# Comment on: "Is Motorized Treadmill Running Biomechanically Comparable to Overground Running? A Systematic Review and Meta-Analysis of Cross-Over Studies"

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LETTER TO THE EDITOR

# Comment on: "Is Motorized Treadmill Running Biomechanically Comparable to Overground Running? A Systematic Review and Meta-Analysis of Cross-Over Studies"

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Dear Editor,

We read with great interest the recent article *Is Motorized Treadmill Running Biomechanically Comparable to Overground Running? A Systematic Review and Meta-Analysis of Cross-Over Studies* by Van Hooren et al. [1], and we compliment the authors on providing an overview of the biomechanical comparison between motorized treadmill (MT) and overground running. Although other studies on differences in running biomechanics on a MT have been published [2–5], a systematic review was timely, due to the extensive use of MT running in training, research and in clinics. However, we believe that further considerations of the technical specifications of the MT could offer some valuable insights to better understand the biomechanical differences with overground running. For example, within the authors' arguments, differences in MT stiffness may be partly responsible for the reported biomechanical difference observed with overground running. Therefore, the authors suggest future research to assess surface stiffness [6] and match it between running conditions. Another critical factor presented in the current study may contribute to the observed biomechanical differences: the belt-speed variations [4, 7–10], which depends on technical specifications of the MT [11]. Despite the potential importance of this aspect, the authors do not suggest any perspective to take into account this factor in future studies.

Accordingly, we wish to take this opportunity to shed light on the potential effect of the intra-stride belt-speed variability on the biomechanics of running particularly, to the difference in the braking/pushing phases of running. To do so, we have re-analysed the data of Dewolf et al. [12, 13] considering the instantaneous velocity of the belt.

The fore-aft ground reaction force ($F_f$) and the instantaneous speed of the belt ($V_{belt}$) were measured (Fig. 1a) while running from 0.27 to 5.5 m s$^{-1}$. $V_{belt}$ did not change by more than 5% of the average speed of the belt over one stride ($\overline{V}_{belt}$). In the fore-aft direction, the power spent by the subject on the belt or by the belt on the subject ($P_{belt}$) and the energy ($E_{belt}$) due to the variations of the belt speed can be computed as:

$$P_{belt} = -F_f\left(V_{belt} - \overline{V}_{belt}\right) \text{ and } E_{belt} = \int P_{belt} dt.$$

The positive and negative work done each step can then be computed as the positive and negative increments of the $E_{belt}$ ($W^+$ and $W^-$, respectively). When running on a MT, $P_{belt}$ is mainly positive and $E_{belt}$ generally increases with time, meaning that the runner performs positive work against the belt (Fig. 1b). When the velocity of the belt is considered as constant, as in most of the studies comparing the biomechanics of overground and MT running cited in [1], the positive work done to sustain the fore-aft motion of the center of mass (i.e., the propulsion) is underestimated (Fig. 1c). This positive work, $W^+$, increases with running speed. Furthermore apart from fast running speeds where the belt performs some work on the runner ($W^-$), the net work ($W_{net}$) done at all running speeds can be approximated by $W^+$.

This additional $W_{net}$ done against the belt, which does not exist during overground running, may partly compensate the supplementary work done against air resistance overground

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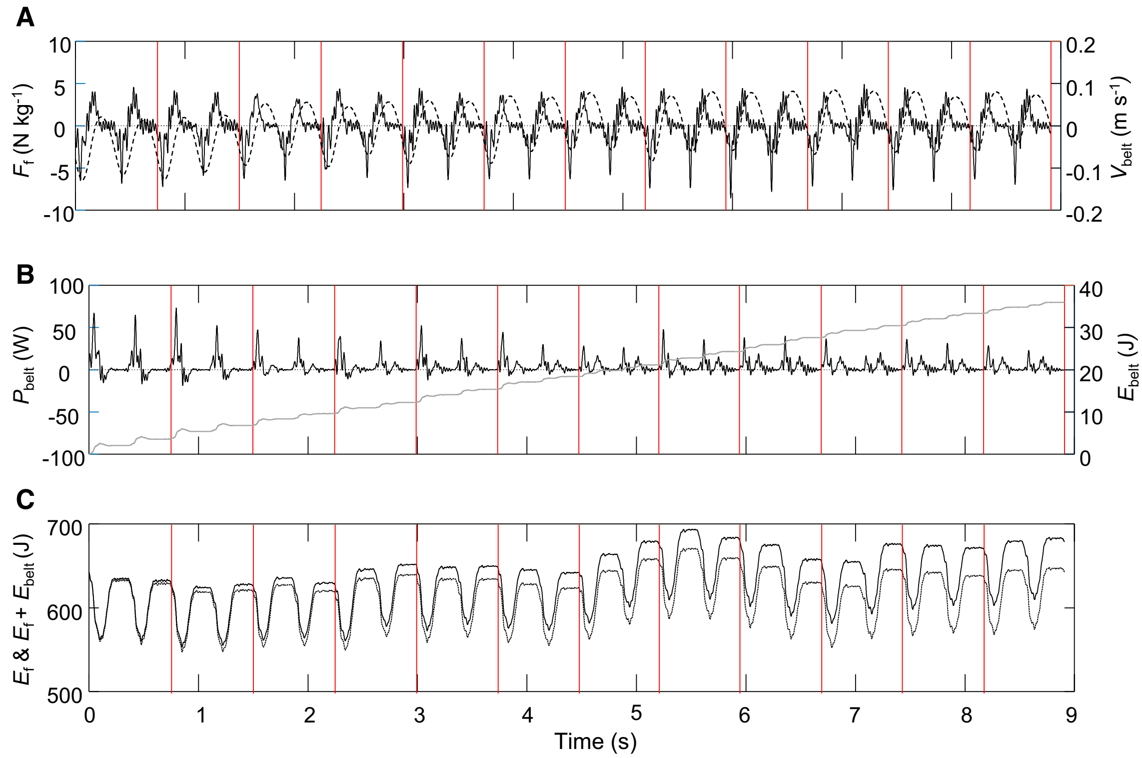


**Fig. 1** Typical time traces of a subject running at ~ 3.6 m s$^{-1}$ on a motorized treadmill. **a** Fore-aft component of the ground reaction force ($F_f$—black continuous line) and the instantaneous velocity of the belt ($V_{belt}$—interrupted line). **b** Power spent by the subject on the belt or by the belt on the subject ($P_{belt}$—black line) and the energy due to the variations of the belt speed ($E_{belt\text{–}grey\ line}$). *c* Kinetic energy of the COM ($E_f$) with and without taking into account the speed-belt variation (continuous and interrupted lines, respectively). In each plot, the vertical red lines correspond to a right-heel strike

[14, 15]. However, a major difference with air drag is that $P_{belt}$ is not constant throughout the step (Fig. 1b). Indeed, apart from small modifications of body surface, the drag is about the same during the brake (when $F_f$ is negative) and propulsive (when $F_f$ is positive) phases. When $W^+$ is divided into the work done against the belt during the brake ($W^+_{brake}$) and during propulsive ($W^+_{push}$) phases, a considerable imbalance is observed (Fig. 2). For comparison with recent data [16], $W^+_{push}$ and $W^+_{brake}$ were computed per kg of body mass over 30 min of running through an estimation of the average energy loss per running cycle (Fig. 2). The majority of $W^+$ is done during the braking phase, *i.e.*, when the runner is decelerating himself forwards, part of his work is done to decelerate the belt (in other words, this energy is lost). In addition to the lack of air resistance during MT running, the small $W^+_{push}$ may hardly contribute to the reduced propulsion observed on a MT [17].

This modification of the push vs. brake phases (so-called 'landing–takeoff asymmetry' [12, 18–21]), may significantly affect the biomechanics of running on a MT. Recently, Cheung et al. [16] have observed a hysteresis in the center of mass force–displacement curve between the brake and the push phase. By comparing elite and novice runner during MT running, these last authors have estimated a loss of energy of approximatively 0.9 kJ kg$^{-1}$ over 30 min of running in elite runners and of 1.3 kJ kg$^{-1}$ in unexperienced runners (extrapolated to match their running speeds). The difference observed here due to the belt is about two times greater, confirming that $E_{belt}$ should affect the biomechanics of running. Indeed, as speculated by Cavagna [22], a landing–takeoff asymmetry reflects a deviation from an elastic rebound, in turn inducing a smaller running efficiency (e.g., when running on sand, deviation from elastic rebound results in a higher oxygen cost of running [23, 24]). In addition, such landing–takeoff asymmetry has already been associated with a reduction of lower-limb stiffness [13, 20, 25].

While Van Hooren et al. [1] thoroughly discuss the differences in surface stiffness as partly responsible for the reported biomechanical differences between MT and overground running, we argue here that the (relatively small) kinetic and kinematic differences could also partly be explained by a greater landing–takeoff asymmetry. As for the stiffness, this asymmetry will depend on technical specifications of the MT [11]. For example, slightly different results were observed on a low-cost fitness treadmill [26].

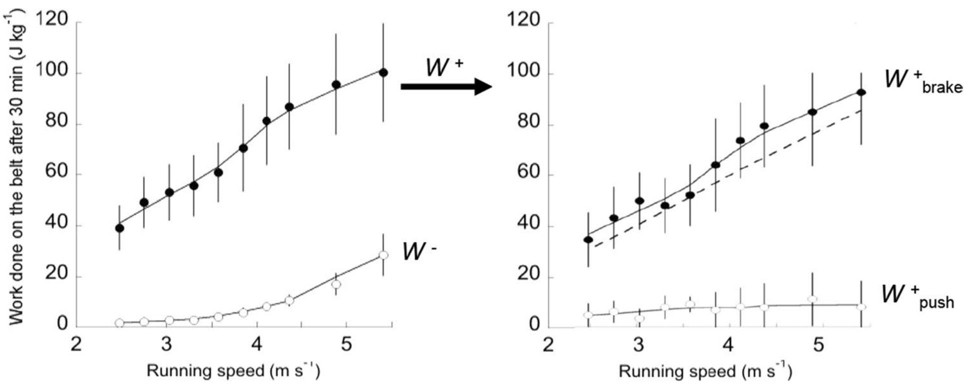


**Fig. 2** Positive and negative work done on the belt. Left—the mass-specific positive (closed symbols, superscript +) and negative (open symbols, superscript −) mechanical work done again the belt each stride is given as a function of running speed. Right—the mass-specific positive mechanical work done again the belt is divided in $W^+_{\text{brake}}$ (closed symbols) and $W^+_{\text{push}}$ (open symbols), the work done to decelerate or accelerate the belt, respectively. The interrupted line represents the net work done ($W^+$–$W^-$). In each plot, symbols and bars represent the grand mean of the subjects and the standard deviations (when the length of the bar exceeds the size of the symbol). The continuous lines were drawn through the experimental data (weighted mean, Kaleidagraph 4.5)

In addition, it is worth stressing that this asymmetry will be even more pronounced on an inclined MT, since the vertical forces will also generate a power against the belt). We, therefore, suggest that researchers, clinicians and athletes assess the belt-speed variability and take it into consideration to understand and anticipate the biomechanical differences between MT and overground running.

## Compliance with Ethical Standards

**Conflict of interest** All authors disclose that they do not have any financial and personal relationships with other people or organizations that could inappropriately influence (bias) their work.

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## References


1. Van Hooren B, Fuller JT, Buckley JD, Miller JR, Sewell K, Rao G, et al. Is motorized treadmill running biomechanically comparable to overground running? A systematic review and meta-analysis of cross-over studies. Sports Med. 2020;50:785–813.
2. Milgrom C, Finestone A, Segev S, Olin C, Arndt T, Ekenman I. Are overground or treadmill runners more likely to sustain tibial stress fracture? Br J Sports Med. 2003;37:160–3.
3. Elliott BC, Blanksby BA. A cinematographic analysis of overground and treadmill running by males and females. Med Sci Sports. 1976;8:84–7.
4. Nigg BM, De Boer RW, Fisher V. A kinematic comparison of overground and treadmill running. Med Sci Sports Exerc. 1995;27:98–105.
5. Willy RW, Halsey L, Hayek A, Johnson H, Willson JD. Patellofemoral joint and achilles tendon loads during overground and treadmill running. J Orthop Sports Phys Ther. 2016;46:664–72.
6. Colino E, Sánchez-Sánchez J, García-Unanue J, Ubago-Guisado E, Haxaire P, Le Blan A, et al. Validity and reliability of two standard test devices in assessing mechanical properties of different sport surfaces. Polym Test. 2017;62:61–7.
7. Frishberg BA. An analysis of overground and treadmill sprinting. Med Sci Sports Exerc. 1983;15:478–85.
8. Schache AG, Blanch PD, Rath DA, Wrigley TV, Starr R, Bennell KL. A comparison of overground and treadmill running for measuring the three-dimensional kinematics of the lumbo-pelvic-hip complex. Clin Biomech (Bristol, Avon). 2001;16:667–80.
9. Kram R, Griffin TM, Donelan JM, Chang YH. Force treadmill for measuring vertical and horizontal ground reaction forces. J Appl Physiol. 1998;85:764–9.
10. Sloot LH, Houdijk H, Harlaar J. A comprehensive protocol to test instrumented treadmills. Med Eng Phys. 2015;37:610–6.
11. Savelberg HHCM, Vorstenbosch MATM, Kamman EH, van de Weijer JG, Schambardt HC. Intra-stride belt-speed variation affects treadmill locomotion. Gait Posture. 1998;7:26–34.
12. Dewolf AH, Willems PA. Running on a slope: a collision-based analysis to assess the optimal slope. J Biomech. 2019;83:298–304.
13. Dewolf AH, Peñailillo LE, Willems PA. The rebound of the body during uphill and downhill running at different speeds. J Exp Biol. 2016;219:2276–88.
14. Pugh LG. The influence of wind resistance in running and walking and the mechanical efficiency of work against horizontal or vertical forces. J Physiol (Lond). 1971;213:255–76.
15. Bailey J, Mata T, Mercer JA. Is the relationship between stride length, frequency, and velocity influenced by running on a treadmill or overground? Int J Exerc Sci. 2017;10:1067–75.
16. Cheung VCK, Cheung BMF, Zhang JH, Chan ZYS, Ha SCW, Chen C-YC, et al. Plasticity of muscle synergies through fractionation and merging during development and training of human runners. Nat Commun. 2020 (**under review**).
17. Riley PO, Dicharry J, Franz J, Della Croce U, Wilder RP, Kerrigan DC. A kinematics and kinetic comparison of overground and treadmill running. Med Sci Sports Exerc. 2008;40:1093–100.
18. Dewolf AH, Willems PA. A collision-based analysis of the landing-takeoff asymmetry during running. Comput Methods Biomech Biomed Engin. 2017;20:65–6.
19. Cavagna GA. The landing-take-off asymmetry in human running. J Exp Biol. 2006;209:4051–60.

20. da Rosa RG, Oliveira HB, Gomeñuka NA, Masiero MPB, da Silva ES, Zanardi APJ, et al. Landing-takeoff asymmetries applied to running mechanics: a new perspective for performance. Front Physiol. 2019;10:415.
21. Maykranz D, Seyfarth A. Compliant ankle function results in landing-take off asymmetry in legged locomotion. J Theor Biol. 2014;349:44–9.
22. Cavagna GA. The two asymmetries of the bouncing step. Eur J Appl Physiol. 2009;107:739–42.
23. Lejeune TM, Willems PA, Heglund NC. Mechanics and energetics of human locomotion on sand. J Exp Biol. 1998;201:2071–80.
24. Dewolf AH, Lejeune TM, Willems PA. The on-off ground asymmetry during running on sand. Comput Methods Biomech Biomed Eng. 2019;22(supp 1):325–7.
25. Cavagna GA. Symmetry and asymmetry in bouncing gaits. Symmetry Mol Diver Preserv Int. 2010;2:1270–321.
26. Gosseye TP, Willems PA, Heglund NC. Biomechanical analysis of running in weightlessness on a treadmill equipped with a subject loading system. Eur J Appl Physiol. 2010;110:709–28.