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Letter to the editor

Stepping back in sprinting

Kraan et al. (J. Biomech. 34 (2001) 211) analysed an intriguing phenomenon that can be observed when someone starts to sprint from a standing position. When sprinting from an upright position, people tend to step backwards, previous to the push-off. The results of this study indicated that this step backwards enhances the force and power exerted. The paper surprised us in the way this phenomenon was investigated. We address seven points that will be discussed.

Remark 1. Kraan et al. computed the power by the following equation:

$$P = \frac{Fs}{\Delta t}, \quad (1)$$

it is unclear from the text which variables are exactly expressed. From the results section it became clear that F is the mean force in the running direction (F_y) and (s) the displacement of the centre of mass, both during push-off. This equation puzzles us, as power is strictly defined. The power exerted by a force equals the force multiplied with the velocity of the point of application. As seen in the definition of the free body diagram in Figs. 2 and 3 of Kraan et al. (2001) F_y cannot account for the power output as the velocity of its point of application is merely zero.

Rewriting Eq. (1), by dividing s by Δt, leads to the conclusion that the *mean* ground reaction force is multiplied with the *mean* speed of the centre of mass. The result of this product is not (an approximation of) the mean power exerted by the sprinter.

If the mean power must be calculated, we suggest the following steps:

$$P_m = \frac{\sum A}{\Delta t}, \quad (2)$$

with A being the work done by the sprinter and Δt the time during push-off.

$$P_m = \frac{1/2 m \Delta v^2}{\Delta t}, \quad (3)$$

where P_m is the mean power, m is the mass, Δv is the end speed, as speed is zero at start. Eq. (3) calculates the mean power by the dividing the energy that was exerted during the push-off to increase the kinetic energy of the centre of mass in horizontal direction, by the time work was done.

Remark 2. From the methods section it is unclear how position, velocity and acceleration of body centre of mass have been calculated or measured.

Remark 3. Kraan et al. stated that during push-off the ground reaction force must point towards the centre of mass to prevent a somersault. This is in general not true. The *average* change of angular momentum should equal zero. This does not mean the push-off force should be directed towards the centre of mass *at all times* (Jacobs and van Ingen Schenau, 1992).

Remark 4. It is also stated that the *first* phase of forward acceleration of the centre of mass must be produced by the horizontal component of the ground reaction force. Notwithstanding the lack of defining this "first phase", forward acceleration of the body centre of mass is always produced by the horizontal component of the ground reactions force, as it is the only force in this direction.

Remark 5. Figs. 4–6 of Kraan et al., show different kinematic variables as a function of time. These figures correspond with the three sprint types: (a) starting out of standing position at the subjects own initiative, (b) starting out of standing where no step backwards was allowed and (c) starting out of standing where the two feet are already in front of each other. The results show that in the first condition 95% of the subject first stepped back when sprinting to their maximum. This way of sprinting led to the highest power output. However, exploration of the maximum end speed does not show this favourite effect at all. The end speeds indicated by the figures are approximately 1.8, 14($\pm$50 km/h in 0.735 s!) and 4.5 m/s. When more power is exerted, kinetic energy must also increase. As mean mass in all cases is equal, the square of the end speed of the body centre of gravity is a measure for kinetic energy. It is clear that kinetic energy is far most in start type (b) less in (c) and far less in (a). How can this be, as it should that after start type (a), the body centre of mass must posses the most kinetic energy?

Remark 6. Figs. 5 and 6 clearly show that there is a fair amount of ground reaction force in horizontal direction, measured prior to the start. As this is the only force in the horizontal plane exerted on the defined free body diagram of the runner, there must be an acceleration of the centre of mass, and therefore a development of speed prior to the defined begin time. Two questions can be addressed: How can it be that the centre of mass possesses speed prior to the start, as can

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be seen in Figs. 5 and 6? Also, begin time was defined by the authors when the horizontal ground reaction force becomes larger then 10 N. It can be seen in Figs. 5 and 6 that the ground reaction force in horizontal direction is raised far above 10 N long before the begin time was marked.

Remark 7. In the discussion the authors state that stepping back results in a higher force and power output, and therewith a positive contribution to the start. Apart from the discussion if the power is correctly calculated, it is not the issue if mean *power* output is enhanced or not. The question should be if the total *work* done during the push-off is enhanced, because work equals mean power *multiplied by the time power is generated*. This work is related to the end velocity of the centre of mass.

Final Remarks

In the discussion of Kraan et al. it is stated that the positive contribution to the start originates from the impulse at foot impact resulting from the kinetic energy of the leg in the step backwards. We think that this cannot contribute to the positive effect of a step backwards. The same negative impulse must be surmounted when accelerating the whole body in a forward direction, yielding net zero contribution of the leg's kinetic energy prior to the push-off.

We think that people step backwards for a different reason. Generating a forward ground reaction force in the upright position would result in a net backward angular momentum. A reverse angular momentum is obtained, averaging net zero angular momentum, by projecting centre of mass in front of the support area. When starting from total upright position, this can be achieved in two ways. The first way is to rotate the body in a forward direction (sprint type (b), Kraan et al., 2001). Beside it, the support area can be displaced backwards (sprint type (a) Kraan et al., 2001). The forward angular acceleration in sprint type (a) depends mostly on the cosine of the angle between the body's longitudinal axis and the floor. This results in a low initial angular acceleration, and therewith a fair amount of time before actual push-off force can be developed. Stepping backward however, provides a much quicker method to project the centre of mass in front of the support area. In our opinion this is a more plausible explanation why people step backwards during sprinting from an upright position.

References

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