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REVIEW ARTICLE

Biomechanics of lateral movements: A review

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ABSTRACT

Lateral displacements are part of the so-called unusual patterns of human locomotion, a motor activity of great interest for the sciences of human performance, rehabilitation, engineering, and biomechanics. Sagittal plane displacements, abundantly studied, present mechanical and energetic differences, but also very similar muscular structures and synergies. The mechanical, energetic behavior and muscular synergies of lateral displacements in humans, on the other hand, are less well known. Studies that incorporate mechanical work, energy cost and muscular synergies simultaneously, would be of great contribution to give an integral answer to this modality of human locomotion. Given the identification of the absence, through a previous systematic review, of approaches that simultaneously incorporate these variables, this article aims to present an argumentative review of the literature, focusing on the mechanical and energetic aspects and the mechanical models of lateral displacements as part of non-habitual patterns of human locomotion. A better understanding of the determinants and mechanical models of lateral displacements is relevant to generate advances in their application in areas such as clinical rehabilitation, injury prevention, robotics, expenditure activities and performance in different sports, among others.
Keywords: Locomotion, Lateral movements, Mechanical work, Biomechanics, Energetics.

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INTRODUCTION

Human locomotion with displacement in the sagittal plane as primary, has been classically studied in controlled conditions, at different speeds and directions. (Saibene and Minetti, 2003). Walking and running allow progress in the sagittal plane by means of symmetrical phases repeated in time, both representing the usual patterns of locomotion. However, in everyday life, there are multiple challenges to be faced other than just sagittal displacements. Overcoming obstacles (Gilchrist, 1998), climbing and descending stairs, changes of direction, and lateral displacements in the workplace such as scaffolding and ramps (Chien, 2004), are some examples of other different patterns of human locomotion that incorporate different planes, among them, lateral displacements. Lateral locomotion, using the transverse plane as the primary plane, allows displacement facilitating adjustments in mobilization, movement in narrow places and accommodation of steps in motor actions to avoid obstacles, so it is relevant for rehabilitation purposes, therapeutic training and in a large number of sports disciplines such as basketball, volleyball, soccer and Parkour (Daneshjoo et al., 2013).

Studies regarding different intervening variables in lateral locomotion (Soangra and Lockhart, 2017; Iosa et al., 2019; Bloomfield et al., 2007; Yamashita et al., 2013; Chang et al., 2017), represent a significant contribution in the field, but the associations between different energetic (metabolic cost and performance) and mechanical (work and mechanical efficiency) parameters seeking a comprehensive view of the behavior and an applicability of the results for this type of locomotion still need to be deepened. An argumentative review is presented based on a previous systematic review that addressed topics such as: mechanical models of locomotion, energy cost, lateral mobilization patterns, activation control and coordination, variability, dual task and motor control in lateral gait and stability-maneuverability relationship in lateral steps among others. For the previous review, we considered articles containing metabolic and mechanical data from participants performing gait or side-step tests at different speeds. PICOT was used as a method of advanced question construction and multidimensional, specific, source and mixed databases for searches in PubMed (US National Library of Medicine. Free, biomedical area), ScienceDirect and EBSCO host, Boolean operators and, or, not and signs (""). A double-entry table was constructed with variables (lateral gait, metabolic cost, mechanical work, biomechanics and keywords and related terms. The keywords structured search combinations for review systematization. For the advanced search inclusion criteria we defined articles in English and Spanish, full articles, clinical trials, case-control studies, (review articles were excluded), only study in humans 18 years or older without restriction of publication date. On the selected titles, a full-text screening was performed following prism methodology guidelines. At the end of this process, no papers were identified that simultaneously considered mechanical work, energy cost and muscle synergies. A total of 4 articles that met the criteria and considered lateral displacements were considered. The hypothesis is raised that there are no studies that contain the variables of energy cost, mechanical work and muscular synergies simultaneously, which makes a comprehensive understanding of this type of mobilization difficult.

LATERAL GAIT AND MECHANICAL MODELS OF LOCOMOTION

Walking, running and galloping represent forms of locomotion that are explained under different mechanical models (Saibene and Minetti, 2003; Margaria, 1976; Margaria, Cerretelli, Aghemo, and Sassi, 1963). From the mechanical point of view, gait can be described with the inverted pendulum model (Margaria, 1976; Saibene and Minetti, 2003), Figura 1. where potential energy increases during the first stance phase and kinetic energy decreases. In the second stance phase, potential energy decreases and kinetic energy increases (Cavagna, Thys and Zamboni, 1976). Thus, kinetic energy and potential energy are in phase opposition, favoring an interconversion between them (Cavagna et al., 1963; Cavagna et al., 1976). The variations of potential and kinetic energy of the center of mass as a function of time determine the mechanical work and the level of "*pendulum*" exchange, or "*recovery*" (Cavagna et al., 1976). In walking, there is an intermediate speed where the exchange between kinetic and potential energy is maximum and consequently, the metabolic cost is minimum (Mian et al., 2006). On the other hand, with kinetic and potential energies varying in phase, the mass-spring mechanical model is representative of running, with the contribution of the elastic energy stored in the tendons (Blickan, 1989; McMahon and Cheng, 1990).

An intermediate mechanical model between walking and running, including a pendulum phase with double support, followed by an elastic ballistic phase, describes the bipedal gallop or *Skipping*, enunciated as a paradigm by Minetti (1998) as the third pattern of human locomotion. It is an asymmetric pattern where both limbs perform different functions, *trailing* and *leading* (landing and take-off) with high transport cost in relation to other locomotion patterns (Minetti et al., 2012; Pavei et al., 2015), so its use is reserved to particular situations (Saibene and Minetti, 2003).

The different biomechanical patterns of mobilization from walking to running are revealed as speed increases in forward locomotion, in a transition from a pendulum mechanism to a rebound mechanism according to the models analyzed. Maximum speed increments in walking are limited by the pendulum frequency. If the centrifugal force of the body exceeds gravity, the feet leave the ground (Minetti, 1998; Saibene and Minetti, 2003; Usherwood, 2005) and subjects switch from walking to running or jogging.

On the other hand, lateral gait increases support times in each lower limb. In populations such as amputees, children with cerebral palsy and people with sequelae of cerebral vascular accident, this locomotion modality, used as a training exercise, provides significant transfer contributions and improvements in the quality of frontal gait, even greater than those reported with backward gait (Yang YR, et al., 2005). The different contributions (physiological, kinematic and electromyographic) of this form of gait can help physical rehabilitation with an adequate program during the rehabilitation exercises.

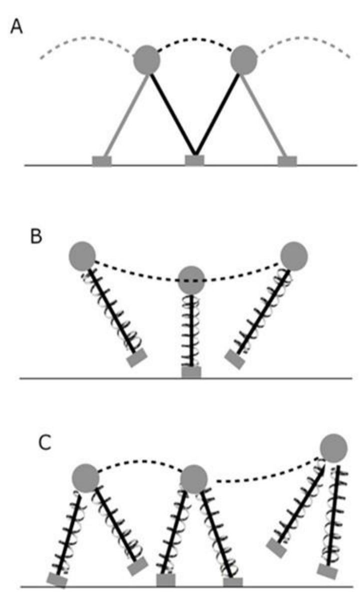

Figure 1. Mechanical models of walking (A: inverted pendulum), running and trotting (B: mass-spring), skipping and galloping (C: pendulum and spring). The gray circle represents the center of mass, and the dashed line its trajectory. Source Biancardi et al., 2020.

SIDESTEP WALKING AND ENERGY COST

Locomotion is undoubtedly an expensive activity, in terms of the metabolic energy used for the movement of the muscles involved: it is enough to see how the distribution of cardiac output changes at rest and during muscular activity to realize this fact. The energetic (metabolic) cost of locomotion within the aerobic sustainable range can be evaluated by measures of gas exchange (VCO2; VO2). The oxygen uptake and its energetic equivalent, the metabolic power, generally increase with speed within all gaits (Saibene & Minetti, 2003). However, the metabolic cost at different gaits and speeds is generally expressed as the cost of transport (COT; J/kg/m), the amount of energy necessary to move one unit mass one unit distance (Schmidt-Nielsen, 1972).

The plot of the COT of walking at different speeds displays a "*U*" shaped curve, with a minumim COT at the natural "*self selected*" speed of walking, which makes walking the most economic for of locomotion for humans (Saibene & Minetti, 2003).

In running, the COT is almost constant at any speed if we consider the aerobically sustainable range (Pavei et al., 2015).

The energetic cost of walking and running are generally lower than the cost of "*unusual*" gaits, such as bipedal galloping (Pavei et al., 2015; Pequera et al., 2023). It has been determined that walking and running backwards demands higher oxygen consumption, COT, metabolic response, cardiorespiratory and energy expenditure (Grasso et al., 1998; Adesola & Azeez, 2009).

Lateral displacements are used continuously in sports with random characteristics that require acyclic or intermittent movements such as soccer, basketball, volleyball, Parkour and other individual and collective sports. Repeated changes of direction increase the energetic cost (Minetti & Pavei, 2018) and the anaerobic fraction, with consequent increase in blood lactate concentration and fatigue in athletes.

Asymmetrical gait patterns, such as lateral gait, result in increased activity.

Analysis of metabolic and cardiovascular responses have demonstrated the higher energetic cost of side-stepping locomotion versus conventional forward locomotion in the sagittal plane at slow or fast speeds, walking or running. The energetic cost of lateral movements would be not significantly different from the energetic cost of backwards locomotion (Williford, et al., 1998).

Clearly there will be a close relationship between energy cost and mechanical energy saving and exchange models. However, energy cost is not the only determining factor in the choice of different gait patterns. Dynamic stability is also an important factor (Patla, 2003), which may in some cases put energy efficiency in the background (Minetti et al., 2012; Bona et al., 2017; 2019).

LATERAL MOBILIZATION PATTERNS

The biomechanical analysis of lateral mobilization patterns reflects that the lower limbs perform asymmetric tasks, assuming different roles and joint moment patterns (Kuntze et al., 2009), thus, unlike what occurs during forward locomotion, where both limbs are used symmetrically since they adopt a lateral location to the direction of movement, during gait or lateral steps, these are aligned forward and backward in the direction of the movement of displacement, with a single impulsive function performed by the hind limb. Given this relationship of limbs in the forward plane, in lateral gait, an asymmetrical gait pattern similar to the gallop or *skipping* with phases of support and flight like this is constituted (Minetti, 1998). Considering these functional and mechanical performances, the movement patterns generated in lateral mobilization as a result of increasing the speed of mobilization, it is understood that they will also be different from those of gait and running in the sagittal plane, as is well evidenced and can be seen from the results obtained on this subject in the work of Yamashita, 2013. In these studies, for preferential lateral locomotion gait patterns at incremental speeds, treadmill tests from 1.3 km/h to 6.1 km/h with increments every 20 s were performed. Three different lateral gait patterns were reported as preferred: At low speeds, a pattern characterized by a double stance phase without flight phases and symmetric foot contact rhythm could be observed in all subjects, in contrast to at high speeds, where two different types of locomotion are differentiated: in the first 13 out of 15 (87%) of the subjects showed double stance and flight phases and an asymmetric foot contact rhythm. Finally, only two of 15 subjects (13%), performed a lateral mobilization pattern in which there is a flight phase without the presence of a double support phase (Yamashita, 2013). The three patterns described turn out to be similar to walking, running and forward canter, while most of the participating subjects performed a lateral displacement pattern resembling a high-speed canter (Yamashita, 2013). Regarding the reported canter gait transition speeds, these present much lower values than those corresponding to traditional forward mobilization, standing at average values of 3.5 km/h (Yamashita, 2013) and those reported in other studies, 6.6 km/h (Terblanche et al., 2003), which could be explained by the fact that the stride length is limited in lateral gait when one limb is in front of the other if it is not allowed to cross the limbs as in the case of this protocol, with the consequent appearance of an early flight phase at slower speeds compared to mobilization in the sagittal plane.

An important issue to consider, from the point of view of the mechanical model of lateral movements, lies in the fact that the mechanisms of energy exchange and recovery of the inverted pendulum are verified only around the rear limb and not around the front limb, as in the case of sagittal plane gait, which would explain its energetic behavior. (Yamashita, 2013).

In lateral gallop, the distribution of shock absorption, propulsive force generation, vertical force and braking functions are performed separately by the hind and front limbs respectively (Yamashita, 2013).

From the point of view of the distribution of functions, in lateral locomotion, the limbs should be considered as front and rear with different roles as opposed to left and right as in the sagittal plane gait, establishing differences inherent to mobilization in different planes.

When analyzing the pattern of near-running locomotion with bouncing in the sagittal plane and in lateral locomotion, we again find significant differences. In the sagittal plane, both limbs perform functions of shock absorption, vertical force, propulsion and braking. When it comes to forward running with knee flexion and extension, both limbs can perform this function. In lateral locomotion, on the other hand, the described strategy does not prove to be as efficient and functional, since the knee joint has limited mobility in the direction of movement. The hip and ankle joints could compensate in this case the function of the knee joint (Yamashita, 2005). These considerations must be assumed and taken into account in the mechanical model of lateral displacements.

In summary, in lateral gait, the natural selection of the mobilization pattern will depend on the speed of movement. For the case of gallop-type lateral gait, the functions described for the limbs seem to be distributed between forelimb and hindlimb (Kuntze et al., 2009).

ACTIVATION CONTROL AND COORDINATION

Optimization of the control mechanisms of muscle activation and coordination is another important factor (Pequera et al., 2021). Despite the energetic and mechanical differences, in gait, running and canter the oscillations of the lower limbs are in the sagittal plane, and present a very similar modular structure of muscle activation (synergies), suggesting a possible unified pattern control center at the neural level (Cappellini et al., 2006; Pequera et al., 2021).

Knowing the relationships between the different parameters (physiological, mechanical and electromyographic) can contribute to the prescription of physical training for athletes (Bloomfield et al., 2007; Jana Fleischmann, 2011).

MOBILIZATION AND APPLICATION PATTERNS

Gait training in a different direction than usual, such as backward, has been used in rehabilitation to add to the benefits it presents in improving forward gait variables (Yang et al., 2005), as balance training, muscle strengthening and fall prevention measures (Falconer, 2012).

The comparative benefits of lateral gait training over backward gait in the rehabilitation setting have been reported in hemiplegic stroke, suggesting that its use in this group of people would represent even greater benefits than even backward gait (Yang YR, et al., 2005). These findings have been verified in 10 m walking tests, increased stride length, gait speed and decreased gait symmetry index and double support period, (Chang, et al., 2017) . Apparently, the protagonist participation of the adductor, abductor and hip extensor muscle groups in this lateral gait plane would be particularly significant in patients with hemiplegia and influence on limb synergy (Schmitz, 2001). Also, lateral gait would generate an increased muscle activation in proportion to the effort, demanding a better functional performance than conventional forward and backward gait. These results presented by lateral gait, which establish positive modifications on the variables of habitual forward gait, impact on patient rehabilitation times (Friedman, 1990) and improvements in gait symmetry, providing a clinically significant factor for recovery (Chang, et al., 2017). Hus, the assessment of gait performance and the use of clinic-specific tools make it possible to verify the impact of kinematic changes on functional gait modifications and the implications on modifications in motor control (Desmurget and Grafton, 2020).

Lateral gait on the other hand is especially useful in clinical rehabilitation for balance training, flexibility, body weight bearing training and for practicing postural regulation and adjustments in the transverse plane (Carr and Shepherd, 2010).

In the usual gait in the sagittal plane, the effort is developed in the direction of gait to progress the center of mass and avoid the effect of gravity, however, an important part of the work is performed on the transverse plane of the hip in relation to the stability of the pelvis and trunk, against gravity (Eng and Winter, 1995). The relevant role of the gluteus medius, not only in supporting the body, but also in propelling the body forward in the stance phase, has been verified by mathematical models (Liu, et al., 2006). In summary, lateral gait has evidence in the field of stroke neurological patient rehabilitation regarding benefits in improving locomotion skills in this group through a simple implementation strategy (Chang, et al., 2017).

Currently, lateral gait training is used with little evidence of its efficacy, for example, in clinical rehabilitation and sports therapy, lateral gait training is used to accomplish several objectives (Montoye et al., 1995) including its use as a strengthening exercise for the lateral hip and knee muscles, adductors and abductors (Williford, et al., 1998).

Notwithstanding, the contribution of the studies conducted in the area, further evidence must be.

The study also provides information on follow-up and long-term effects on different groups of interest, incorporating biomechanical parameters by means of controlled tests with electromyographic recordings, and direct quantitative data on the types of gait and planes used in question.

VARIABILITY, DUAL-TASKING AND MOTOR CONTROL IN LATERAL WALKING

Variability is a powerful biomarker of stability when people walk (Soangra and Lockhart, 2020). Increased variability has been linked to decreased motor control in older people (Buzzi et al., 2003) and an increase in the amount of support time variability was associated with a higher incidence of mobility disability in this group of people (Brach et al., 2007). Thus also an increase in gait variability in step time and step width as an indicator of fall has been reported (Hausdorff et al., 2001), (Owings and Grabiner, 2004). In summary, older people present, due to aging, an increased risk of falls which is correlated with changes in movement dynamics and variability. The management of passive mechanical behavior and active control depending on the forward or anatomical plane of gait will have fundamental implications in the elderly, as well as in different rehabilitation groups. Previous studies (O'Connor, Kuo, 2009) on lateral gait have shown less variability and also less involvement of active control of the central nervous system in the direction of progression. Soangra and Lockhart (2020) report as a result of their research, significant decrease in the complexity of the time series of stride intervals during lateral gait for both young and older adults, as well as a decrease in the complexity of the time series in lateral step gait. This loss of complexity, which depends on the nature of the intrinsic dynamics of the system and the capacity for short-term adaptive change required to meet the demand of a task, reduces the ability to adapt to stress with aging and disease (Lipsitz, and Goldberger, 1992).

Regarding direction-dependent stability control, anteroposterior gait achieves stability control based on passive dynamics mediated by mechanical constraints and spinal reflexes as opposed to stability in the transverse plane direction which is actively supported by supraspinal higher brain centers (O'Connor, and Kuo, 2009). The quantification of the structure of variability determined by the level at which values appear in a predictable manner determines its temporal organization, thus, it can be assessed as a greater or lesser ability to adapt to external perturbations.

It is also known that there is a strong relationship between fall risks, dual-task and gait changes in the elderly (Bloem, et al., 2003) (Verghese et al., 2002). It is then important to understand the dynamics of the relationships between dual-task, variability and direction of movement. Soangra and Lockhart report the loss of fractal properties in kinematic signals, which implies less neural control involved in the movement.

FRACTAL STRUCTURE OF MOBILIZATION AND LATERAL WALKING

Forward gait contains a repetitive and cyclic biomechanical pattern structure in which, at self-selected speeds, stance and swing phases retain their proportionality relationship in different mobilization contexts. It has been proposed that this symmetry is maintained between different motor activities (Burnett et al., 2011), but the behavioral dynamics of these proportionality relationships are almost nonexistent for other gaits such as lateral or backward gait.

Iosa et al. 2019, studied the behavior of the modifications of these support and swing phase relationships in different types of mobilizations such as, forward walking, backward walking, stair climbing and descending and lateral walking by Baropodometric assessment, finding a proportionality ratio between support and swing of 1.63 in comfortable forward walking, backward walking and stair descending, similar to the "*golden ratio*" of gait (1.618..) i.e. these mobilization modalities reflect the fractal structure of such ratio. Walking forward and backward have almost identical kinematics, although reversed in time. The aim of the study by Losa et al. (2019) was to measure possible differences in gait phases between different locomotor tasks and along these lines, significant differences were found for slow (p = .010), fast (p < .001) and lateral (p < .001) gait, as well as for stair climbing (p < .001) for the support and swing relationships. So also, the gait ratio resulted significantly different from the golden ratio for slow (p = .011) and fast (p < .001) gait, for lateral gait (p < .001), for stair climbing (p = .001), as well as for stepping in place (p = .034) (Burnett et al., 2011).

As previously reported, in lateral gait, the stance and swing phases have presented different proportion ratios to those of anterior gait, backward gait and stair descent. In lateral gait, average stance phases of 65.9% were found to be very different from those recorded in other forms of mobilization (Burnett et al., 2011). In this sense, the considerations are oriented in the direction that unlike forward or backward gait which are performed in the sagittal forward plane recruiting preferably flexor and extensor muscle groups, lateral gait is performed in a transverse plane, using abductor and adductor musculature preferentially and that eventually, this form of mobilization, responds less directly related to the inverted pendulum model of conventional forward gait, dependent on the isochronism of the pendulum and its relation to the proportionality of the body segments (Iosa et al.,2019). It is worth recalling again at this point, the work of Chang (2017), regarding training in hemiplegic stroke patients using lateral gait that showed beneficial effects over conventional gait in the sagittal plane. Resulting in a direct application of lateral gait for the gait usually used, forward.

The behaviors of the different forms of mobilization exposed in the preceding studies, particularly Iosa et al. (2019) also add explanatory foundations from the energetic aspects. Climbing stairs represents the motor task with the highest energetic cost of those analyzed because it is probably more distant from the pendular and energetic recovery models of conventional gait, while the ideal (golden) gait described at self-selected speeds is representative of the lowest energetic costs. Finally, lateral mobilization represents a less habitual and predictable task (Fusco et al., 2014).

STABILITY-MANEUVERABILITY RATIO IN LATERAL PASSAGES

The use of conventional gait in the sagittal plane in daily activities includes changes of direction and lateral maneuvers to overcome obstacles (Glaister et. al., 2007).

The modifications produced on the behavior of maneuverability, stability and energy requirements in gait maneuvers with different lateral foot positioning have been studied (Acasio et al., 2017). An attempt has been made to determine the impact and relationship between varied mid-lateral positioning of the push-off foot, with cross to lateral steps and its relationship with maneuverability and stability. The results indicate that as the step width of the push-off leg increases in the induced maneuvers, the lateral margin of stability, joint work and maximum lateral impulse increases. On the other hand, it has been verified that when the maneuvers have not been induced or anticipated and there is freedom to determine the mediolateral foot placement, the preferred position of choice is one intermediate between the extreme mediolateral positions. This reported evidence suggests biomechanical trade-offs where, during anticipated maneuvers, people select foot placement strategies that allow them to balance stability, actively generate impulses, and minimize mechanical energy costs (Acasio et al., 2017). Different combinations of foot placement selection in the transverse plane can occur to modulate gait and position the body center of mass in this plane (Vallis and McFadyen, 2003; Paquette et al., 2008).

Since passive stability and maneuverability are in inverse relationship, adopting strategies that determine stable gait mechanics will hinder maneuverability (Dickinson et al., 2000), so greater impulses must be generated to execute different types of maneuvers. In situations where stability and maneuverability are required as prerequisites to develop certain motor tasks, subjects should generate gait patterns that allow greater impulses and stability to maintain control (Wu et al., 2015; Hak, et al., 2013). Thus, the selection of strategies that increase the width of support will increase stability and performance in the transverse plane and those gait patterns that tend to favor maneuverability through impulsive efforts will have a consequent increase in energy cost (Lyon and Day, 1997). In accordance with these relationships, studies by Acasio et al., (2017) show that the total work of the lower extremity joints in the sagittal and frontal planes was significantly higher during *step out* and lower during step *in*. In agreement also with previous studies by Rankin et al. (2014) and Dean and Kautz, (2015) which point to the mechanical state of the supporting limb as a strong predictor of mediolateral placement of the swinging limb. The lateral limit of stability of the preparation limb decreased when the mediolateral placement of the pushing limb was narrower. The reduction of the lateral limit of stability of the preparation step turns out to be favorable in terms of reducing the passive resistance to lateral impulses made in the direction of the maneuver, as part of anticipatory adjustments to changes in direction and decreasing the lateral limit of stability by modulating and anticipating maneuvers in the direction. Patla et al. (1991) already reported on the advantage of the line of action of force in the extensor muscle groups.

The Acasio 2017 stability and maneuverability reports evidenced a significant increase in the total mechanical energy of the thrust limb as the step width progressively increased, a condition that could have been related by the conditional request to perform the maneuvers at maximum execution speed.

In summary, the weighing of advantages and disadvantages of stability and maneuverability during gait considers biomechanical factors related to passive stability, force input required for maneuvering, and mechanical energy requirements. Stability and maneuverability are not independent factors, but are closely related to the maneuvers performed in laterally directed gait.

CONCLUSION

The objective of this article was to present a review of the literature, which discusses aspects fundamentally associated with the mechanics, energetics and other aspects of lateral displacements, comparing their behavior with the different existing mechanical patterns and models of human locomotion. It is important to review concepts, analyze studies, existing evidence and explain the different parameters that serve to understand lateral displacements as a form of locomotion and to understand future research.

Lateral displacements that develop in the transverse plane as the primary plane, whether in the form of steps, gallop or lateral running, are part of the so-called non-habitual patterns of human locomotion. Important advances and significant contributions have been made in this area, but there are still many elements to be evaluated, such as kinematic parameters (contact times or *duty factor*), cycle times and frequency, distance traveled per cycle, trajectory of the center of mass, kinetic and potential energies, mechanical work, transport cost, estimation of mechanical efficiency of lateral displacements, among others.

On the other hand, determining the synergy modules and their temporal patterns in each limb would be relevant, where it would be expected that the *trailing* and *leading* synergies would be different from each other. Lateral displacement synergies would be expected to be different from those of anteroposterior displacements due to a greater performance of the abductor and adductor muscles.

In conjunction and simultaneously with the above, analysis of electromyographic signal magnitudes and frequencies to determine fiber type contribution would be significant from a sports and clinical performance standpoint.

Finally, a systematic review prior to this article was carried out by the authors to present the existing evidence in relation to lateral displacements; as a result, the lack and need to formulate research studies that consider in a unified manner the kinematics, energetics and mechanics of lateral mobilization patterns, in order to record and contrast with objective data, the behavior of this type of locomotion, is evident. Studies that simultaneously incorporate mechanical work, energy expenditure and muscular synergies will be of great contribution to give an integral answer to this modality of human locomotion. Probably due to the challenge of equipment and technological and human resources that this implies, there are no studies with these characteristics in this subject as if they were identified for the usual locomotion patterns. This is probably a pending challenge for the laboratories and researchers that have contributed and will continue to contribute so much to knowledge in this area.

AUTHOR CONTRIBUTIONS

Luis A. Parada: conceptualization, formal analysis, project administration, writing – original draft, writing – review and editing. Renata L. Bona: conceptualization, project administration, view, methodology, supervision. Carlo M. Biancardi: conceptualization, formal analysis, project administration, software, view, methodology, supervision.

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