GRAVITY'S ROLE IN ACCELERATED RUNNING - A COMPARISON OF AN EXPERIENCED POSE® AND HEEL-TOE RUNNER

Graham Fletcher[1], Marcus Dunn[2], Nicholas Romanov[3]

University of the Fraser Valley, 33844 King Rd, Abbotsford, BC, Canada[1]
Sheffield Hallam University, Sheffield, England[2]
Posetech, Miami, FL, USA[3]

The purpose of this study was to determine gravity's role in accelerated running using an experienced male Pose® and heel-toe runner as a comparison. A two-step accelerated run found that maximum horizontal acceleration of the centre of mass (COM) occurred before maximum horizontal ground reaction force (GRF). Maximum horizontal and angular acceleration of the arms and trunk occurred at or before maximum horizontal acceleration of the COM. At maximum horizontal GRF both participants' stance feet were vertically accelerated. It is suggested that acceleration of the COM occurs via a gravitational torque with GRF being the consequence of, not the cause of these movements. Therefore, practitioners might find this novel perspective helpful when applied to accelerated running.

KEYWORDS: Pose®, heel-toe, gravity, centre-of-mass, accelerated running

INTRODUCTION: A novel running technique, the Pose® method has made claims it is an effective way to run (Fletcher *et al*., 2008). The Pose® method of running teaches that movement occurs by changing from one support foot to the other while the centre of mass (COM) falls forward of the point of support (COP) via a gravitational torque, defined as $mg\,r\,\sin\theta$ (where m is mass, g is gravity, r is vector from COP to COM and θ is the angle between r and global vertical) (Romanov & Fletcher, 2007). This is achieved by pulling the support foot upwards from the ground toward the hip using the hamstring muscles as the body falls forward after mid-stance (Fletcher *et al*., 2008). The ipsilateral leg is not driven forwards during flight but allowed to fall to the ground under the COM to land in the next running Pose® (Romanov & Fletcher, 2007).

A recent critique (Brodie *et al*., 2008) asserted that during a complete running cycle, gravity does no net work and from mid-stance to terminal-stance actually retards the athlete in constant speed running. To date, research on Pose® running has focused on constant speed running, however accelerated running might provide a clearer explanation of gravity's role. Heel-toe (HT) runners encounter the same forces when running (ground reaction force (GRF), muscle force, gravity and muscle elasticity and air resistance) as Pose® runners. To accelerate, the runners' COM must experience a net external force, e.g. gravity and/or GRF. Therefore, the purpose of this study was to provide a comparison of accelerated running using an experienced HT and Pose® runner to further understand gravity's role in running.

METHODS: One male Pose® (age: 53 years, stature: 1.73 m, mass: 71.0 kg) and one male HT (age: 55 years, stature: 1.69 m, mass: 72.5 kg) runner participated in the current study. Both were experienced runners (>30 years) and considered to be exemplars of their respective techniques. Prior to participation, ethics approval for all procedures was obtained from Schriners Gait Laboratory, Vancouver and both participants provided written informed consent. Both participants used a two-step start for a fast acceleration run across a force platform measuring 0.40 × 0.50 m (AMTI, OR65), for 10 trials using a right foot contact. The force platform was integrated with an online, eight camera motion analysis system (Motion Analysis Corporation, Santa Rosa, CA), tracking the movement of 41 retro-reflective markers (NIH marker set). Three-dimensional kinematic and kinetic data were collected at 240 Hz and 1200 Hz respectively using EVaRT (5.0.4, Motion Analysis Corporation, CA, USA) and exported to C3D files for further analysis in Visual 3D (3.79, C-Motion, MD, USA). Kinematic and kinetic data were filtered using a second order, low-pass Butterworth bidirectional filter with cut-off frequencies of 10 and 50 Hz respectively and applied to a full-body kinetic model.

Calculated data, including full-body and segment COM position data, were exported to ASCII files for analysis in MATLAB (R2006b, The MathWorks, MA, USA). Linear and angular data were calculated relative to global and pelvis coordinate systems respectively, instantaneous velocity and acceleration were calculated as first and second time derivatives respectively.

RESULTS AND DISCUSSION: Running and in particular accelerated running is a component of many sports. Hence understanding whether the horizontal acceleration of a runner's COM occurs by pushing off of the ground by the foot or falling forwards via a gravitational torque while pulling the foot from the ground, is important for teaching running technique. Figure 1 shows that maximum horizontal acceleration of the runner's COM occurred before the maximum horizontal GRF in both runners. Usually, maximum horizontal GRF is associated with the foot pushing from the ground in order to increase the horizontal acceleration of the runner. Therefore, it was important to identify the runner's movements at maximum horizontal acceleration of the COM and at maximum horizontal GRF (Figure 1; Table 1).

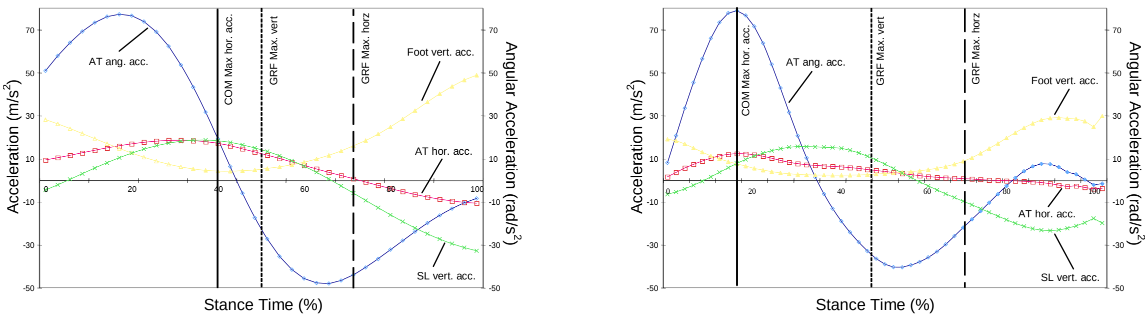

Figure 1: Pose® (left) and HT (right) runner's motion in stance (mean of ten trials)

At the instant of maximum horizontal acceleration of the COM (Figure 1: solid vertical line), the horizontal and angular acceleration of the HT runner's arms and trunk (AT) peak, whilst the angle of inclination of the COM (θ) is near vertical (Table 1). In contrast, the AT of the Pose® runner had just passed maximum horizontal acceleration and angular acceleration of the AT was approaching zero. At the same instant, the Pose® runners' stance foot had its lowest vertical acceleration, whereas vertical acceleration of the HT runners' stance foot was still decreasing. Also, the Pose® runners' swing leg (SL) achieved near maximum vertical acceleration whereas vertical acceleration of the HT runner's SL was still increasing.
Just before maximum horizontal GRF (Figure 1: dashed vertical line), the HT runners' support foot is accelerated superiorly. At this time, linear horizontal acceleration of the AT was approximately zero (velocity close to maximum). Minimum angular acceleration of the AT occurred at 55% of stance while vertical acceleration of the SL is zero at 60% of stance before the foot is then vertically accelerated. Minimum angular acceleration of the Pose® runner's AT occurred at 65% of stance while vertical acceleration of the SL passes through zero. At this time, the stance foot was vertically accelerated before maximum horizontal GRF (Figure 1: dashed vertical line) and horizontal acceleration of the AT passes through zero.
Therefore, at maximum horizontal acceleration of the COM, the support foot has minimal vertical acceleration and the AT has maximum horizontal acceleration in both runners. However, the angular velocity of the AT is near maximum in the Pose® runner but close to zero in the HT runner. At maximum horizontal GRF, the horizontal acceleration of the AT, horizontal acceleration of COM and vertical acceleration of the SL were close to zero in the Pose® runner as the support foot initiates its vertical acceleration. The HT runner is less coordinated at this time owing to negative vertical acceleration of the SL, but generally follows a similar movement pattern. At maximal horizontal acceleration of the COM, the HT runner experienced greater angular acceleration of AT by 67.9 rad/s^2 (13.1) owing to an increased forward lean of the upper body owing to θ being close to the vertical (Table 1).

Table 1 Pose® and HT movement variables at key instants during stance ($\bar{x} \pm s$)

Instant	Runner	GT (Nm)	AT hor. vel. (m/s)	SL ang. acc. (rad/s^2)	COM hor. vel. (m/s)	θ (°)	Foot vert. vel. (m/s)
Initial contact	Pose®	-64.4 ± 16.0	3.74 ± 0.09	-84.6 ± 10.7	4.16 ± 0.09	-5.8 ± 1.5	-0.66 ± 0.30
	HT	-80.2 ± 22.0	2.93 ± 0.17	-64.5 ± 5.7	3.31 ± 0.13	-7.3 ± 2.0	-0.60 ± 0.11
Max COM hor. acc.	Pose®	122.9 ± 20.8	4.68 ± 0.21	0.83 ± 21.6	4.51 ± 0.16	11.2 ± 1.8	0.12 ± 0.05
	HT	-0.8 ± 21.3	3.19 ± 0.12	-48.0 ± 7.0	3.44 ± 0.14	-0.2 ± 2.0	-0.09 ± 0.07
Max vert. GRF	Pose®	165.8 ± 9.7	4.91 ± 0.09	36.6 ± 27.0	4.62 ± 0.11	14.9 ± 0.9	0.17 ± 0.01
	HT	131.0 ± 7.9	3.69 ± 0.13	8.1 ± 13.1	3.70 ± 0.12	12.0 ± 0.7	0.13 ± 0.01
Max hor. GRF	Pose®	268.6 ± 16.2	5.12 ± 0.13	82.9 ± 18.9	4.83 ± 0.15	23.0 ± 1.4	0.49 ± 0.10
	HT	240.5 ± 4.1	3.83 ± 0.09	65.5 ± 11.7	3.83 ± 0.11	21.0 ± 0.4	0.30 ± 0.05
Terminal stance	Pose®	391.1 ± 19.4	4.83 ± 0.13	99.5 ± 15.1	4.92 ± 0.13	31.0 ± 1.5	1.94 ± 0.12
	HT	380.3 ± 12.3	3.80 ± 0.11	80.9 ± 8.8	3.95 ± 0.12	30.4 ± 0.9	1.52 ± 0.10

GT = gravitational torque (*mg r sinθ*), AT = arms and trunk, SL = swing leg, θ = angle of vector COP-COM to vertical, hor. = horizontal, vert. = vertical, vel. = velocity, acc. = acceleration, ang. = angular.

However, at the same instant the Pose® runner experienced greater horizontal acceleration for the AT and the COM by 3.8 (1.8) and 1.8 (0.03) m/s respectively. It appears the Pose® runner was able to translate rotational movement into linear movement more successfully possibly owing to a greater gravitational torque because the COM was forward of the support foot. At maximum horizontal GRF the stance foot's vertical velocity was 61% greater in the Pose® runner highlighting a stable stance position which enables foot lift rather than SL drive. We briefly suggest several reasons for these similarities and differences between the two techniques. Recently, Chang *et al*. (2000) found that not only the vertical but also the horizontal GRF experienced by runners was affected by reductions in Earth's gravity. For example, when decreasing gravity by 75%, horizontal GRF impulse decreased by 53% whereas with a 30% increase in only the inertial force, there was only approximately a 9% increase in horizontal GRF impulse. They deduced from these data that differences in the horizontal impulses were due solely to gravity, but offered no explanation for the reduction in horizontal GRF. A vertical force, for example gravity, cannot affect a horizontal force. The horizontal force that resists the foot is friction (*F*) or horizontal GRF. The equations of motion (1-2) presented below, are for a runner with the rotational term reflecting motion of the COM about the support foot.

$$F \text{ (hor GRF)} = m\, dv_x / dt \qquad (1a)$$
$$N \text{ (vert. GRF)} = mg + m\, dv_y / dt \qquad (1b)$$
$$I_{COM}\, d\omega / dt = N\, r \sin\theta - Fr \cos\theta \qquad (2)$$

where m is mass of the runner, v_x and v_y are velocity components of the COM, r is the distance from the COM to the support foot's COP, I_{COM} is the moment of inertia about an axis through the COM, and angular velocity $\omega = d\theta / dt$

If F is less than the coefficient of friction (μ) and vertical GRF (N) then the runner does not slip and their body can then rotate about their support foot and the following equations are valid. Hence, $v_x = r\,\omega \cos\theta$ and $v_y = -\,r\,\omega \sin\theta$. Therefore,

$$F = m\, r\, (\cos\theta\, d\omega / dt - \omega^2 \sin\theta) \qquad (3)$$
$$N = mg - m\, r\, (\sin\theta\, d\omega / dt + \omega^2 \cos\theta) \qquad (4)$$

Equation 3 illustrates F is related to the angular acceleration of the runner about the support foot. Angular acceleration of the runner's COM is caused by a gravitational torque as the substitution of equations 3 and 4 into 2 yields,

$$\frac{d\omega}{dt} = \frac{d^2\theta}{dt^2} = \omega^2 \sin\theta \qquad (5)$$

Equation 5 shows gravity's affect on GRF because equation 5 can also be derived by equating the gravitational torque $mg\ r \sin\theta$ about the support foot (Romanov & Fletcher, 2007). In support, Chang et al. (2000) found the resultant GRF vector at maximum horizontal GRF remained nearly constant between normal and 75% gravity. Hence, the changes in the magnitude of the vertical component of GRF were accompanied by proportional changes in the horizontal component of GRF to maintain the orientation of the resultant force vector. Therefore, gravity does affect F by virtue of the radius about the support foot and therefore its torque. The faster a runner rotates around their support foot, the greater the increase in F, owing to increased angular acceleration (equation 3) without the need for additional internal, muscle force to push-off against the ground. Horizontal acceleration of the COM occurs because of the rotation of the body via a gravitational torque ($v_x = r\ \omega \cos\theta$). Maximum F appears to be the optimal and stable time for the body to act as a support (see Zatsiorsky, 2002; angle of friction) to begin to pull the support foot from the ground as the body minimises angular and linear acceleration.

CONCLUSION: Findings indicate that both runners' bodies rotate about a near stationary support foot at maximum horizontal acceleration of the COM via a gravitational torque before the onset of maximum horizontal GRF. Accelerations of the AT and SL were zero close to maximum horizontal GRF for the Pose® runner except for the support foot, which was accelerated superiorly. The HT runner followed similar movement patterns to that of the Pose® runner but was less coordinated between the upper body and swing leg. Gravity completes no net work during stance in constant speed running, but achieves angular work via a gravitational torque accelerating the COM in both constant speed and accelerated running. The current study was limited with regard to sample size however, this research does enable practitioners to re-examine running technique from this novel perspective. Future research should consider these findings within larger groups.

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Acknowledgment

The authors would like to thank Alec Black at Schriners Gait Laboratory, Vancouver.