

**A relação entre postura corporal, biomecânica de corrida e o uso de palmilhas sensoriais: uma revisão**

**The relationship between body posture, gait biomechanics and the use of sensory insoles: a review**

**La relación entre la postura corporal, el funcionamiento de la biomecánica y el uso de plantillas sensoriales: una revisión**

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**Resumo**

**Objetivo:** O objetivo deste estudo foi realizar uma revisão de literatura, buscando sintetizar informações sobre a relação entre postura corporal, biomecânica de corrida e o uso de

palmilhas sensoriais, bem como contribuir com as investigações que vêm sendo realizadas acerca desta temática. **Metodologia:** A pesquisa foi realizada nos bancos de dados: Science Direct, MEDLINE/PubMed, Web of Science e Scielo. Os descritores utilizados para a busca dos artigos foram: postura corporal, corrida, lesão, pressão plantar, sensores e palmilhas sensoriais; esses termos também foram usados em associação entre si. **Resultados:** Dentre as publicações, foram selecionados artigos que incluíssem revisões de literatura, tratamentos ou pesquisas *in vivo*, até o ano de 2020. Esta revisão identificou a existência de diversos sensores de pressão disponíveis no mercado, com tecnologias de sensores capacitivos, resistivos, piezoelétricos e piezoresistivos. Este trabalho também identificou diversas vantagens do uso da tecnologia da palmilha: melhorias no equilíbrio e na velocidade de oscilação, na direção ântero-posterior; redistribuição da pressão plantar durante a caminhada em pacientes diabéticos; e mudança na relação pressão em função do tempo, em toda a área plantar. **Conclusão:** O progresso feito pelo uso desses sensores, durante os últimos anos, tem motivado pesquisadores a buscar melhorias no desempenho e na praticidade desta tecnologia, podendo ser utilizados para o diagnóstico dos distúrbios do equilíbrio, fator relacionado à postura corporal e à biomecânica de corrida.

**Palavras-chave:** Pressão plantar; Biomecânica de corrida; Sensores; Palmilha.

### Abstract

**Objective:** This study is a literature review aimed at synthesizing information regarding the relationship between body posture, gait biomechanics, and the use of sensory insoles, as well as contributing to the investigations on this topic. **Methodology:** We have collected the research data from the databases Science Direct, MEDLINE/PubMed, Web of Science and Scielo. We used the following descriptors in the search for the articles: body posture, running, injury, plantar pressure, sensors, and sensory insoles; we have also associated these terms with one another in our search. **Results:** We have selected the articles that contained literature reviews, treatment, or on-site surveys, published up to 2020. This review has identified the existence of several commercially available pressure sensors, with technologies such as capacitive, resistive, piezoelectric, and piezoresistive sensors. This study has also identified several advantages in the use of the insole technology: improvements in balance and speed rates in the anteroposterior region; redistribution of plantar pressure during walking for diabetic patients; alteration of the pressure over time relationship throughout the entire plantar region. **Conclusion:** The progress obtained by the use of these sensors over the past few years has been motivating researchers to aim for improvements in its performance and practicality,

allowing for its use in diagnosing balance disorders, which can be related to body posture and gait biomechanics.

**Keywords:** Plantar pressure; Running biomechanics; Sensors; Insole.

## Resumen

**Objetivo:** El objetivo de este estudio fue realizar una revisión de la literatura, buscando sintetizar informaciones sobre la relación entre postura corporal, biomecánica de carrera y el uso de plantillas sensoriales, así como contribuir a las investigaciones que se han llevado a cabo sobre este tema. **Metodología:** La investigación se realizó en las siguientes bases de datos: Science Direct, MEDLINE/PubMed, Web of Science y Scielo. Los descriptores utilizados para buscar los artículos fueron: postura corporal, carrera, lesiones, presión plantar, sensores y plantillas sensoriales; estos términos también se usaron en asociación entre sí.

**Resultados:** Entre las publicaciones, se seleccionaron artículos que incluían revisiones de literatura, tratamientos o investigaciones *in vivo*, hasta 2020. Esta revisión identificó la existencia de varios sensores de presión disponibles en el mercado, con tecnologías de sensores piezoeléctricos capacitivos, resistivos. y piezoresistivos. Este trabajo también identificó varios beneficios de usar la tecnología de la plantilla: mejoras en el equilibrio y la velocidad de oscilación, en la dirección anteroposterior; redistribución de la presión plantar durante la marcha en pacientes diabéticos; y cambio en la relación de presión en función del tiempo, a través del área plantar. **Conclusión:** El progreso realizado por el uso de estos sensores en los últimos años ha motivado a los investigadores a buscar mejoras en el rendimiento y la practicidad de esta tecnología, que puede utilizarse para el diagnóstico de trastornos del equilibrio, un factor relacionado con la postura corporal y la biomecánica del funcionamiento.

**Palabras clave:** Presión plantar; Biomecánica de carrera; Sensores; Plantilla.

## 1. Introduction

Running has become one of the most popular sports in the world. The number of runners in Brazil has increased over the past few years, and approximately 5% of the population participates in street races, which amounts to approximately 10 million runners (Van Middelkoop, Kolkman & Van Ochten, 2008; Tonoli *et al.*, 2010; Purim *et al.*, 2014; Rios *et al.*, 2017). People can run for pleasure, rehabilitation, or as a competitive sport, all of

which bring upon a positive impact on the individual's health, physical capacity, well-being, and quality of life (Hespanho & Lopes, 2013).

However, alarming rates of running-related physical injuries have been reported, with associated economic costs (Fukuchi, Fukuchi & Duarte, 2017; Fokkema *et al.*, 2017). In that sense, we can affirm that gait biomechanics are associated with the etiology of the injuries that incur from this sport. The ankle joint is the most commonly injured one during running and is a considerable source of morbidity and long-term incapacitation (Albano Junior & Nelson, 2019); ankle injuries usually result from indirect mechanisms (falls, sports activities, among others) that force their rotation, abduction or adduction and cause injuries that vary from sprains to fracture-dislocations.

Alterations in the structure of the foot may change the load distribution on this part of the body and inevitably result in biomechanical alterations in the lower limbs. Studies suggest that there is a causal link between the structure of the foot and alterations in lower limb kinematics, which may predispose a person to general musculoskeletal disorders (Zhao *et al.*, 2018; Denyer, Hewitt & Mitchell, 2013; Riskowski *et al.*, 2012). Furthermore, there are reports that the occurrence and development of musculoskeletal disorders are associated with the reduction of muscular strength of the foot and ankle, as well as low physical performance (Stewart *et al.*, 2016; Golightly *et al.*, 2011).

Analyzing the distribution of plantar pressures (the pressure applied to the plantar region of the foot during contact with surfaces) can help reveal the potential for the static and dynamic overload of specific structures or anatomic areas of the foot, as well as deliver considerations about its function and postural control (Filippin *et al.*, 2008). Alterations in foot pressure can provoke an uncommon alignment of the lower limbs, abnormal stress to the foot and its related structures, and culminate in orthopedic disorders (Chuter & Janse De Jonge, 2012).

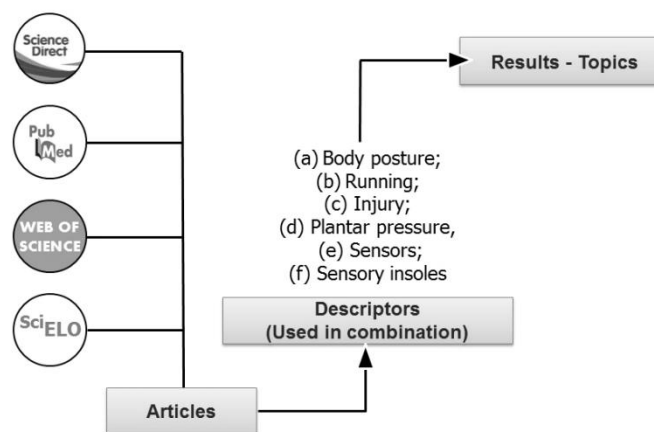
The most common insole pressure sensors measure the distribution of plantar pressure among the feet. The progress obtained by these sensors has motivated researchers to focus on improving the performance and practicality of sensor recognition in realistic environments, among other ways (Cornacchia *et al.*, 2017; Ayena *et al.*, 2018).

This study performs a literature review to synthesize information about the relationship between body posture, gait biomechanics, and the use of sensory insoles, and contribute with the current investigations on the subject.

## 2. Methodology

For this study, we have performed a literature review of scientific articles from across the world, using an exploratory research approach to become better acquainted with the subject in order to better elucidate it. We extracted the data used in this study from the Science Direct, MEDLINE/PubMed, Web of Science e Scielo databases (Figure 1), and used the following descriptors to search for the articles in this review: body posture, running, injury, plantar pressure, sensors, and sensory insoles, as well as combinations of these terms.

**Figure 1** - A schematic representation of the search for articles.



Source: Elaborated by the author (2020).

We have selected articles that contain literature reviews, treatment reports, or on-site surveys, published from 1996 to 2020. The inclusion criteria also include an analysis of the publications and classification based on the themes approached by each study. Duplicate articles and patent filing applications were excluded. Therefore, the Results and Discussion session was divided into topics in order to better elucidate this study's approach.

## 3. Results and Discussion

### 3.1 *Body posture and gait biomechanics*

Body posture is commonly understood as the relationship between the human body parts in a vertical position and specific parts of the body, such as head and neck, torso, and upper and lower body limbs, which are involved in the body's final posture (Czaprowski *et*

*al.*, 2018; BAHRI, 2019). A good body posture is considered to be ergonomically advantageous when standing up, mechanically efficient when moving, and favorable of the normal functioning of internal organs (Lu, Waters & Werren, 2015).

Body posture is described by three reference planes: sagittal, coronal, and transverse planes, which maintain a state of muscular and skeletal balance that protects the body's support structures against injuries and progressive deformities, regardless of the posture (e.g. upright, lying down, crouching or tilted) in which these structures are working or resting (Czaprowski *et al.*, 2018). A *good* body posture is considered to be ergonomically advantageous when standing up, mechanically efficient when moving, and favorable of the normal functioning of internal organs (Werren, 2015).

Stretch reflexes, intermuscular reflexes, and intrinsic muscular properties provide postural stabilization (Feldman, 2016). Postural control is achieved through the integration of vestibular, visual, and somatosensory information, which contribute to head/body orientation and stabilization in space (Borel & Ribot-Ciscar, 2016).

Postural control requires a complex interaction between the motor and sensory components integrated by the central nervous system to work adequately (Vassimon-Barroso *et al.*, 2017; Zouabi *et al.*, 2016). The posture is considered to be ideal when it presents an alignment where the Headline starts at the external ear canal or the mastoid part of the temporal bone, vertically runs across the acromion, lumbar vertebrae, and headland then goes slightly below the axis of the hip joint and slightly ahead of the knee joint one, ending at the lateral malleolus or slightly in front of it (Lu, Waters & Werren, 2015).

The ability to control the body's balance and stability during locomotion is essential to avoid falling and recover from disturbances (Farrell *et al.*, 2014). In this regard, the benefits that incur from regular runs are widely recognized, considering that running has become a very popular means of physical exercise among individuals who adopt a healthy lifestyle. However, the number of reports of running-related injury rates and associated economic costs is alarming (Fukuchi, Fukuchi & Duarte, 2017; Fokkema *et al.*, 2017).

Running injuries are very common, especially on the lower limbs (Souza *et al.*, 2016; Malisoux *et al.*, 2017), which depend on the storage and release of elastic energy, especially around tendons and joints, to reduce the mechanic demands of the lower body muscles (McDonald *et al.*, 2016). The workload applied during training for street runs overloads the plantar region of the foot. The strength of contact between the ground and foot soles generates great pressure that irradiates through the feet to the rest of the body, therefore associated injuries are triggered by morphologic alterations caused by plantar pressure (Schmidt &

Bankoff, 2011). It is important to highlight that exhaustive exercise without adequate professional guidance can contribute to the increase in sports injuries (Bennell & Crossley, 1996).

### ***3.2 Plantar pressure in runners***

Plantar pressure is defined as the pressure applied on the sole of the foot during contact with the ground. Plantar pressure measurement has been employed for a very long time to manage foot and lower limb disorders associated with the orthopedic and neurologic systems. This is an important component that affects the performance of the foot and ankle. Alterations in plantar pressure distribution may result in a decrease of the foot's functions, such as support and flexibility when walking, running, standing up, or performing other functional activities (Zulkifli & Loh, 2018; Chow *et al.*, 2018).

Plantar pressure measurement is crucial for performance monitoring in health and sports, in areas such as walking gait phase detection speed acceleration performance (Tee *et al.*, 2017). The most commonly used sensory devices for these measurements are classified as plantar pressure platform systems and sensory insoles (Zhang *et al.*, 2019). Prolonged running increases the load on the lower limbs, especially knee, ankle, and good. The accumulated load experienced by long-distance runners can alter their plantar pressure (García-Pérez *et al.*, 2013). Plantar pressure is a biomechanic measure that provides both trainers and athletes with important information to prevent foot injuries such as skin injuries and stress fractures. (Bisiaux & Moretto, 2008; Rocha *et al.*, 2014).

The increase in pressure affects each region of the foot differently. For example, a pressure increase under the metatarsal head beyond exhaustion may result in a risk of stress fractures. Metatarsal bone stress fractures are usually reported by long-distance runners as a result of excessive strain and are considered to result from a multifactorial process. Potential causes include intense or frequent mechanical load, anthropometric factors such as step length or the type of foot, muscular fatigue, bone health, and duration or intensity of the runner's training (Nagel *et al.*, 2008; Escamilla-Martinez *et al.*, 2013).

Alterations in plantar pressure can cause a abnormal alignment of the lower limbs or abnormal stress on the feet and related structures and also cause multiple orthopedic disorders such as plantar fasciitis and knee pain (Chuter & Janse De Jonge, 2012). Identifying a possible relationship between morphologic and mechanical properties of the muscles of the foot, or between the foot and plantar pressure, can help us better understand the factors that



cause or stem from abnormal plantar pressure on the structures of the foot, as well as aid in the development of better strategies for training and treatment (Tas & Cetin, 2019). Therefore, studying plantar pressure is fundamental to understand those mechanisms and injuries and to explore interventions and training that can improve recovery and avoid future injuries.

### ***3.3 Sensors and the plantar pressure signal acquisition system***

The biofeedback technique was developed approximately 50 years ago and can be used for several medical disorders, including application in physical education activities. For motor learning, the biofeedback methodology is very simple: the professional positions one or more sensors on outer devices across the body to measure specific physiologic processes (Moss *et al.*, 2003). The biologic signals are electronically processed and sent back through auditory or visual feedback. This way, the user can be more aware of the partial or complete evolution of the biologic processes (Pitta *et al.*, 2006; Franklyn-Miller, 2014).

Pedometer and accelerometer are two examples of commonly used movement sensors. There is, however, a broad selection of commercially available products to track the user's physical activity (Badawi, Eid & Saddik, 2012). The sensors are based on the amount of movement and anthropometric characteristics, facilitating the measurement of energy spent during physical exercise (Barton *et al.*, 2016). Movement sensors quantify physical activity for a given period of time, and in some cases, may even estimate the energy consumption of the physical activity. Pedometers are simple devices that register the number of steps taken by a person. Accelerometers are more technologically advanced and register both the number of movements performed and their intensity (Chernbumroong *et al.*, 2013; Howcroft, Kofman & Lemaire, 2013).

Movement records associated with the individual's anthropomorphic characteristics result in an estimation of the activity's energy consumption, which is provided by the movement sensors (Janidarmian *et al.*, 2017). Among those, the insole pressure sensors measure the force that acts upon each sensor during contact with the foot (Orlin & Mcpoil, 2000). There are usually several sensors in multiple areas of these sensory insoles, providing pressure distribution data, given that the pressure distribution pattern is a predictor of gait or body instability (Tao *et al.*, 2012).

The most commonly used pressure sensors measure the plantar pressure distribution across the foot (Ayena *et al.*, 2018). Every loss of balance, slip, stumble, sudden crouching, and ankle twist is associated with surface-specific environmental conditions, such as slippery



floors, irregular surfaces or obstacles along the way, which create a plantar pressure exclusively on the foot, generating distribution patterns that can be measured with sensory insoles. Learning algorithms classify the loss of balance events using spatial and temporal resources that reflect data patterns exclusive to plantar pressure (Brassard *et al.*, 2012; Antwi-Afaria *et al.*, 2018).

The progress obtained by the employment of sensors over the past few decades motivates researchers to improve the performance and practicality of sensory recognition in multiple realistic environments (Cornacchia *et al.*, 2017). This is a complex process that follows five essential steps: 1) selecting and implementing the appropriate sensors on the human body or on the environment in order to capture the user's behavior or alterations in the environment where the user is training; 2) collecting the data from the sensors and processing it in accordance to the activity performed by the user; 3) extracting useful resources from the sensor data for classification; 4) training the classification models with the appropriate machine learning algorithms to infer activities; and 5) testing the learning models for performance reports (Lara & Labrador, 2013; Nweke *et al.*, 2018).

### **3.4 Sensory receptors**

Professional athletes need their nervous system to quickly recognize and adjust the position of their limbs and joints to practice the sport more efficiently (Ducic *et al.*, 2004). Afferent signals from the peripheral nervous system send somatosensory information to the central nervous system, where they are processed along with visual and vestibular information to orient the execution of agile and coordinated actions (Peterka, 2002).

The somatosensory system detects the subtle movement of the lower limbs (Horak, 2006; Kars *et al.*, 2009). The plantar area of the foot has an abundance of cutaneous receptors that provide proprioceptive information, associated with touch, pressure, and kinesthetic pressure (Qu, 2015). These receptors are critical for providing athletes with information about static and dynamic posture, stability, and joint positioning during the coordinated execution of agile movement (Perry *et al.*, 2000).

Many healthy athletes try to improve their performance by reinforcing their somatosensory system with wearable devices (suspenders, sleeves, insoles) (Fioravanti *et al.*, 2019). These devices are suggested to partly improve the proprioceptive feedback obtained by cutaneous receptors, in order to improve feeling, proprioception, and performance. Cutaneous

receptors improve the development of sports gear, as they have the potential to apply direct stimulation to improve the somatosensory system (Kars, 2009).

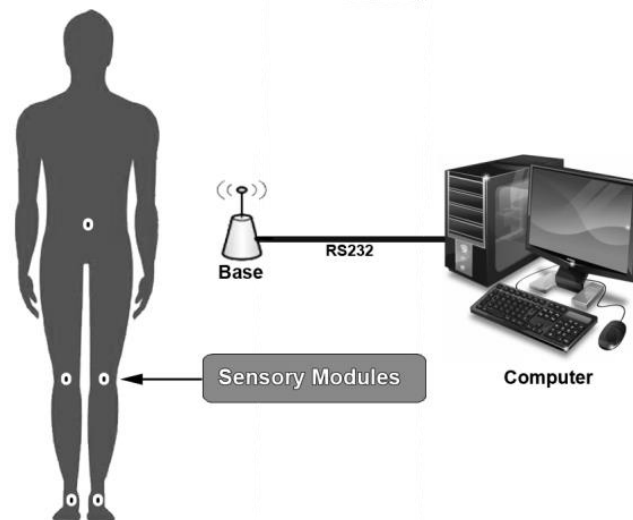
Sensory enhancement insoles use the technology of stochastic resonance (SR) to improve the postural oscillation and reduce gait speed variability for healthy individuals (Galica *et al.*, 2009; Stephen *et al.*, 2012; Lipsitz *et al.*, 2015). SR is a non-linear phenomenon of the biologic systems in which the recognition of the sensory signal is enhanced through the introduction of low levels of uncorrelated input noise. The mechanism through which SR improves sensitivity is possibly a partial depolarization of the receptor's membrane, pushing the receptor closer to its action potential (Priplata *et al.*, 2003; Alfuth, 2017).

Stochastic resonance, when applied to receptors, including skin receptors, muscular spindle, and ligaments, can enhance touch, joint positioning, senses, and balance when defined on a level lower than the feeling threshold (Priplata *et al.*, 2006). Studies have shown that SR can be used to enhance balance, which results in a good athletic performance. A combination of the positive balances and the walking results provided by insole sensory enhancement results in improved athletic performance (Hrysomallis, 2011).

### ***3.5 Inertial sensors and their relationship with human movement***

There is a steady increase in the use of inertial sensors to monitor human movements and biomechanics, as well as relate this data to day-to-day activities (Espinosa *et al.*, 2015). The evolution of these sensors has enabled the study of human movement in various situations, with only a few sensors in contact with the body. The collected data can provide some important variables like acceleration, angular velocity, height, and direction in a non-invasive way (Chang, Georgy & El-Sheimy, 2015). The inertial measurement system is composed of three main elements: a computer, a base station to start and finish the data collection, and five sensory modules that capture and store data on a security digital card (SD), as depicted in Figure 2.

**Figure 2** – A inertial measurement system.



Source: Elaborated by the author (2020).

This way, an inertial measurement unit (IMU), combined with inertial sensors such as the accelerometer, gyroscope, and other types of sensors like the magnetometer, allows for a new approach to quantifying movement disturbance. IMUs represent the advance of wearable, portable, and practical technology for the efficient evaluation of movement disturbances (Kotiadis, Hermens & Veltink, 2010; Rahimi *et al.*, 2011). The most common inertial sensors are the accelerometer, which measures linear acceleration, and the gyroscope, measuring angular velocity (rotation).

The accelerometer is an electromechanical sensor designed to measure the acceleration of a body due to the application of an external force that can result in dynamic accelerations, like speed variation during movement, vibrations or shock, or static acceleration (e.g. when the device is inclined and the gravitational acceleration is projected among its sensibility axis). This device transforms an acceleration vector into an electric signal, which can then be collected and processed by electronic devices (Silva, 2016). There is a large variety of available accelerometers, with piezoelectric crystals, piezoresistive sensors, electronic sensors among the most commonly used ones (Kionix, 2017).

We can combine and correlate the information captured by these sensors to evaluate movement and human posture. The accelerometer is, simply put, composed of a small mass connected to a spring, that is attached to a structure to measure its movement. External acceleration makes the mass shift, and the magnitude of its movement is proportional to the body's acceleration and inversely proportional to the stiffness of the spring. In other words, we can infer the body's linear acceleration by the length of the spring's stretch. We can use

piezoelectric, capacitive, piezoresistive transducers, among others, to convert this position shift into electrical signals. Accelerometers are sensible to the gravitational pull, therefore the movement orientation affects the output signals (Zeng & Zhao, 2011; Torres, 2018).

Gyroscopes are sensors for measuring angular velocities of a specific rotation axis, ignoring other linear movements. The signals generated by these devices are normally expressed in degrees per second, and their dynamic range can reach several hundred degrees per second (Greene *et al.*, 2010; Morgado, 2019). A classic gyroscope is essentially composed of a freewheel whose high buoyancy, along with mechanisms for compensation of friction, allows for approximating its rotation as a forceless motion in an inertial state. If the platform spins, the principle of conservation of angular momentum maintains the freewheel at a stationary position, making the angular velocity vector to change directions inside the movement's reference platform's system. We can derive the platform's rotation angle by observing this alteration (Kempe, 2011).

We must also mention the inertial sensors based on micro-electromechanical (MEMS) systems, as those are not only largely commercially available, but also the most commonly used sensors on smartphones and day-to-day devices, as they are the most compatible ones with portable systems (Kempe, 2011). MEMS-based devices are basically composed of actuators and sensors. These two types of microdevices can share common functionalities, such as signal acquisition, processing, and digital control. The factors that boosted MEMS-based technology are essentially the same ones that popularized microelectronics: miniaturization, reliability, mass production, and cost reduction (Ferreira, 2013; Fraga *et al.*, 2014).

Due to the stride in technology over the past few decades and the current state-of-the-art MEMS technology, we can now integrate microelectronic circuits and mechanical structures in a single integrated circuit (chip), which allows us to develop smaller, lighter, cheaper and more functional devices. These factors combined generated significant impact in many industrial sectors, such as the automotive, aerospace, autonomous vehicle production, smartphone, industrial automation, and biomedicine sectors (Ferreira, 2013; Fraga *et al.*, 2014).

### ***3.6 Sensory insoles: definition, characteristics, and application***

The analysis of plantar pressure distribution has received considerable attention from biometric and sports research, to evaluate the pressure of the interface between foot sole and

footwear (Razak *et al.*, 2012). Artificial motion sensors are applied to diagnose balance disorders and evaluate energy consumption. Among these sensors, we have insoles, which consist of any material placed between foot and footwear that affects the pressures on the foot. Insoles are used to evaluate and diagnose alterations on balance and body posture (Ravi, Dandekar & Mysore, 2005; Caldwell, Mcnair & Williams, 2003).

With the increasing focus on the relationship between the type of shoe and gait biomechanics, insole-based sensors represent a promising approach to studying the foot-shoe relationship on the runner's normal behavior on training environments (Dixon, 2008; Willy & Davis, 2014). Insoles are commonly used to prevent and treat injuries that incur from excessive use and aim to alter the movement biomechanics and absorb shock in order to reduce pain or the degeneration of musculoskeletal structures (Alfuth, 2017).

Pressure insoles are placed into the running shoes, and provide information about the vertical force exercised during walking for a limited time, providing a more truthful image of the plantar pressures during daily activities such as walking and running. Due to their portable nature, insoles can acquire information continuously, allowing specialists to draw more realistic conclusions about which areas the foot exercises higher pressure, increasing the level of reliability of their predictions (Martínez-Nova *et al.* 2007; Mann *et al.*, 2016).

The plantar pressure analysis that takes place during postural evaluations in both static and dynamic situations (through baropodometry, which evaluates the plantar pressure distribution during walking) provides the specialists with the necessary information to accurately develop insoles that reduce violent impact and risk of injury, improving the conform for the user (Ribeiro *et al.*, 2011). Sensory insoles can measure plantar pressure through their incorporated pressure sensors, with force-sensitive resistors (FSR). This is the main component used to map the distribution of pressure across the foot.

In order for the sensors to correctly measure pressure across the insoles, they must be placed on high-pressure spots (Tee *et al.*, 2017; Zhang *et al.*, 2019). These devices must interfere minimally in the function of the foot, and provide consistent data for clinical decisions (Hurkmans *et al.*, 2006; Putti *et al.*, 2007). Various studies have used plantar pressure measurement systems to analyze plantar pressures with different types of shoes (Soler, 2001; Duenas *et al.*, 2002; Alemany *et al.*, 2003), insoles (Sánchez-Rodríguez, 2006), plantar pressure variations (Escamilla-Martínez *et al.* 2020) and surgical treatments (Lafuente *et al.*, 2002).

There are several commercially available plantar pressure sensors based on capacitive, resistive, piezoelectric and piezoresistive sensors. These sensors provide electrical signal

output (tension or current) proportional to the measured pressure. The paramount specifications for the performance of the sensors include linearity, hysteresis, sensor size, and sensitivity to temperature (Razak et al., 2012).

The BioFoot® (IBV, Valencia, Espanha) and Pedar® (Novel, Munich, Germany) plantar pressure measurement systems are some examples of commercially available pressure sensors. These systems contain insoles connected to a signal amplifier, strapped to the user's hip, that emits data to a computer through digital telemetry. The digital telemetry system has a reach of 200m, which allows the users to move freely and enables measurements in sports fields. The system collects the measurements at a sampling rate between 50 and 250Hz. To obtain a safe result, multiple interactions of the test are necessary (Escamilla-Martínez *et al.* 2020).

The plantar pressure systems available in the market or research vary in sensor configuration, to satisfy different application requisites. The data acquired by these systems must be reliable and have good repeatability if it is intended for clinical or research purposes. This guarantees that specialists will base themselves on consistent measurements when making clinical judgments. To achieve this level of reliability, we need a consistent protocol that controls cadence and extracts the average of a large number of steps (Martínez-Nova et al., 2007).

Among the perks of the using of insole technology, we can avoid the need of covering an entire predetermined route to measure pressure, force and area of contact of each foot independently; acquiring the data for several rounds of every walking event, instead of the habitual one or two stages, as it occurs for the force platforms. This information is critical when evaluating gait quality (Ivanic, 2003). The reliability of the insole's plantar pressure measurements is fundamental for obtaining precise results. The high level of test-retest reliability of the insole devices during linear walking and running is well documented (Godí *et al.*, 2014).

In a study performed by Beltrán (2008) with 105 patients (male and female, between 18-60 years old) with postural problems that were re-evaluated after two months, the author observed that 91,57% of the patients had a decrease in pain and felt more comfortable with upright posture. The results indicate that exteroceptive insoles are appropriate to treat foot disorders and adapt global posture that reflects on the foot, as well as efficiently improve multidisciplinary treatment.

Gagey *et al.* (2012), Hijmans *et al.* (2008), and Priplata *et al.* (2012) reported improvements in balance and oscillation speed on the anteroposterior region with vibrating

insoles. These insoles have a mechanical noise that allows for auditory feedback, with a positive impact on postural stability (Christovão *et al.*, 2013). Tsung *et al.* (2004) evaluated the effectiveness of insoles on plantar pressure redistribution during walking for diabetic patients. The results show that flat insoles reduced the average peak pressure and increased the contact area throughout the entire foot in comparison to no insole. They have also verified a significant shift in the pressure over time relationships on the foot. Results showed that custom-fitted insoles are more effective than soft insoles.

Analyzing different variables such as traverse speed and pressure and balance center provides important information to improve comprehension of the many factors that influence running efficiency. Therefore, techniques that can precisely and efficiently measure foot pressure are vital for future developments, as well as developing sensory insoles for evaluating the implications of running on musculoskeletal alterations and postural adequacy. That is because alterations in physiological spatial relationships cause muscular imbalance and, consequently, adaptative changes to the new mechanical conditions.

#### **4. Conclusions**

This literature review shows that for the postural control to work efficiently, we need a complex interaction between motor and sensory components integrated by the central nervous system.

The ability to maintain balance and body stability is essential to avoid falling and aid in disturbance recoveries, especially for people who practice regular physical exercise, more specifically runners. Postural control is vital for monitoring health performance during sports activities in areas such as gait phase detection and speed acceleration performance.

The most commonly employed devices for this type of monitoring are classified as plantar pressure platforms and sensory insoles. Many studies discuss the existence of several commercially available pressure sensors with capacitive, resistive, piezoelectric and piezoresistive sensor technologies, along with the benefits of insole technologies, such as improvements in balance and speed rates in the anteroposterior region.



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