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[Bernard Delalande](#) *

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Article

Step by Step: The Forefoot as Natural Norm of Human Gait

Bernard Delalande 

Physiotherapist, 280, avenue de la Pierre Dourdant, 38290 La Verpilliere, France; bernard@somasimple.com

Abstract

The heel-strike (HS) paradigm of human gait originates from 19th-century chronophotographic studies conducted on Georges Demeny, a gymnasium instructor whose performed, exaggerated gait was never representative of natural locomotion. A compounding martial bias further normalised HS through military marching drill. A multi-disciplinary convergent argument analysis is conducted, integrating philological, zoological, anatomical, biomechanical, neurological and socioeconomic lines of evidence. All seven lines of argument support a forefoot-first model in which the centre of mass (CoM) leads the movement, stabilisers control equilibrium proactively, and the *Triceps surae* works in continuous eccentric mode—its natural functional state. Heel-strike generates impact forces up to 700 N with an ascending braking vector, under-recruits *Gluteus maximus*, progressively impoverishes plantar mechanoreceptors, and transmits repeated microtraumatic impulses up to the brain. Natural human gait is organised around forefoot contact, progressive CoM advance, and continuous eccentric stabiliser activity. The proposed model rediscovers **lightness**: a dance with gravity rather than a war against it. The HS paradigm is a culturally conditioned artefact with measurable pathological consequences for joints, the lumbar spine, and beyond.

Keywords: human gait; forefoot strike; heel strike; centre of mass; Triceps surae; eccentric contraction; biomechanics; physiotherapy; osteoarthritis prevention; plantar mechanoreceptors

1. Introduction

At the turn of the twentieth century, the Station Physiologique in the Bois de Boulogne became the world's first instrumental laboratory of human movement analysis. Étienne-Jules Marey developed chronophotography there and his collaborator Georges Demeny served as the principal experimental subject [9,10]. The resulting imagery formed the implicit reference for the dominant heel-strike (HS) paradigm of human gait.

A fundamental methodological limitation has been largely overlooked: Demeny was a *gymnasium instructor*, fully aware that he was being filmed. Such a subject invariably produces a gait exaggerated in its amplitudes—not representative of natural locomotion. This *gymnast bias* is compounded by a *martial bias*: HS was institutionalised by infantry battalions for collective synchronisation, not on biomechanical grounds.

The present article proposes a reassessment of the HS paradigm through seven convergent lines of argument. The central thesis: natural human gait is organized around forefoot contact, progressive CoM advance, and continuous eccentric stabilizer activity. This model does not oppose gravity—it **plays** with it.

2. Theoretical Framework and Lines of Argument

2.1. Biomechanical Vector Analysis

The ground reaction force (GRF) analysis provides an objective comparison of the two models [2]. In HS, initial contact generates a braking force peak approaching 700 N. The foot is placed far anterior to

the vertical projection of the CoM, while the heel, always posterior to the ankle, absorbs the impact. This configuration generates a *posterior* (braking) horizontal force component. This discontinuous vector propagates through the ascending articular chain: ankle, knee, hip, lumbar spine, and, accumulated over millions of cycles, **brain** [1,2].

In the forefoot model, the GRF is initially near zero and increases progressively as the CoM advances. The resultant vector is propulsive [4]. No impulse peak. Energy is absorbed and returned by the plantar arch, the musculotendinous complex, and the Achilles tendon. The model significantly reduces vertical CoM excursion [7]: a near-uniform translation rather than a costly vertical sinusoid.

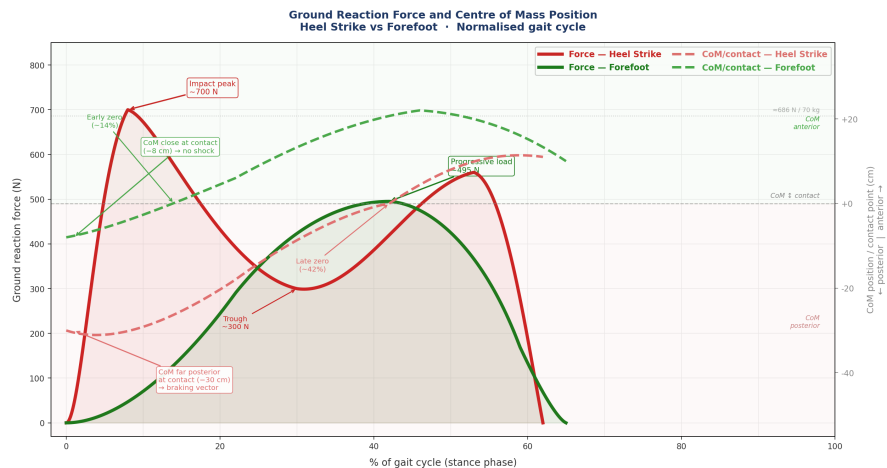


Figure 1. Ground reaction force (solid lines, left axis) and centre of mass position relative to the contact point (dashed lines, right axis) during the stance phase, expressed as a % of the gait cycle. Under heel strike, the CoM is far posterior at peak impact (≈ 700 N, -30 cm): the resultant vector is braking. Under forefoot gait, force and CoM advance are in phase (≈ 495 N, zero crossing at ≈ 14 %): the resultant vector is propulsive. Curves are schematic, drawn with Bézier functions from normative literature data.

2.2. Philological Argument

From Old French *marchier*, "to strike or press the ground downward," the concept of walking was originally understood as a vertical, active downward thrust, not a heel-to-toe roll. Horizontal progression is the mechanical resultant, not the conceptual origin. Pre-industrial cultures conceptualized walking as active downward loading, consistent with forefoot contact.

2.3. Zoological Argument

high-performance mammal does not strike the heel during active locomotion. Digitigrade species (*Felidae*, *Canidae*, *Equidae*) and plantigrade primates in active bipedal posture contact the ground through the forefoot or midfoot [1]. The classification of *Homo sapiens* as plantigrade indicates that the full plantar surface *can* contact the ground, not that heel initiation is the functional norm.

2.4. Anatomical Argument

The distal insertions of the primary ankle stabilizers all converge in the forefoot and midfoot, not in the calcaneus (Table 1). These tendons *pass behind the malleoli*, acting as pulley systems. Their mechanical efficiency is maximal with the **heel raised**. Under heel strike, this pulley system is neutralized: stabilizers arrive in reactive catch-up mode, out of phase with their natural activation sequence.

Under heel strike, *Gluteus maximus* – the primary hip extensor and frontal-plane pelvic stabilizer –is sub-optimally recruited: the impact phase desynchronizes its activation relative to the CoM progression cycle. Under forefoot gait, it is recruited early and coordinately. Its chronic under-recruitment under HS provides a direct mechanistic explanation for the high prevalence of lumbar pain: the lumbar spine assumes stabilizing loads that *Gluteus maximus* should absorb.

Table 1. Distal insertions of ankle and foot stabilising muscles.

Muscle	Insertion at foot	Malleolar passage	Forefoot
<i>Tibialis anterior</i>	1st cuneiform + base 1st metatarsal	Anterior to ankle	✓
<i>Tibialis posterior</i>	Navicular + cuneiforms	Behind medial malleolus	✓
<i>Fibularis longus</i>	Base 1st metatarsal (plantar)	Behind lateral malleolus	✓
<i>Fibularis brevis</i>	Base 5th metatarsal	Behind lateral malleolus	✓
<i>Flexor hallucis longus</i>	Distal phalanx hallux	Behind medial malleolus	✓
<i>Flexor digitorum longus</i>	Distal phalanges 2nd–5th	Behind medial malleolus	✓
<i>Extensor hallucis longus</i>	Distal phalanx hallux (dorsal)	Anterior to ankle	✓
<i>Extensor digitorum longus</i>	Phalanges 2nd–5th (dorsal)	Anterior to ankle	✓
<i>Triceps surae</i>	Calcaneus	Direct — no pulley	—

8 of 9 muscles achieve maximal mechanical efficiency with the heel raised. The *Triceps surae*, inserting solely on the calcaneus, is optimised in forefoot loading for its role as eccentric brake on tibial advance—not as a simple propulsive actuator.

The Achilles tendon functions as an elastic energy storage and return spring [7], a mechanism optimal under forefoot loading. Under heel strike, it is mechanically bypassed in its propulsive function.

2.5. Physical Argument — Ascending Constraint Chain

At 6,000–8,000 steps per day, even a modest mechanical excess per step accumulates into millions of microtraumatic events [2].

Ascending constraint chain under heel strike: (1) tibiotalar joint—partial absorption by ligamentous and capsular complex; (2) femorotibial compartment—compression amplified by quadriceps contraction; (3) coxofemoral joint—axial compression and shear, with under-recruitment of *Gluteus maximus*; (4) lumbosacral segment L4–L5, L5–S1—residual absorption by intervertebral disks and facet joints; (5) thoracic and cervical spine—attenuated propagation through vertebral curvatures; (6) brain—repeated accelerations of the cerebral mass, cumulative microtrauma over millions of cycles. This pattern is **entirely absent** from the forefoot gait.

2.6. Empirical Validations

Classical dance and martial arts universally adopt the forefoot guard: the only configuration that allows instant multidirectional response.

Tightrope walking: heel contact on a cable is mechanically impossible. The forefoot system with eccentric *Triceps surae* is the only one available—and sufficient to cross a cable at height [1].

Backward walking: heel strike is mechanically excluded. The CNS retrieves the forefoot pattern instantly and without conscious instruction—direct evidence that the natural motor program is intact, merely inhibited. A first-line rehabilitative tool.

Descent in unstable terrain: heel strike generates a horizontal component that destabilizes stones. The forefoot creates an essentially vertical force that *locks* the stone. The same physics as ski carving.

Ontogenesis: the child learning to walk spontaneously adopts the forefoot pattern, without instruction [4]. This program is progressively inhibited by rigid-soled footwear.

Unshod populations: significantly lower rates of lower-limb osteoarthritis compared to shod Western populations [4].

High-heeled shoes: forced forefoot load in *captive* mode – documented increased valgus moment at the knee [8]. Confirms that the *free* forefoot is the prerequisite for biomechanical efficiency.

The child on the kerb: walks in perfect forefoot balance along the edge of a pavement. The parent warns: “careful, you will fall”—thereby revealing that the parent has lost this very capacity. Cultural transmission of motor pattern degradation enacted in commonplace exchange.

3. The Conceptual Reversal: CoM, Stabilisers, Forefoot

The proposed model is based on a three-phase mechanical sequence:

Phase 1 — Forefoot contact: the forefoot contacts lightly, without impact, while the CoM remains posterior. Exploratory, adaptive contact. No shock force transmitted to the proximal structures.

Phase 2 — CoM advance: progressive loading, increasing ankle dorsiflexion. *Triceps surae* resist tibial advance in eccentric mode—eccentric contraction by definition.

Phase 3 — Continuous regulation: stabilizers act proactively and anticipatorily. *Triceps surae* is a CoM progression regulator—not merely a propulsive actuator.

This model inverts the classical causal logic: the foot does not initiate movement—the CoM organises it. The foot is its distal expression.

4. Trunk and Upper Limbs: Three-Dimensional Co-regulation

Human gait is not a purely sagittal lower-limb phenomenon—it is a three-dimensional co-regulation involving the pelvis, spine, and arms.

Upper limb swing, in counter-phase with the lower limbs, generates segmental counter-rotation that reduces global angular momentum around the vertical axis and unloads the stance limb through temporal offset.

Smartphone use during walking constitutes a clinically significant disruption: arms immobilized, three-dimensional co-regulation suppressed, lumbar loading increased. An underestimated contemporary risk factor.

5. The *Triceps Surae* in Eccentric Mode

Eccentric *Triceps surae* strengthening is a well-established therapeutic recommendation in Achilles tendinopathy (Stanish–Curwin protocol [5]; Alfredson heavy-load protocol [6]), chronic ankle instability, and plantar fasciitis.

The proposed model provides the direct explanation: as the CoM advances over the forefoot, the ankle enters progressive dorsiflexion. *Triceps surae* resists tibial advance by braking—eccentric contraction by definition. It is fundamentally a CoM progression regulator, not a simple propulsive actuator. Eccentric protocols retrain the muscle in this natural role that the heel-strike gait has progressively withdrawn from it.

6. Neurological Dimension

6.1. Plantar Sensory Impoverishment Through Footwear

The plantar surface concentrates Meissner’s corpuscles, Pacinian corpuscles, Ruffini endings, and Merkel’s disks. Footwear progressively deprives these mechanoreceptors of stimulation. By activity-dependent plasticity, plantar discriminative sensitivity is reduced: nociception becomes the dominant signal [4]. Children walk painlessly on gravel; adults who have worn shoes since childhood experience immediate pain.

6.2. The Orthotic Paradox

Foot orthoses add a further layer between the foot and the ground, aggravated by the plantar sensory impoverishment they are intended to compensate. They do not address the primary cause: the loading pattern.

6.3. Toe-Walking Labelled Pathological

A child spontaneously walking on the forefoot manifests the species' natural motor program. Correcting towards HS means imposing a cultural norm over a natural one. A clinically and ethically significant reversal.

7. Rehabilitation and Prevention Implications

7.1. Plantar Sensory Re-Education

Barefoot walking on varied surfaces, progressive exposure to gravel, stimulation of textured ground. Goal: restoration of plantar sensory richness—a prerequisite for postural re-organization.

7.2. Backward Walking

A first-line rehabilitative tool: compels the CNS to retrieve the forefoot pattern automatically. Progressive integration—flat ground, then gentle slope—for effective motor reprogramming.

7.3. Proprioceptive Training

Balance boards should be used in forefoot loading position with CoM slightly anterior—not in flat-foot stance as currently practised. This distinction activates the primary stabilizing system rather than the compensatory one.

7.4. Eccentric Triceps Surae Strengthening

Stanish–Curwin [5] and Alfredson [6] protocols: mechanistic rationale now explicit within the proposed model.

7.5. Progressive Jump Protocol

The jump constitutes the most complete expression of the natural forefoot loading pattern. The correct technique rests on a single principle: **propulsion from the rear leg and landing on the forefoot**. At take-off, the rear leg extends the hip and ankle, fully engaging *Gluteus maximus* and *Triceps surae* concentrically. At landing, the forefoot receives the CoM as it continues to advance: *triceps surae* immediately enters eccentric mode to brake tibial advance, the plantar arch flattens as a spring, and the ankle stabilisers activate in real time to orient the CoM.

This propulsion–flight–landing pattern is identical across all three planes: antero-posterior, lateral, and diagonal. Recommended progression: in place → antero-posterior → lateral → diagonal → combined multidirectional. Each direction engages a different combination of stabilizers and calibrates plantar mechanoreceptors throughout the full spatial range.

8. Socioeconomic Dimension

In France, approximately 113,000 total knee arthroplasties and 165,000 total hip arthroplasties (~115,000 for coxarthrosis) are performed annually. The mean TKA cost is approximately EUR 7,000. Chronic low back pain is the leading cause of long-term work incapacity in Europe.

If even a modest fraction of these pathologies is related to a mechanically pathogenic gait pattern, the economic implications of gait-correction-based prevention are considerable. The cost-effectiveness ratio of preventive intervention is incomparable to that of arthroplasty.

9. Discussion

The present analysis does not deny that heel-strike exists as a locomotor pattern; it questions its status as a biological norm. A pattern can be common without being optimal; widespread without being harmless. The HS paradigm has been naturalized through a combination of methodological artifact, cultural bias, and confirmation momentum in the literature.

The philosophical dimension deserves emphasis. The HS paradigm is *military* in its origin—*strike, impact, attack*. Our model rediscovers **lightness**: a partnership with gravity rather than a war against it. The CoM glides. The stabilizers play.

Deep motor re-education requires time, patience, and above all—**play**. Not performance: play. The child on the kerb is not optimising. She is playing. And in playing, she does exactly what biomechanics recommends.

Let us be children again.

Limitations: theoretical and argumentative analysis; no original experimental data. The article constitutes a convergent argument framework that calls for a targeted empirical investigation.

10. Conclusions

The reviewed evidence supports the hypothesis that natural human gait is organized around forefoot contact, progressive CoM advance, and continuous eccentric stabilizer activity. The heel is a rest support and emergency damper—not a locomotor initiator. This conceptual reversal has direct implications for ankle proprioceptive rehabilitation protocols, lower limb osteoarthritis prevention strategies, and the integration of gait pattern assessment into the follow-up of patients at articular risk. Controlled studies are needed to validate these clinical hypotheses.

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