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Authors' response

We thank D. Kistemaker and H. Faber for their valuable and critical remarks and we welcome the opportunity to correct some inaccuracies and to better explain our method and views.

1. About the calculation of power.

Kistemaker and Faber correctly criticised the way the power was calculated. The original idea was to integrate the force F_y over the (forward) y displacement of the centre of gravity of the body. It can be shown that the result equals the kinetic energy associated with the y translation of the centre of gravity of the whole body. Replacing the integral by a multiplication of average force and total displacement of the centre of gravity to calculate work was an oversimplification that we regret. We have now calculated the power as a function of time using the expression $P = F_y v_y$. The power from this expression is only the power for accelerating the centre of gravity of the body. It is less than the total power exerted by the leg muscles during push-off.

We have also calculated the mean power P_m in the way as suggested by Kistemaker and Faber, expressed in joule per kilogram body mass. Measured values (see Table 1 of this response) have been taken from a typical example.

Start a:

$$P_m = \frac{\frac{1}{2}(1.95)^2}{(0.845 - 0.610)} = 8.09\ \mathrm{J/kg}.$$

Start b:

$$P_m = \frac{\frac{1}{2}(0.42)^2}{(0.845 - 0.286)} = 0.16\ \mathrm{J/kg}.$$

Start b*:

$$P_m = \frac{\frac{1}{2}(2.93)^2}{(1.330 - 0.286)} = 4.11\ \mathrm{J/kg}.$$

Start c:

$$P_m = \frac{\frac{1}{2}(2.37)^2}{(0.700 - 0.290)} = 6.85\ \mathrm{J/kg}.$$

Start a: start with a step back. Start b: start where a step back was not allowed; the same time was used as the end time for Start a. Start b*: same start as Start b but then until the time of leaving the force plate. Start c: start with the push-off foot already on the force plate and the other foot in front of the force plate.

2. About calculating position, velocity and acceleration.

The forward force component F_y accelerates the body centre of gravity with an acceleration of F_y divided by the total body mass. Velocity and position of the centre of gravity follow from integration.

3. About the direction of the ground reaction force.

We meant to say that the ground reaction force should point *approximately* to the centre of gravity.

4. With the first phase of forward acceleration, we meant the forward tilting of the body about the ankle flexion axis, but, of course, the relationship between the horizontal component of the ground reaction force and the forward acceleration will still hold after this phase.

5 and 6. About the results shown in Figs. 4–6.

Figs. 5 and 6 were in error. Figs. 1 and 2 of this reponse replace the original Figs. 5 and 6.

7. Power or work in sprint optimization.

The athlete optimises his motion in order to arrive at a certain distance in the shortest time possible. Reaching a high speed at the end of the run is not enough: the speed must be increased as soon as possible. As a consequence, the best strategy is not maximizing the total work done by the end of the run, but doing the work at the beginning with a high power output.

Fig. 3 shows force, velocity, displacement and power of the three starting strategies synchronised in time. Starting with a step backwards, compared to starting with no step backwards allowed, shows a higher velocity and a larger displacement at 0.8 s, which is the time of leaving the force plate when using a step backwards. When no step backwards is allowed, it takes longer to maximise velocity and therefore it takes longer to leave

Table 1

	Begin time (s)	End time (s)	Impulse time (s)	Velocity (m/s)	Displacement (m)
Start a	0.610	0.845	0.235	1.95	0.25
Start b	0.286	0.845	0.559	0.42	0.12
Start b*	0.286	1.330	1.044	2.93	0.86
Start c	0.290	0.700	0.410	2.37	0.52

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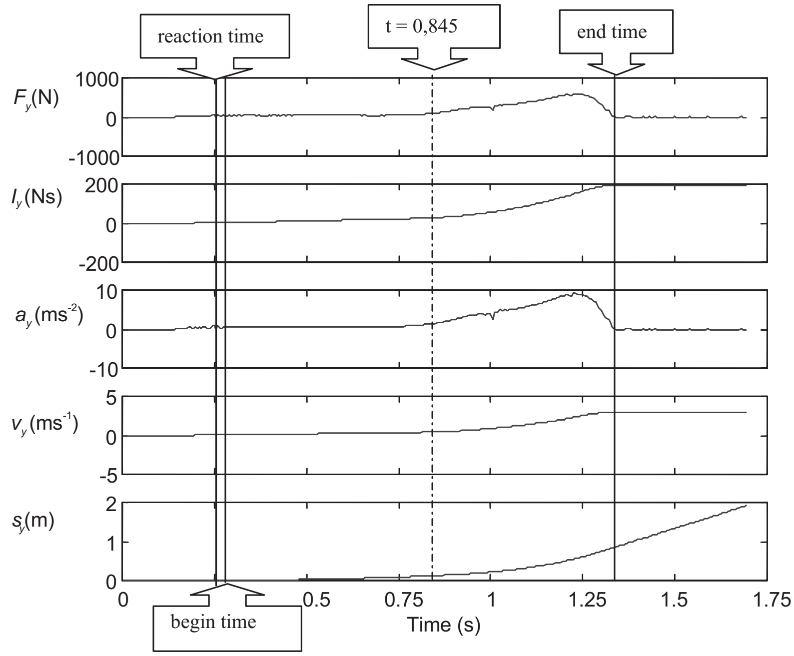

Fig. 1. Force (F_y), impulse (I_y), acceleration (a_y), velocity (v_y) and displacement (s_y)—time history in the y-direction. Starting with no step backwards allowed.

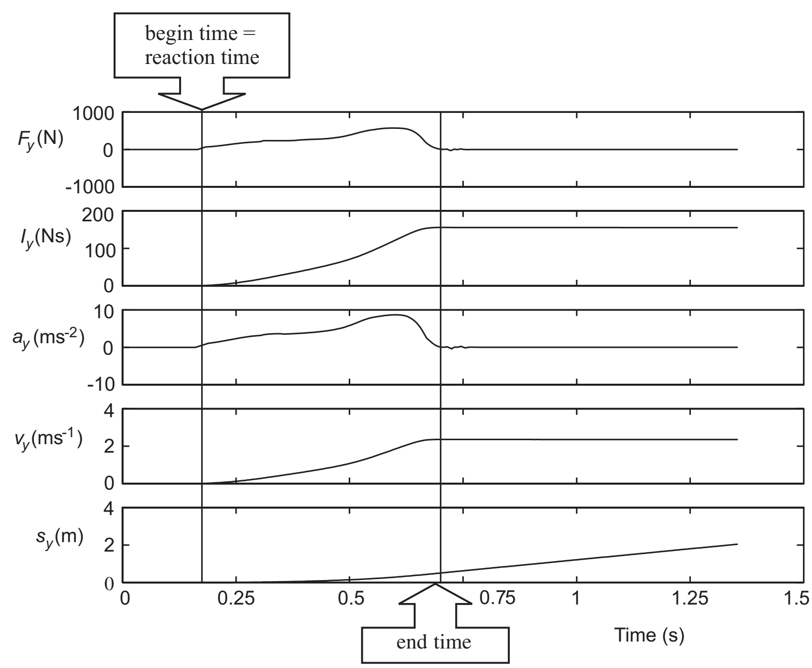

Fig. 2. Force (F_y), impulse (I_y), acceleration (a_y), velocity (v_y) and displacement (s_y)—time history in the y-direction. Starting with one leg posterior to the other.

the force plate. In the meanwhile a second step can be made in the case of the step backward strategy. Additional forward force generation and acceleration of the body centre of gravity can be accomplished. With a step backward, the work is done at the beginning of the start with a high power output. With no step backwards allowed, high power output can only be achieved later when the body centre of gravity is in front of the point of action of the foot reaction force.

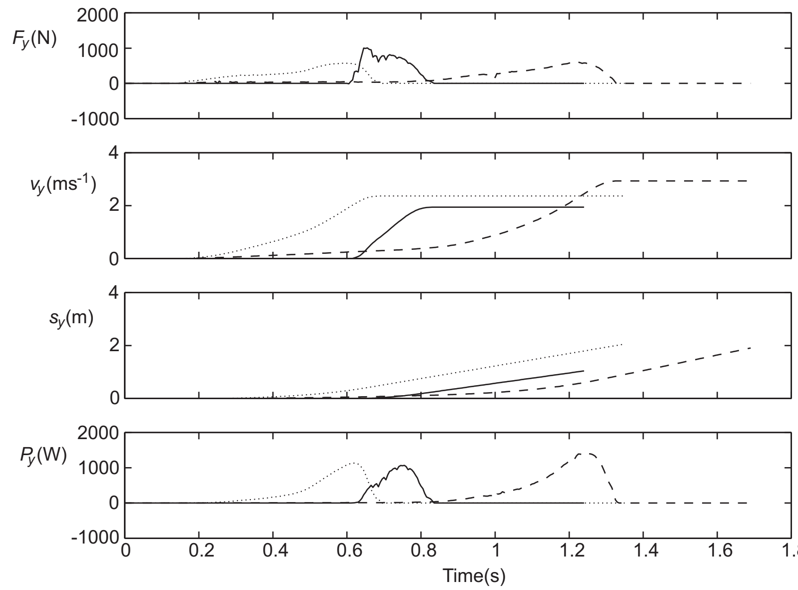

Fig. 3. Force (F_y), velocity (v_y), displacement (s_y) and power (P_y)—time history in the y-direction. Starting with a step backwards (——), starting with no step backwards allowed (- - - -), starting with one leg posterior to the other (· · · · · · · · ·).

8. About the negative impulse of the leg stepping back.

The negative impulse of the leg is not a drawback for the acceleration of the whole body. When the backward moving foot touches the ground, a large forward force will be exerted by the ground on the foot. This force will brake the backward motion. The relevance of the force may have had too much stress in our article, but its effect is not adverse.

9. About the reason for stepping backward.

The views of Kistemaker and Faber have a lot in common with our views. For example, the backward angular momentum they mention is what we meant with a somersault. Eventually, the conclusions mentioned in our original article are all still valid.

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