RUNNING BIOMECHANICS: WHAT DID WE MISS?

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This presentation describes a series of studies re-examining some basic aspects of running biomechanics. Kinematic data from ~20,000 subjects were collected in the field, at marathons and other running events. Responses to on-line surveys from over 2,000,000 runners were used to characterise the running demographic. The results show substantial differences between the runners participating in distance running events and the subjects employed in laboratory studies. Race participants are notably older, slower, have higher BMIs and are more frequently female than laboratory subjects. Foot contact patterns were found to occupy a normally distributed continuum rather than the discrete classes usually assumed. Runners have difficulty self-identifying their foot contact "type".
At speeds in 2–3 m s^{-1} range, we observed a high incidence of "grounded running" gaits. Grounded running is, energetically, a running gait, with a potential energy minimum in mid-stance but there is a brief period of double stance and no aerial phase. This gait is common in other cursorial bipeds but has not been reported previously in humans.

KEY WORDS: distance running, gait, foot strike, foot contact, grounded running.

INTRODUCTION: Running is elemental human gait and a component of most sports activities. While it is the most studied sports-related movement, much uncertainty remains. The nature and frequency of foot contacts and which type is optimal remains a subject of debate, for example. Is barefoot running more natural? More fundamental questions also persist – Why unlike other cursorial bipeds, do humans not demonstrate an intermediate gait between walking and running? The studies described in this paper were motivated by a weekend seminar at the 2010 Boston. We were struck by the incongruity between the topics of discussion among experts ("forefoot strike", barefoot running, "pose" and "chi" running styles, etc.) and what marathon participants were doing on race day. Of the more than 30,000 runners who passed by, very few if any had chosen to adopt the recommended biomechanical styles. The resulting questions were straightforward: Who are these people? How are they running? Why? This work encompasses a variety of topics and is ongoing. In this presentation, we will highlight some results related to the running demographic, foot contact patterns and "grounded running" - an intermediate gait not previously reported in humans.

METHODS: Self-reported gender, body mass and stature, training speed and weekly distance, and self-assessments of foot contact type were collected from over 2M visitors to runnersworld.com. Data was collected anonymously and consequently is unverifiable. The demographics of survey respondents was compared to subject characteristics from 100 papers on running biomechanics published in 2013 and 2014.Self-assessments of foot contact type were compared with 240 fps video in 70 subjects running on a treadmill. Sagittal plane video (240 Hz) have also collected at numerous marathon and half marathon events between 2012 and 2016. Individual running have been estimated using various methods, most recently with additional cameras located a known distance before and after the data collection point. Videos were analysed using custom software to identify discrete foot contact type, foot contact angle, contact time, step time and other kinematic variables.

RESULTS:

***Running Demographics*:** Comparing the runners participating in laboratory experiments with those participating in running events, the form are typically young, healthy males – i.e. college students – whereas the survey respondents where more frequently female, had higher BMI's and ran shorter distances at slower speeds. It is also noted that most studies were done in the laboratory and at constant speed for short periods (a few minutes) whereas our kinematics data were collected after a *minimum* of 10 km / 30 minutes or running.

Foot Contact: Figure 1 shows data for self-reported and observed foot contact types. High speed video reveals that most (94%) of runners make have a heel-toe contact sequence. Flat foot ("midfoot") contacts were observed in 4% and forefoot-heel in 2%. Only 8 of the observed subjects had a "pure" forefoot contact without subsequent grounding of the heel. In contrast, only 32% of wear testers reported themselves as "heel strikers". Comparing these reports with high speed video treadmill running in a subsample of 70 subjects, we found it safe to assume that self-diagnosed of foot contact type is unrelated to the actual foot contact.

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Grounded Running: Human bipedal walking is a "inverted pendular" or "compass" gait in which centre of mass (COM) height and potential energy (PE) are maximal in mid-stance. Bipedal running is energetically distinct – a "bouncing" gait in which COM height and PE are minimal in mid-stance and maximal in mid-flight phase. Walking is also characterised by a period of double support in which both feet are in contact with the ground. However, other bipedal specials, in particular cursorial birds have an intermediate gait, "grounded running" – a bouncing gait in which there is a brief period of double support (Andrada *et al*, 2013; Rubensen *et al*, 2004). While grounded running has not between reported previously in humans, we have observed hundreds of cases in our data set. Grounded running gaits most frequently occur in the range of speeds (~2 - 3 m s^{-1}) at which neither running nor walking are "comfortable" or energetically efficient. This suggests that grounded running may be an efficient adaptation at speeds too fast to walk and too slow to run efficiently. However we have no evidence for greater economy as yet. Laboratory experiments will be challenging because minimal energy gaits cannot be imposed but must occur naturally.

We have been able to demonstrate the intermediate gait is, indeed, a running (i.e. "bouncing") gait despite the brief period of double support. Relationships among basic gait parameters as step time, contact time and speed are contiguous with those found in running but not walking.

Laboratory observations using a force treadmill and 500 fps video also provide insights. Figure 3 shows ensemble average force-time averages for the vertical (Fz) and anterior-posterior (Fy) force components from a single subject who was captured walking (WK), running (RN) and grounded running (GR) at the same speed (2.3 m s^{-1}). While the GR forces include features of both WK and RN, it most resembles RN and the double support period is only obvious if consecutive steps are recorded. Also, contemporaneous trajectories of an ipsilateral marker on the greater trochanter reveal that, in contrast to walking, both GR and R show the mid-stance minimum that is characteristic of bouncing gaits.

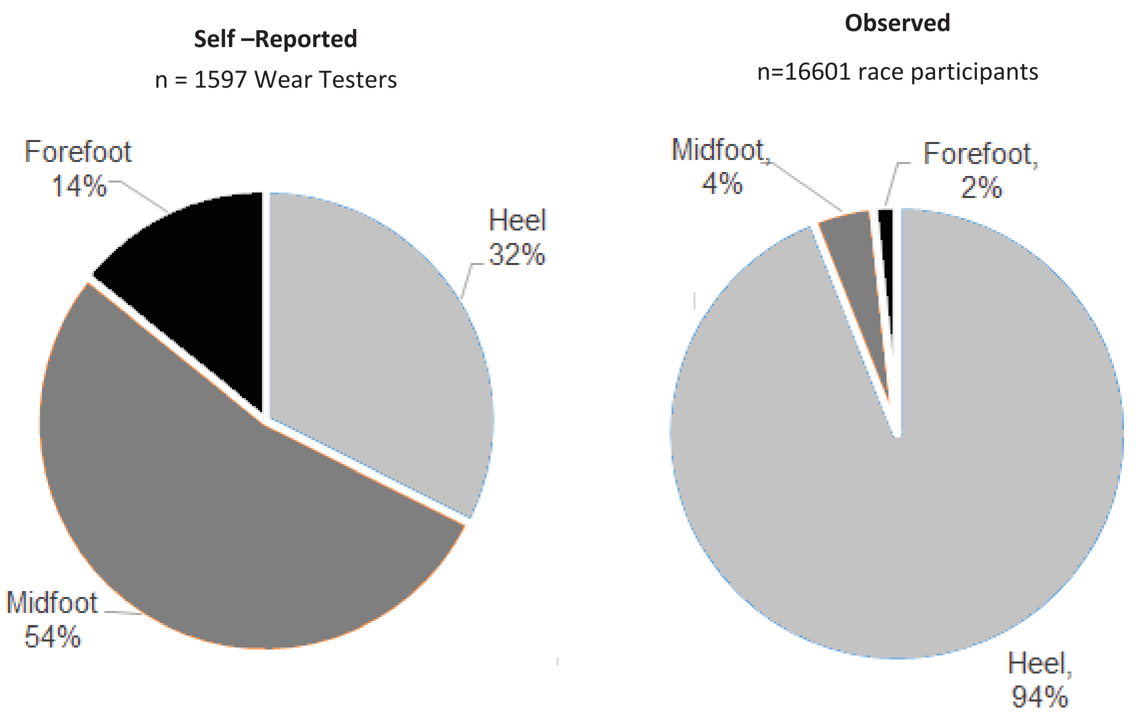

Figure 1: Self-reported and observed foot contact patterns

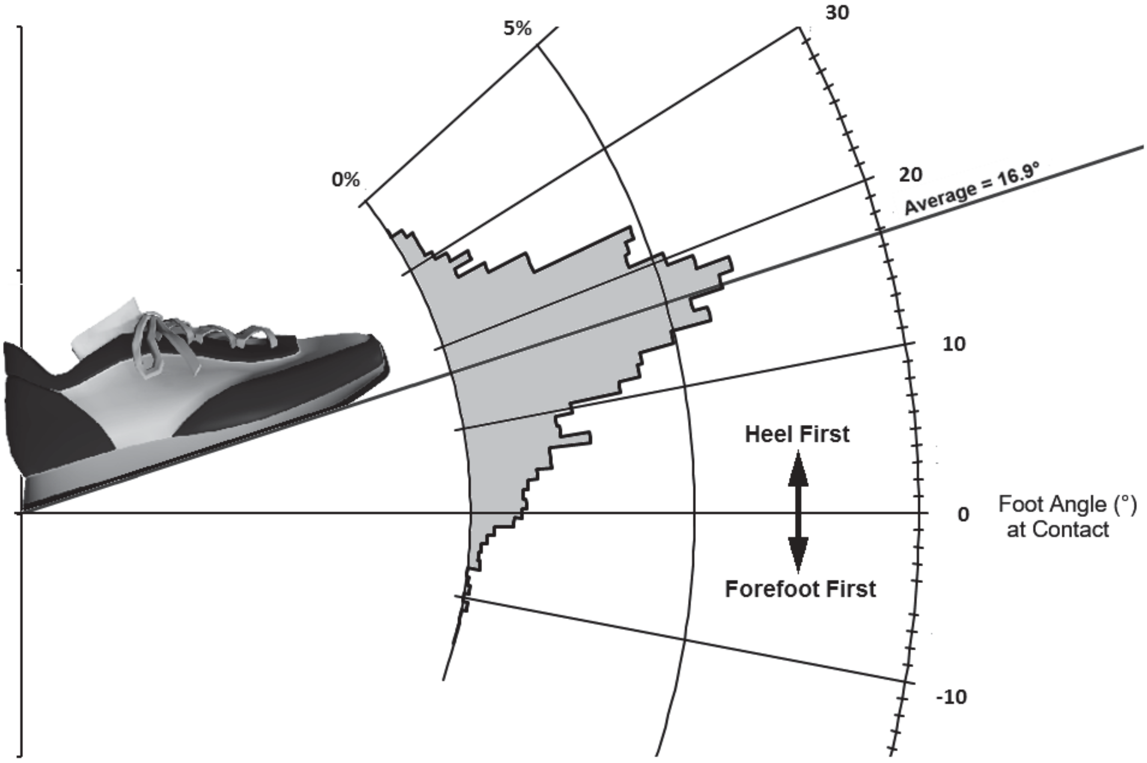

Figure 2: Distribution of foot contact angles in 1843 Boston Marathon participants.

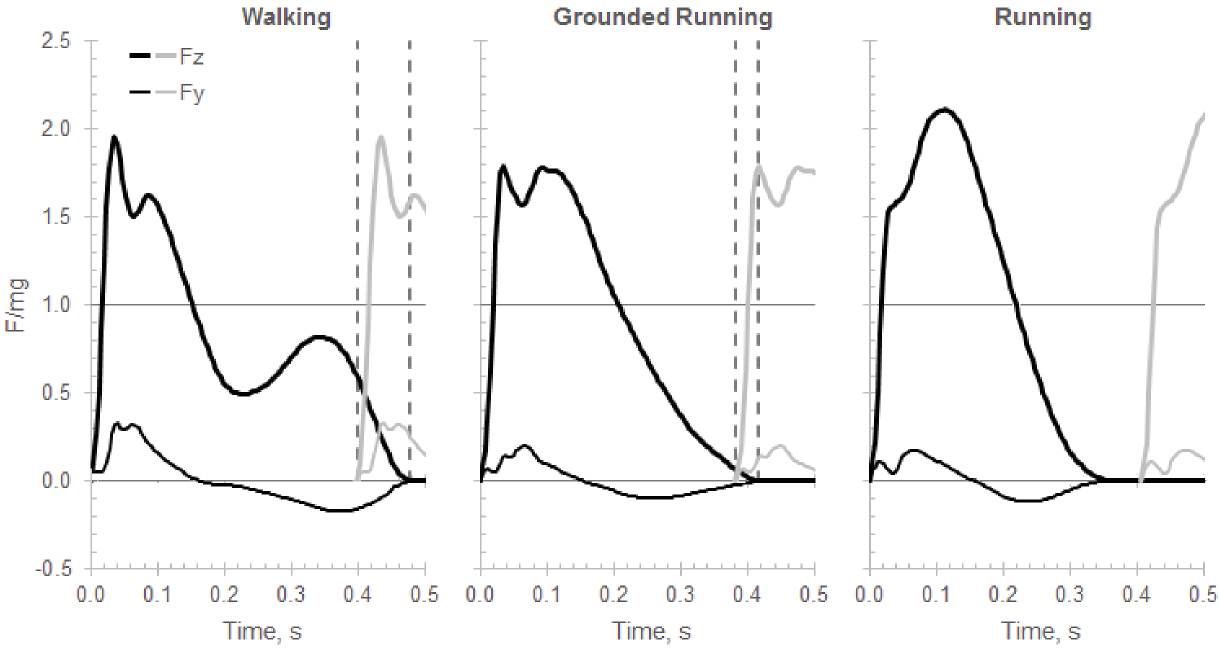

Figure 3: Vertical and A-P forces during walking, grounded running and running at gte same speed. Dashed lines indicate periods of double support.

DISCUSSION & CONCLUSIONS: Despite the decades of effort invested in the study of running biomechanics, we continue to discover that many widely held beliefs are erroneous. Cavanagh and Lafortune (1980), in a seminal and influential paper, described examples of different centre of pressure paths produced by different foot contact patterns. Others redefined their examples redefined as distinct "types". If foot contact patterns are indeed continuously distributed, as our data shows, then recent arguments pro- and con- the benefits of different contact types would be moot. Similarly, running research has primarily investigated young, healthy male students running on a treadmill for short periods of time at relatively high speeds. This subject pool is no longer representative of the running population. We have asked the question "What did we miss?" How about a previously undocumented human gait that, at certain speeds, may be more economical than walking or running? Does that count? Notably, our observations did not require expensive equipment, merely the patience to stand by the side of a marathon course with a camera and notebook. Consequently, we believe that many opportunities remain to test widely held assumptions and to challenge long-standing paradigms that sometimes persist because of convenience and habit despite the scarcity of compelling evidence.

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