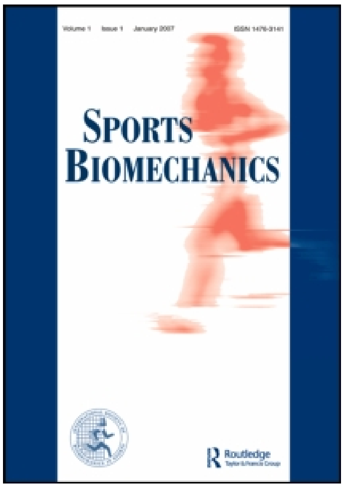

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Comments on "Runners do not push off but fall forward via a gravitational torque" (Vol. 6, pp. 434-452)

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Comments on "Runners do not push off but fall forward via a gravitational torque" (Vol. 6, pp. 434–452)

Romanov and Fletcher claim that from mid-stance to terminal stance the body falls forwards due to a gravitational torque and this makes gravity propulsive. At the time of publication the past editor, Roger Bartlett, noted about the paper: "Read it, you may disagree … but your traditional thinking about running will be challenged". We decided to take up the challenge. To clarify their conclusions, the original authors may wish to respond to the selected points about the biomechanics of the paper outlined below.

Point One: Gravity is by definition a vertical force (Fig. 5b from the paper)

Unless the athlete is running downhill, the gravitational force (Fg) has no component in the direction of motion. Romanov and Fletcher claim (Figure 1) that Fg can be split into the components Fp and Fr. Fp is then called a "propulsive force".

The issues are: (1) Unless the athlete is running downhill, the "propulsive" force (Fp) is not pointing in the direction of the centre of mass (CoM) movement. (2) By definition, the vectors Fp + Fr = Fg, therefore even though Fp may have a horizontal component, Fr has an equal and opposite horizontal component. So unless perpetual motion suddenly becomes possible, the net effect of gravity must be zero in the horizontal direction.

Point Two: An energy analysis shows that gravity is not a propulsive force from mid-stance to terminal stance in running

In running, the accepted simple model is the pogo stick. The athlete bounces along. From impact to mid-stance energy is dissipated. The gravitational potential energy drops as the CoM height decreases. The kinetic energy reduces as the initial foot contact causes braking.

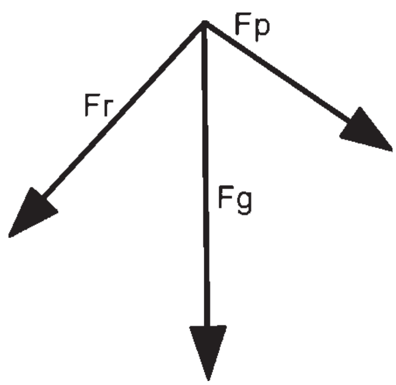

Figure 1. Gravitational force (Fg) can be split into components Fr and Fp, but the net horizontal force of gravity remains unchanged and is zero.

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Some energy is stored as elastic potential energy in the stretched fibres of the stance leg. From mid-stance to toe-off, both the gravitation potential and kinetic energy increase as the elastic potential energy is returned. Additional muscle work is required to make up for energy dissipated.

Romanov and Fletcher appear to concur with the basic motion of the athlete's CoM if not the traditional pogo stick model. An excerpt from their paper that appears to agree with this is: "These muscles (quadriceps and hamstring) therefore resist the work of gravity, as the body lowers from impact to mid-stance".

Romanov and Fletcher claim that from mid-stance to terminal stance the body falls forwards due to a gravitational torque and this makes gravity propulsive. If an external force is propulsive it must be doing positive work on the athlete. But from mid-stance to terminal stance in running, the height of the athlete's CoM is increasing. Gravity is doing negative work because it is opposing the direction of CoM movement and so is actually retarding the athlete.

Point Three: Running kinematics suggests the athlete does not fall forwards due to gravity from mid-stance to terminal stance

Romanov and Fletcher claim that from mid-stance to terminal stance the athlete falls forward via a gravitation torque (clockwise). However, the kinematics of Figure 2 shows that the athlete's trunk actually rotates backwards (anti-clockwise) during the flight phase between terminal stance (b) and impact (a). During the flight phase there is no torque on the athlete, so angular velocity must be constant. Therefore, the net torque about the athlete's CoM from mid-stance to terminal stance must be anti-clockwise. The net torque is due to additional forward directed ground reaction forces generated between the athlete's foot and the ground. If this were not the case, the reader might imagine the athlete falling flat on his face after a couple of strides.

Point Four: The "extensor paradox"

Romanov and Fletcher claim that because of the "extensor paradox" that is present during the propulsive phase of running, gravity must be the "motive" force in propulsion. The extensor paradox is described in the paper as follows: "hip and knee activity begins to decrease as leg extension begins". The paper supports the claim that this "casts doubt that ground reaction forces and muscles can propel the runner into the air".

But EMG measurement of muscle activity is not a measurement of joint rotational velocity, or linear velocity. Maximum force occurs at maximum acceleration. And maximum

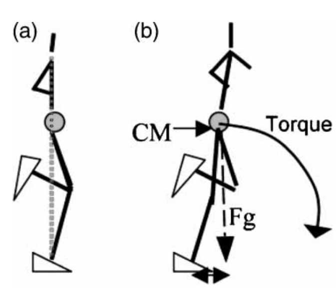

Figure 2. (a) Impact to mid-stance and (b) mid-stance to terminal stance as reported by Romanov and Fletcher.

vertical acceleration in a rhythmical motion like running will occur near zero velocity and impact. By the time the stance leg is extending again, the athlete's CoM vertical velocity has become positive and there is no need for additional muscle work. The athlete does not want to jump into the air, only to maintain his horizontal CoM trajectory.

Some net horizontal force production will be required to overcome losses but this will be very small compared with the vertical force required to counter the effects of gravity. Consequently, the EMG activity in the extensor muscles will be predominantly that required to produce the vertical motion, and the EMG signal, if any, due to horizontal acceleration may be lost. In addition, the athlete has at his disposal elastic energy stored in the tendons. It is estimated that this is up to 45% of the energy originally stored in the tendons during eccentric muscle action. Electromyography may not be able to detect the work done by the elastic potential energy on the athlete's motion from mid-stance to terminal stance.

Conclusions

We agree with Romanov and Fletcher that gravity is important in running. Imagine running in a zero gravity situation, after the first stride you would be somersaulting backwards and travelling away from the support surface indefinitely. But gravity does not propel the athlete horizontally. Over a complete running cycle gravity does no net work, and from mid-stance to terminal stance it actually retards the athlete.

Dynamic balance during running is maintained by reducing the resultant external torque on the athlete's CoM, which reduces unnecessary trunk rotations and results in an efficient "balanced" motion. In practice, to balance the external torque while running, the athlete's average stance will be slightly forward to overcome a small amount of wind drag. The athlete will lean further forwards during periods of acceleration, but lean backwards during periods of braking, and lean sideways into each corner.

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