Commentary

Critical assessment of a wide-spread method for estimating energy expenditure during accelerated running based on positioning tracking systems

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1. Introduction

An innovative method for estimating energy cost is to consider accelerated/decelerated running on flat terrain metabolically equivalent to uphill/downhill running at constant speed.1−3 In this method, the authors estimated an acceleration-dependent body slope. That slope corresponded to a given terrain slope during constant speed running, for which energy costs were known.4 Then they used accelerations (transformed into equivalent slopes) in a previously reported regression equation for energy cost estimation during uphill and downhill running at constant speed.4 This method allows researchers to estimate energy cost via player accelerations, thus making energy estimations feasible in team sports matches.

The method was frequently applied by its developers5−7 and recommended specifically for team sports1,5 despite the originally admitted lack of validity.1 Other research teams referred to this method prematurely, expecting it to be valid and accurate.8−12 In fact, validation attempts by independent research teams failed,12−14 reporting errors between 6%−52% and raising numerous concerns.12−15 Some concerns (e.g., air resistance) were solved in newly improved models,2,3 and others (e.g., sample bias in individual running economy) seem trivial.13 The developers responded that methodological flaws in other studies may explain the errors (e.g., questionable validity of acceleration data below 10 Hz of sampling frequency).2,16

However, we found that the current literature, which includes critics12−15 and model updates,2,3 does not fully explain the observed errors in energy estimation. Therefore, fundamental concerns shall be outlined subsequently to advance the field and to avoid the high risks that attend an inappropriate application of the proposed method.

2. Violated assumption and vertical displacement

The entire method’s concept1—which is based on the transfer of acceleration into equivalent slopes—was built on the assumption that the center of mass has “to maintain equilibrium”1 in the vertical dimension. However, this assumption was violated in the original study as the authors reported that “the centre of mass rises at the very onset of the run”.1 More importantly, this assumption will always be violated because acceleration is always associated with body lean and, therefore, vertical displacement (as depicted in the original Fig. 1A of Di Prampero et al.’s study1). The developers declared this observation negligible after a few steps.1 However, short-distance sprints and changes of direction (<3 m) play a major role in team sports.15,17,18 The exact effect of this violation is unclear.

In addition, the constantly occurring vertical displacement during acceleration requires energy that is not accounted for in the proposed method. This omission contributes to energy expenditure underestimation. Since this displacement is predictable, the acceleration-dependent vertical energy cost could be estimated.

3. Unrecognized energy demands

Other typical team sports movements (e.g., tackles, passes, dribbling, jumping) increase energy demands that cannot be detected by the method.19 Nonetheless, this method was
inappropriately applied to such unrecognizable demands (i.e., shooting, passing, dribbling). Although it was clarified later by the developers, this problem calls into question the method’s validity for many team sports.

Even in purely horizontal locomotion, the method does not account for all differences in energy demands due to variations of locomotion characteristics (e.g., side-steps and backwards running have different demands). Energy estimation decreased by 14% after recognizing air resistance and altered costs for running and walking. Other non-locomotion demands are not estimated at all (e.g., body rotation during changes of direction). Such omissions contribute to energy expenditure underestimation. Accounting for a number of actions like change of direction may improve the method.

4. Exceeding the valid range of accelerations

The applied regression equation was originally derived from incline angles between −0.45 and +0.45, which corresponds with approximately ±4.42 m/s². However, these limits were exceeded in the developers’ investigation (peak = 6.42 ± 0.61 m/s²). The developers argued that this affected only 1/10 of the measurement (i.e., 3 m) and is negligible. However, in team sports, such short distances are highly relevant and, in fact, peak accelerations and decelerations were reported to exceed these limits in 9 out of 14 cases during soccer tasks at maximal intensity (see original Table 1 of Steven et al.’ study). The developers suggested extrapolating the regression equation for values exceeding ±4.42 m/s², considering this to be “somewhat risky” but expecting infrequent occurrences with no substantial errors. However, applying a regression model beyond the limits of the data on which the model was based and developed is problematic. Moreover, team sports locomotion is characterized by frequent deceleration, and the extrapolated regression model reaches a local maximum of energy estimation during deceleration at approximately −4.71 m/s². Further deceleration exponentially reduces estimated energy expenditure, which is without a doubt diametrically opposing reality (Fig. 1). Such values were reported in 5 out of 7 tasks at maximal intensity (overall range: −3.2 m/s² to −9.4 m/s²). Whenever they occur, energy expenditure may be greatly underestimated, even if such decelerations represent only a small portion of the entire measurement, because of the rapidly increasing errors below −4.71 m/s². The number of occurrences and magnitude of error depends on sports and dynamics and should be investigated sport-specifically. To improve model estimations, future research may include the number of highly dynamic changes of directions and sprint starts.

5. Handling the “gold standard” incorrectly

As a reference for energy estimations, energy calculations via indirect calorimetry were acknowledged and used frequently. For validation purposes, the energy consumption at rest should be subtracted from the measured overall gross values since the discussed method considers only the net values required for locomotion. Based on graphical analysis, the developers concluded that others did not implement this adjustment correctly.

One critical study did not describe whether or not excess post-exercise oxygen consumption was included. During stationary post-exercise rest, energy estimation would increase via indirect calorimetry but not via acceleration data. Including excess post-exercise oxygen consumption may account for accumulated anaerobic energy costs.

Fig. 1. Estimation of energy cost via the regression equation by Minetti et al. within and beyond the valid range of accelerations (equivalent to slopes), displaying the range of acceleration observed in soccer and the effect on energy estimation outcome. The solid curve represents the regression equation by Minetti et al. within the valid range of equivalent slopes (gray area) and its extrapolation beyond the valid range of ±4.5. The dashed curve horizontally mirrors the inclining trend of the equation, setting the mirror axis at the −0.2 slope (i.e., local energy minimum). The dotted curve represents a polynomial regression equation similar to Minetti’s approach, aiming for the same energy estimation at the slopes −1 and +1. Neither dash nor dotted curves were based on evident data. However, they represented examples of alternative extrapolations and can be interpreted to be closer to reality than the negative trend by Minetti’s equation (since negative energy cost during high deceleration implies energy gains and conflicts with Newton’s first law).
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6. Conclusion

Despite recent updates\(^2,3\) and clarifications,\(^6\) the proposed method\(^1\) has serious limitations and lacks confirmed validity. As pointed out above, most concerns lead to under- rather than over-estimation of energy expenditure, which may explain systematic underestimation in short-distance shuttle runs\(^7,13\) and over-estimation of energy expenditure, which may explain systemic underestimation in short-distance shuttle runs\(^7,13\) and high-intensity team sports drills.\(^12,15\) Some aspects may be improved in future models to minimize certain errors (e.g., due to unrecognized energy demands), while others remain problematic (e.g., assumption violation and exceeding acceleration range). If applied inappropriately, the proposed method is currently more limited than suggested and certainly leads to underestimations in team sport matches. Nevertheless, this method may be a promising tool for drills if applied appropriately and, with limitations, for matches where indirect calorimetry is not feasible.

Authors’ contributions

PXF reviewed the literature, was involved in data assessment during previous quantitative investigations, identified the critical aspects outlined in this manuscript, drafted and completed the manuscript; PF detected difficulties with the discussed method during previous quantitative investigations, contributed to the literature review, and revised the final manuscript; SPvD reviewed the literature and revised the final manuscript; TYS supervised the writing of the manuscript and revised its final version. All authors have read and approved the final version of the manuscript, and agree with the order of presentation of the authors.

Competing interests

The authors declare that they have no competing interests.

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