
|----------|------------------------------|----------|----------|----------|
|          | Dx - N.C                     | Dx - S.C | Sx - N.C | Sx - S.C |
| 1        | 95,3                         | 94,4     | 94,3     | 93,2     |
| 2        | 90,3                         | 90,4     | 92,3     | 93,1     |
| 3        | 92,7                         | 88,7     | 94,2     | 93       |
| 4        | 89                           | 94,8     | 90,5     | 95,4     |
| 5        | 96,2                         | 96,2     | 97,5     | 95,5     |
| 6        | 95,8                         | 93,4     | 94,6     | 94,7     |
| 7        | 96,3                         | 93       | 91,7     | 93,4     |
| 8        | 95,8                         | 94,9     | 93,5     | 93,8     |
| 9        | 98,2                         | 98,3     | 96,5     | 97,2     |
| 10       | 95,8                         | 96,9     | 96,4     | 95,7     |
| 11       | 95,4                         | 94,9     | 94,5     | 94,7     |
| 12       | 95,9                         | 96,2     | 94,7     | 92,4     |
| 13       | 92,7                         | 94,7     | 93,2     | 94       |
| 14       | 94,1                         | 93,4     | 91,7     | 93,9     |
| 15       | 97,5                         | 95,4     | 95,9     | 97,3     |
| 16       | 95                           | 94,4     | 95,2     | 93,2     |
| 17       | 92,8                         | 96,9     | 92,9     | 94,7     |
| 18       | 97                           | 96,6     | 95,5     | 94       |
| 19       | 97                           | 92,5     | 96,4     | 97,2     |
| 20       | 96,3                         | 93,5     | 96,2     | 95,2     |
| 21       | 96,5                         | 96,8     | 94,4     | 93,1     |
| 22       | 95,2                         | 96,8     | 95       | 94       |
| 23       | 96,8                         | 95,4     | 97       | 94,8     |
| 24       | 94,1                         | 92,5     | 93,6     | 97,7     |
| 25       | 94,8                         | 92,7     | 91,8     | 92,8     |
| 26       | 95,8                         | 95,6     | 95,5     | 96,7     |
| 27       | 96,4                         | 97,7     | 95,9     | 95       |

Tab. 2: step cycle quality index (%) of analyzed subjects

The fourth issue evaluated and exposed here is the single support phase. We wanted to focus in particular on this phase because it is the only phase of the step in which the whole body is supported by only one foot, that is, in which one is in single-stance balance. This phase lasts for a short time on average but is repeated a large number of times during the day, an example with real numbers could help us to better understand the extent of the phenomenon: let's imagine that our single support phase has an average duration of 250ms and that during the day a total of 5000 supports on the ground is completed, at the end of the day we will have completed more than 15 minutes of monopodial supports. For this reason, we considered it appropriate to pay attention to the values shown in the following table (Tab. 3).

| Subjects | SINGLE SUPPORT PHASE (% step cycle) |            |            |            |
|----------|-------------------------------------|------------|------------|------------|
|          | Dx - N.C                            | Dx - S.C   | Sx - N.C   | Sx - S.C   |
| 1        | 37,2 ± 2,4                          | 37,9 ± 4,4 | 42 ± 3     | 42,4 ± 1,7 |
| 2        | 41,8 ± 5,2                          | 37,6 ± 3,4 | 35,2 ± 4   | 43,5 ± 4,2 |
| 3        | 42 ± 2,7                            | 36,6 ± 0,5 | 43,6 ± 0,8 | 45,9 ± 1,8 |
| 4        | 39,8 ± 9,3                          | 39 ± 2,9   | 40 ± 8,9   | 41,2 ± 2,5 |
| 5        | 40,8 ± 2                            | 38 ± 2,2   | 41,7 ± 1,9 | 42 ± 2,3   |
| 6        | 39 ± 4,4                            | 40 ± 5,2   | 38,3 ± 3,7 | 42,6 ± 5,2 |
| 7        | 39,3 ± 6,2                          | 41,1 ± 4,7 | 40,9 ± 4,5 | 40,5 ± 5,4 |
| 8        | 41,7 ± 2,9                          | 43,4 ± 3   | 41 ± 3,3   | 38,9 ± 2,6 |
| 9        | 41,5 ± 2                            | 40,9 ± 1,4 | 40,8 ± ,6  | 41,2 ± 1,1 |
| 10       | 39,4 ± 3,3                          | 37,6 ± 2   | 41,4 ± 3,2 | 41,2 ± 2   |
| 11       | 39,3 ± 3,7                          | 40 ± 4,4   | 42 ± 3,5   | 43,2 ± 2,2 |
| 12       | 42 ± 2,2                            | 44,5 ± 4,6 | 42,4 ± 3,5 | 41,2 ± 3,3 |
| 13       | 38,9 ± 3,7                          | 39,2 ± 3,7 | 36,5 ± 3,6 | 36,8 ± 2,7 |
| 14       | 44,2 ± 3,3                          | 39,5 ± 5,3 | 40,7 ± 4,3 | 43 ± 1,2   |
| 15       | 39,7 ± 4,2                          | 41,6 ± 1,2 | 39,8 ± 3,4 | 40,9 ± 3   |
| 16       | 38,5 ± 4,9                          | 38 ± 4,1   | 42,5 ± 5,1 | 42,3 ± 1,9 |
| 17       | 37,6 ± 6                            | 42,8 ± 2,4 | 38,8 ± 5,9 | 39,1 ± 3,3 |
| 18       | 39,4 ± 4,8                          | 38,3 ± 3,3 | 40,5 ± 4,1 | 39 ± 2     |
| 19       | 41,7 ± ,8                           | 41,2 ± 2,5 | 41,2 ± 2,5 | 41,4 ± 5,7 |
| 20       | 39,7 ± 2,8                          | 43,4 ± 3,5 | 38,7 ± 3,7 | 38 ± 4,3   |
| 21       | 42,4 ± 3,5                          | 41,2 ± 4,7 | 40,9 ± 2,6 | 39,2 ± 2,4 |
| 22       | 42,6 ± 0,8                          | 42,8 ± 1,6 | 42,4 ± ,7  | 41,8 ± 1,7 |
| 23       | 41,2 ± 3,1                          | 40,6 ± 2,2 | 41,7 ± 2,5 | 40,1 ± 4,1 |
| 24       | 43,1 ± 1,6                          | 39,8 ± 1,8 | 42,9 ± 0,8 | 43,7 ± 1,5 |
| 25       | 40,5 ± 4,4                          | 37,8 ± 2,5 | 39 ± 3,4   | 40,6 ± 4   |
| 26       | 40,8 ± 4,2                          | 41,7 ± 1,8 | 41,5 ± 4,1 | 40,7 ± 3,3 |
| 27       | 41,8 ± 4,5                          | 42,8 ± 4,1 | 40,6 ± 3,8 | 39,4 ± 4   |

Tab. 3: single support phase (% step cycle) of analyzed

The inertial unit also allowed us to evaluate the kinematics of the pelvis, that is, to analyze the pelvic angular variations in the frontal, sagittal and transverse planes. In our opinion, this evaluation is important because it allows us to first evaluate the position of the pelvis of the subjects examined, their movements throughout the gait cycle, and possibly reconnect excessive movements to a loss of balance due to the stress situation created during the evidence. As illustrated in the following graphs, which show the most characteristic cases among the subjects analyzed, there is a tendency to deviate from normal values in stress conditions compared to walking in standard conditions, but there is no transversality between the subjects. In fact, each subject has roundabout changes on different floors, as illustrated below. The first band of the graph represents the movement of the pelvis during the right gait cycle, while the second band of the graph represents the movement of the pelvis during the left gait cycle.

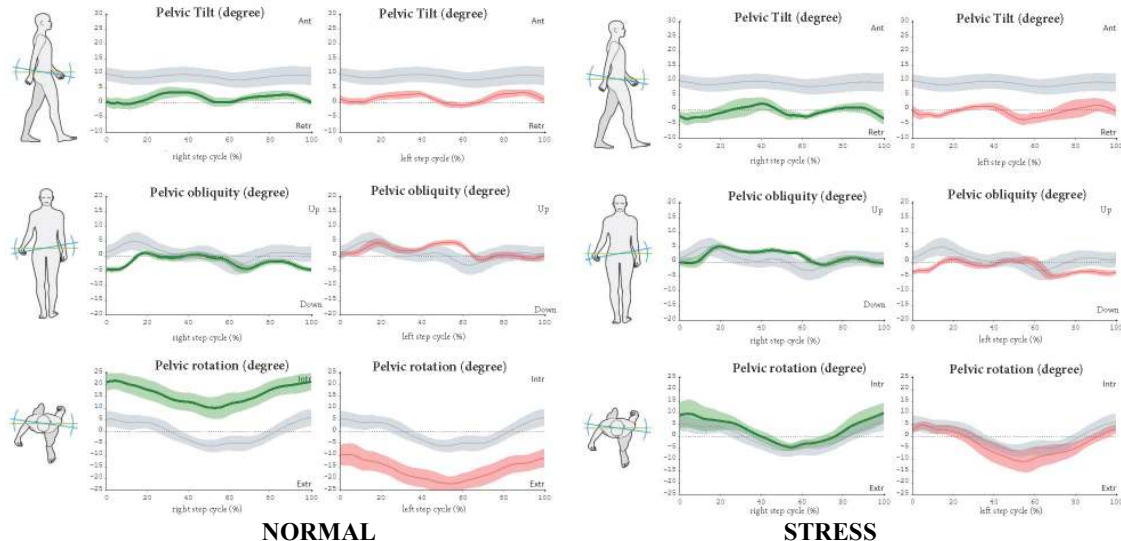
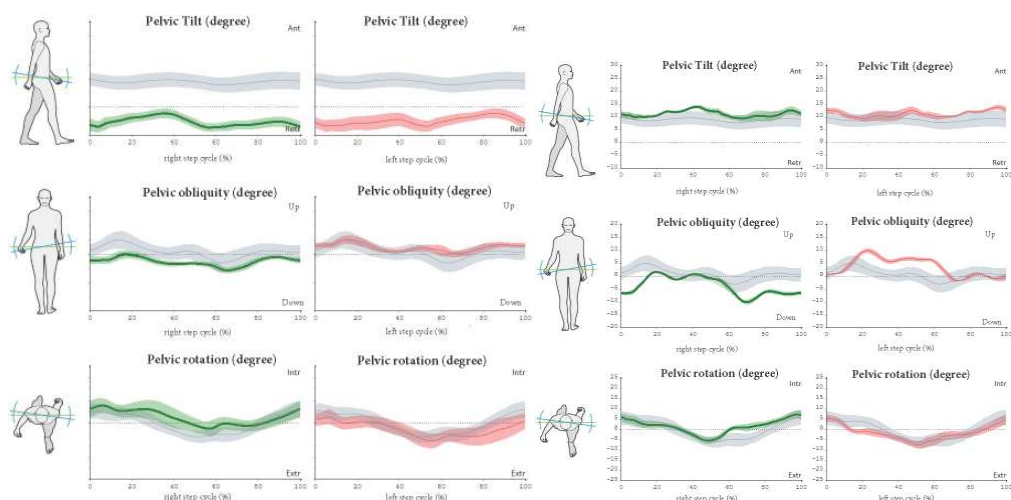


Fig. 4 and 5: graphs of pelvic kinematic subject 1



**NORMAL**

*Fig. 6 and 7: graphs of pelvic kinematic subject 10*

**NORMAL**

**STRESS**

**STRESS**

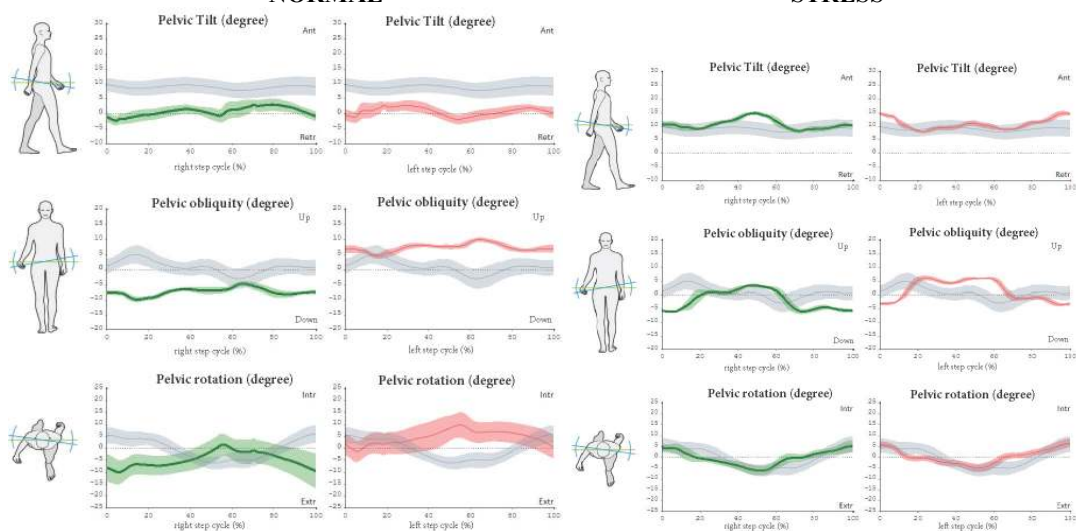


*Fig. 8 and 9: graphs of pelvic kinematic subject 12*

**NORMAL**

**STRESS**

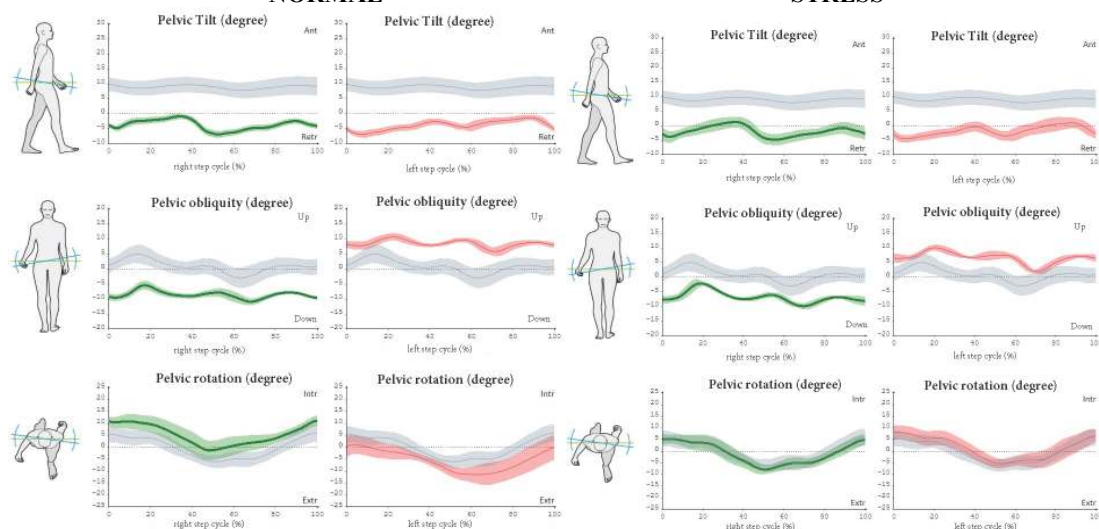


*Fig. 10 and 11: graphs of pelvic kinematic subject 16*

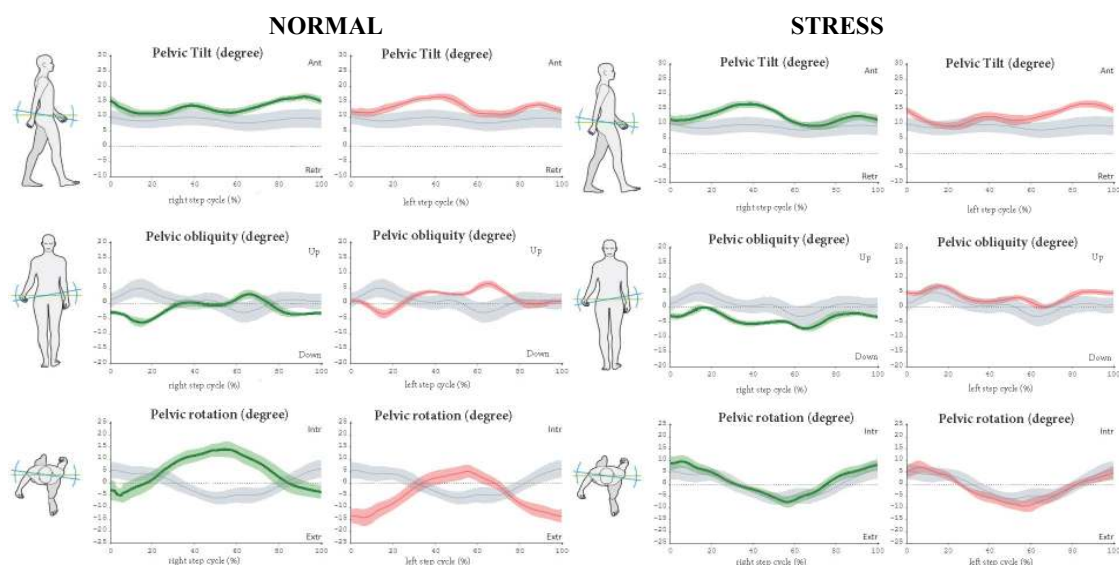


**Fig. 12 and 13: graphs of pelvic kinematic subject 26**

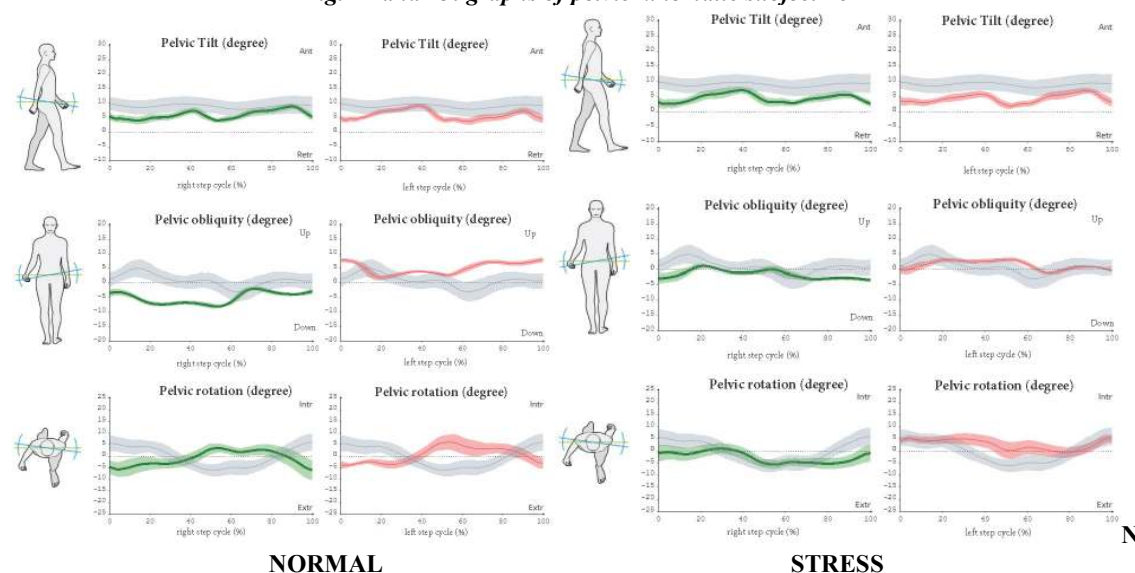


**Fig. 14 and 15: graphs of pelvic kinematic subject 27**

As can be seen from the previous graphs, subjects 1, 12, and 16 show a strong retroversion of the pelvis well beyond the normal values, which we can also see in subject 27, albeit in a much less accentuated way. As mentioned above, there is a worsening of the rotational movements of the pelvis in stress conditions, but if for the subject 1, 12, and 26 this deterioration concerns more the rotations of the pelvis in the sagittal plane, for the subjects 10, 16 and 27 this worsening is also noted on the rotational movements of the pelvis in the transverse plane. In addition to all these issues discussed up to now, thanks to the electromyographic system we have evaluated the specificity of muscle activation during the gait cycle. In our study, we decided to analyze the anterior tibialis and the medial gastrocnemius to see how these two muscles (agonist and antagonist) work during walking. At the beginning of the gait cycle, there is an activation of the anterior tibialis which works in an eccentric way to control the fall of the foot. During the single support phase, when the foot is fully supported, the anterior tibialis should switch off because the action of the gastrocnemius takes over which initially works in an eccentric way to control the forward rolling of the tibia on the foot and immediately afterward must work in concentric to develop the propulsive force necessary to bring the foot off the ground and therefore the limb in flight. During the flight phase, the gastrocnemius no longer has any reason to work and the anterior tibialis takes over again, the function of which is necessary to dorsiflex the ankle and allow the limb to swing, preventing the tip of the foot from touching the ground. The graphs of the EMG signals shown below show in which phases of the gait cycle the switching on and off of each muscle investigated takes place. The gray (darker) bands identify areas where the muscle should be active (normal activation). If the muscles have good coordination, they should have an activation peak in the gray (darker) area and be roughly flat outside of it.

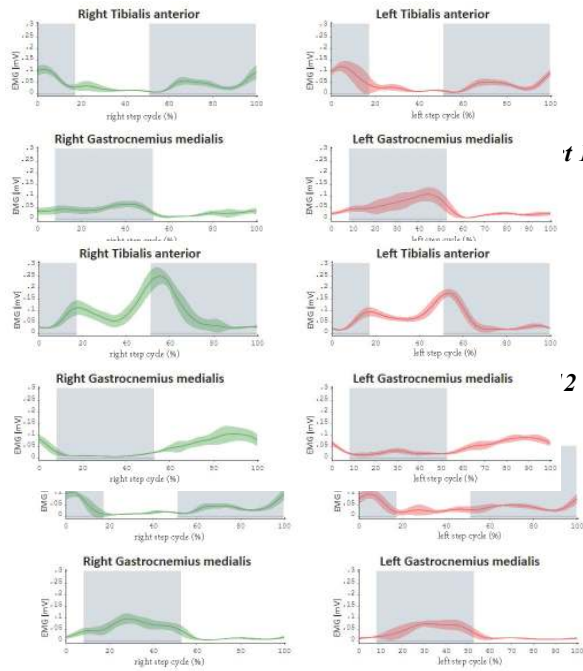


Fig. 20: timing of muscular activation graph subject 26  
graph subject 27

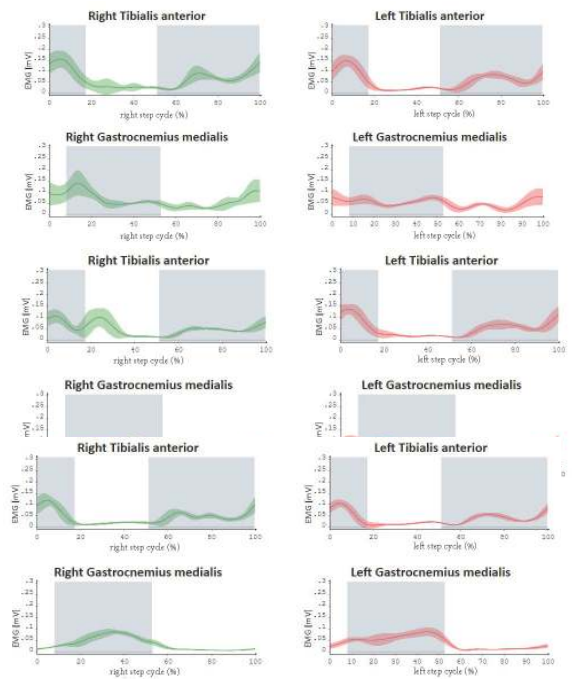


Fig. 21: timing of muscular activation

All subjects analyzed have peaks of activation in the gray / darker areas (the area where the muscle should be active) but are not completely flat outside of them. This means that during some phases of the gait cycle the subjects analyzed show an agonist-antagonist muscle co-contraction. The graphical analysis is supported by the data listed in the two following tables (Tab. 4 & 5), relating to the coactivation index (which allows quantifying the muscle coactivation, the simultaneous activity of the agonist and antagonist muscles acting on a joint) during the d support and flight.

| Subjects | MUSCULAR COACTIVATION Support phase (%) |          |          |          |          |
|----------|-----------------------------------------|----------|----------|----------|----------|
|          | Dx - N.C                                | Dx - S.C | Sx - N.C | Sx - S.C | Standard |
| 1        | 60,7                                    | 57,1     | 56,4     | 49       | <30      |
| 2        | 43,1                                    | 75,3     | 42,1     | 61,2     | <30      |
| 3        | 54,5                                    | 68,4     | 53       | 53,9     | <30      |
| 4        | 49,6                                    | 61,9     | 71,6     | 72,2     | <30      |
| 5        | 58,3                                    | 45       | 74,1     | 63       | <30      |
| 6        | 78                                      | 86,6     | 29,5     | 65,7     | <30      |
| 7        | 73,2                                    | 70,5     | 59,9     | 61,4     | <30      |
| 8        | 84,4                                    | 79,1     | 85,3     | 69,2     | <30      |
| 9        | 72,1                                    | 79,4     | 74,4     | 61,9     | <30      |
| 10       | 59,3                                    | 90,2     | 69,3     | 79,1     | <30      |
| 11       | 79,6                                    | 71,8     | 65,8     | 52       | <30      |
| 12       | 80,1                                    | 33,1     | 68,5     | 54       | <30      |
| 13       | 51,8                                    | 52,5     | 41,7     | 51,6     | <30      |
| 14       | 59,7                                    | 55,5     | 68,6     | 64,2     | <30      |
| 15       | 83,2                                    | 83,1     | 84,8     | 100      | <30      |
| 16       | 95                                      | 73,9     | 68,8     | 67,4     | <30      |
| 17       | 76,4                                    | 83,2     | 66,3     | 76,3     | <30      |
| 18       | 70,7                                    | 81,8     | 75,8     | 81,6     | <30      |
| 19       | 45,5                                    | 51,1     | 61,2     | 62,1     | <30      |
| 20       | 57,6                                    | 51,2     | 51,2     | 54,6     | <30      |
| 21       | 104,6                                   | 91,9     | 94,9     | 81,1     | <30      |
| 22       | 50,1                                    | 42,7     | 65,5     | 58,9     | <30      |
| 23       | 49,5                                    | 77       | 62,9     | 80       | <30      |
| 24       | 35,7                                    | 59,5     | 59,8     | 63,9     | <30      |
| 25       | 60,7                                    | 55,2     | 45,5     | 42,9     | <30      |
| 26       | 58,3                                    | 92,6     | 66,9     | 86,7     | <30      |
| 27       | 55,1                                    | 26,8     | 52,7     | 35,7     | <30      |

Tab. 4: muscular coactivation of analysed subjects during support phase (%)

| Subjects | MUSCULAR COACTIVATION Flight phase (%) |          |          |          |          |
|----------|----------------------------------------|----------|----------|----------|----------|
|          | Dx - N.C                               | Dx - S.C | Sx - N.C | Sx - S.C | Standard |
| 1        | 26,3                                   | 16,2     | 28,2     | 23,6     | <55      |
| 2        | 67,6                                   | 25,8     | 78,6     | 15,8     | <55      |
| 3        | 38,9                                   | 33,2     | 53,3     | 31,7     | <55      |
| 4        | 17                                     | 3,6      | 12,4     | 7,2      | <55      |
| 5        | 84,7                                   | 83,6     | 48,7     | 63,5     | <55      |
| 6        | 36,7                                   | 45,3     | 78,1     | 66,2     | <55      |
| 7        | 79                                     | 44,5     | 29,1     | 42,7     | <55      |
| 8        | 31                                     | 19       | 26,6     | 27,9     | <55      |
| 9        | 47,7                                   | 45,1     | 45,5     | 12,2     | <55      |
| 10       | 38                                     | 46,7     | 42,1     | 39,8     | <55      |
| 11       | 77,6                                   | 78,2     | 81,1     | 67,1     | <55      |
| 12       | 37,4                                   | 60,9     | 69,2     | 47,7     | <55      |
| 13       | 34,7                                   | 28,5     | 21,9     | 21,1     | <55      |
| 14       | 48,9                                   | 44,2     | 46,2     | 48,9     | <55      |
| 15       | 79,5                                   | 77,4     | 76,2     | 64,6     | <55      |
| 16       | 44,3                                   | 45,9     | 78,7     | 77,7     | <55      |
| 17       | 65,9                                   | 78,1     | 70,4     | 71,2     | <55      |
| 18       | 75,2                                   | 74       | 71,4     | 57,8     | <55      |
| 19       | 39,9                                   | 73       | 102,2    | 81,1     | <55      |
| 20       | 30,7                                   | 57,1     | 40,8     | 43,9     | <55      |
| 21       | 47,5                                   | 45,8     | 66,2     | 74,2     | <55      |
| 22       | 17,8                                   | 38       | 45,5     | 40,7     | <55      |
| 23       | 52,6                                   | 39,7     | 45,9     | 36,4     | <55      |
| 24       | 63,1                                   | 42       | 74,5     | 50,4     | <55      |
| 25       | 33,8                                   | 14,7     | 34,7     | 19,6     | <55      |
| 26       | 29,7                                   | 32,7     | 23       | 29,6     | <55      |
| 27       | 23                                     | 57,6     | 33,6     | 53,3     | <55      |

Tab. 5: muscular coactivation of analyzed subjects during flight phase (%)

We can easily trace the data of the two tables (4 & 5) to the graphs examined previously. The comparison allows us to understand both at what moment muscle coactivation occurs, and to what extent. All the analyzes reported in this chapter will allow a thorough and complete evaluation of the subject during walking, which will allow at first to choose the most suitable working and/or corrective protocol for the subject and at a later time to benefit from the rehabilitation work. carried out not only in the sports field, ut also in a broader context of everyday life.

## Discussion

Based on the results obtained during the tests it is possible to make the following considerations:

- the global index of symmetry tends to decrease, after the execution of the test, in almost all the athletes examined, this means that the respective phases of support and flight phases of the right and left limb tend to deviate from the values of normality. The symmetry index also tends to increase and that is, the stance and flight phase tend to change, in%, more on one limb than on the other. The variations of these two indices could mean a loss of equilibrium of the subjects examined under stress conditions, confirming the studies found in the literature.
- from the analysis of the data relating to the single support phase of the gait cycle (phase in which all the weight of the body rests on only one of the two lower limbs) we noticed similar values between the right and left leg in standard conditions, while in of stress there is a tendency to be greater (always in% of the gait cycle) in the non-predisposition leg, but with discordant values among the athletes, perhaps due to the not yet fully developed laterality of the subjects examined in this study, given their age (with particular reference to the stabilization of dominance). The results confirm the trend, also found by Gstottner et al. in their 2009 study and it would all make sense, given that the non-predisposition leg is the most used to support the weight of the body while the predisposition leg performs the gesture. Even if we are talking about thousandths of a second with regard to the single gait cycle, as mentioned in the previous chapter, if we consider the high number of monopodial supports during a day, these data take on considerable weight;
- as regards the analysis of the kinematics of the pelvis, it is difficult to create correlations between all the boys examined. What we can certainly notice is, in most of the cases examined, a departure from normal values in stressful conditions (therefore after the "suicide" test) compared to the first walk in standard conditions. This increase in the oscillation of the pelvis during walking in conditions of physical stress, would confirm the fact now taken for granted in the literature, that in the presence of fatigue the balance would tend to decrease. However, each subject is different from the other and, while some have the most obvious differences on the frontal plane, others show instability on the

transverse plane, still others on the sagittal plane. The inertial tools, therefore, allow us to analyze, especially in pre-adolescent boys where corrective interventions can give the best results, important aspects of walking as regards the movement of the pelvis on the three main planes, but in our opinion this tool is more useful for a 'subjective and personalized analysis, focusing on what can be, for example, attitudes of marked retroversion of the pelvis (athlete n.1,4,6,9,12,13,16,17,18,22,23,24,25 ) or on the contrary antversion (athlete 21) with respect to the physiological plane of movement;

- The muscle co-activation index in all the boys analyzed was higher than the normal values as regards the support phase. Values are probably due to the fact that the boys performed the tests during training, undergoing the tests one at a time. They, therefore, arrived already in a state of relative fatigue, in which the muscles examined had high values of coactivation. From a practical point of view, this co-activation does not indicate any kind of joint problem, but the usefulness of this double activation seems to be an attempt by the body to protect the joints. When there is a double contraction, the joint is more compressed and protected so it can be considered a form of prevention for the body. This can be useful for explaining the higher values during the stance phase rather than during the flight phase, as during the latter the body could perceive a lower risk for the joints involved in the movement.

## Conclusions

In light of these considerations, it is our opinion that it would be useful to propose a protocol for children that has proprioceptive training as a minimum common denominator. This type of training is intended as a practice based on the stimulation of the neuro-motor system in its entirety. Proprioceptive training is composed of a set of exercises that create situations of different levels of instability, in order to evaluate and improve the use of proprioceptive signals coming from the peripheral parts of the body, in particular from the lower limbs. The primary objective of proprioceptive training is to re-establish proprioceptive reflexes, the fastest reorganization of balance (fine control of one's body) in advanced dynamic and dynamic motor elements, in order to again obtain optimal control of the posture and the joints involved. Proprioceptive training is of fundamental importance for a fine knowledge of one's parts of the body (muscles, joints, etc.), obtaining complete recovery after a trauma (to restore reflexes and reactivate all the information channels interrupted by the injury), the prevention of injuries (to have a more rapid control of the muscles during game actions and to favor the solicitation of entire muscle groups avoiding isolated contractions) and also for sports training (to have a strong sense of balance and absolute control of the technical gesture), together with the enormous importance it could have in elder people. The proprioceptive training should also contain situations that induce the athlete to lose balance, even with "borderline" requests according to the qualities that the age is taken into consideration suggests, therefore to activate the muscles quickly and correctly for a recovery in shorter times. The latter consideration would be extremely important, as suggested a little earlier even in older ages where the balance factor and falls, think of the elderly for example, become an even greater danger factor.

The improvement of balance occurs through the maintenance of the position combined with the ability to quickly correct imbalances. The specific training technique is based on controlled and applied stresses to the joints, using both unloading and natural load exercises, resting on the ground or on oscillating surfaces of varying difficulty, such as tablets, bouncers, bosu, trampolines, etc. All proprioceptive exercises must also be proposed firstly avoiding wearing shoes, so as not to distract the proprioceptive sensations due to the shoe. To further intensify the training it is possible to perform the exercises with closed eyes, as the balance is also controlled by the exteroceptors (sight and vestibular apparatus), which receive information from the outside world and which together with the proprioceptors, give exact information about the position of your body. Eyes closed exercises are used to disrupt balance information systems and force the athlete to be more sensitive to other remaining information channels. Finally, to make proprioceptive training even more difficult, it is possible to create paths with many boards, platforms, and unstable terrain, where you can walk, run, jump and perform technical gestures related to your sport. Also including some exercises aimed at strengthening the abdominal muscles, and relaxing the muscles of the anterior thigh and spine can be useful for correcting excessive hyperlordosis due to a strong retroversion of the pelvis, a condition also found in many of the boys analyzed.

The technical teams, the athletes will therefore be able to draw significant advantages from these data obtained therefore useful for elaborating work cycles to improve a certain technique, insert recovery cycles in the training program in case fatigue and pathologies of the muscular or joint system are found, understand the economy of movement at the muscle level as intensity increases, determine the degree of fatigue after a certain number of repetitions of the same exercise, verify the effect of training on the athlete overtime to finally individualize the work plans. In conclusion, this work has given us the opportunity to evaluate with extremely advanced equipment some parameters of walking that we consider fundamental and that allows us to combine a purely observational evaluation or in any case of non-maximum precision with reliable objective data for the creation. of increasingly specific and effective intervention protocols as reported above. We believe that the data obtained and the evaluations made in this study on walking can expand into more dynamic movements such as running and even more so in advanced dynamic movements (which characterize many sports activities). We often wonder about how to improve a certain technical gesture, we believe that the analysis of the problems must

start from the support base of all dynamic gestures and more, such as steps, walking, etc. because we are convinced that with a solid base of support the whole system of the structure benefits enormously.

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 Statistical analysis: Cejudo A., Izzo R.  
 Writing, original draft preparation: Izzo R., Bertoni M.  
 Writing, review and editing: Izzo R., Hosseini C.  
 All authors have read and agreed to the final version of the manuscript.

#### Acknowledgements

For this study, we especially thank BTS Engineering Italy, K-Sport World, Italy and ARGES, Advanced Research Group in Sport (Urbino Un., K-Sport World), for expertise and making available the most advanced sport dedicated technologies, database and above all the engineering expertise for the study. This study did not receive any financial support or other assistance. Conflicts of Interest: The authors declare no conflict of interest.

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