# GENERATING AND APPLYING KNOWLEDGE IN SPORTS BIOMECHANICS: EXAMPLES FROM ROWING AND RUNNING

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Sometimes new knowledge, gleaned from our biomechanics experiments, is surprising, even counter-intuitive. Some examples from rowing and footwear biomechanics research illustrate this phenomenon. A study of ergometer rowing reveals a flexion moment at the knee joint while it is extending during the drive phase with implications for strength and conditioning. On-water rowing measurements of rower power output underline the importance of recovery phase technique. Observations of multi-segment foot motion while running have exposed the barefoot as a flexible power generator, raising questions about the efficacy of footwear. These experiences, surprising at their time, were signs of pushing the envelope and fine tuning of our models.

**KEY WORDS:** joint power, energy, range of motion, specificity, footwear

**INTRODUCTION:** Biomechanics enables us to ascribe cause and effect between elements of the execution of a movement and its outcomes. It provides the conceptual framework for understanding the mechanisms of sport movements and thence to improve performance, minimise injury and suggest novel techniques and improvements to equipment. It is rare for biomechanical analysis to be at the instigation of paradigm shifts in technique such as the somersault long jump and the Fosbury Flop. More often biomechanics contributes incrementally to small gains in performance. This paper is a glimpse at the experience of these processes by one sports biomechanist through rowing and footwear research.

***Case One: Ergometer rowing***

**BACKGROUND:** Rowing takes place recreationally and competitively on ergometers. To maximise performance it is helpful to understand the mechanisms of power production. Joint powers, developed during execution of the task, describe the relative contribution of the major muscle groups to total external power output, their implications for strength and conditioning and, with further modelling, insight into the causes of pain or injury (Greene, Sinclair, Dickson, Colloud, & Smith, 2013).

**METHODOLOGY:** Fifteen injury-free elite male rowers (age 25.2 ± 4.4 years, height 1.915 ± 0.072 m and body mass 91.0 ± 7.4 kg) volunteered to participate in this study approved by the Human Ethics Review Committee of the University of Sydney. Rowers were asked to warm up for 5 min then perform 1 min rowing at 80 % maximal power at 32 strokes/min on a Rowperfect rowing simulator equipped with handle and stretcher force transducers.
The 3D trajectories of fifty two retroreflective markers were tracked by a nine camera motion capture system synchronised with the recording of simulator force transducer outputs at 100 Hz. Toe, ankle, knee and hip joint centres were calculated from this data. The force and filtered (5 Hz) joint centre data were input to a nine segment, sagittal plane, inverse dynamics model of the rower (Winter, 1979).

**RESULTS:** The mean joint energy per drive phase generated by the rowers was 479 ± 24 J (hip), 231 ± 16 J (knee), 211 ± 18 J (lumbar), 125 ± 8 J (shoulder) and 108 ± 5 J (ankle). The knee joint absorbed energy during the drive phase between 23% and 36% of the stroke due to the knee moment becoming a flexion moment for this period (Figure 1). Inspection of the emg record for muscles crossing the knee supported this finding in that the rectus femoris and vastus lateralis muscles were highly activated after the catch but passed through a minimum while the hamstrings' activation reached a maximum in this same 23% – 36% period.

**DISCUSSION AND CONCLUSION:** It is counter-intuitive that the knee joint should be exerting a flexion moment in the middle of the drive phase of rowing. However, consider that at this point in the stroke almost all body weight is supported by the feet of the rower. Thus there is a large external extension moment applied to the knees until the knees are fully extended. This explanation was supported by observation of activity in muscles crossing the knee extensor muscles. The same pattern of muscle activation was found for rowing on-water by (Fleming, Donne, & Mahony (Fleming, Donne, & Mahony, 2014). This pattern is clearly different to the pattern observed in the dead lift, a common strength training activity for rowers. A more specific activity for rower's lower limb muscles should be introduced into the strength training program.

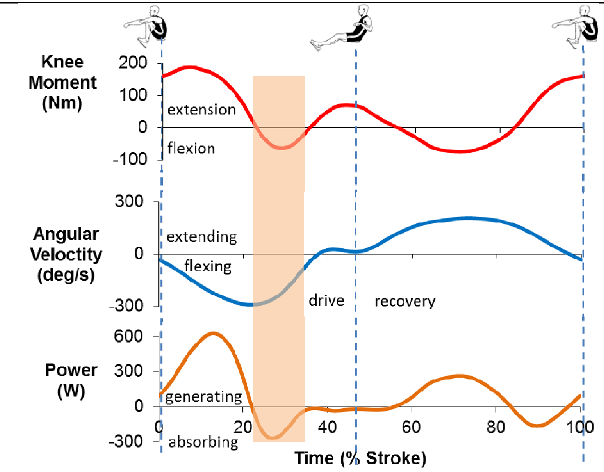



**Figure 1: Mean knee moment, angular velocity and knee power during rowing at 32 strokes/min. on a Concept 2 fixed rowing ergometer. The shaded area is the period where the knee joint is absorbing power.**

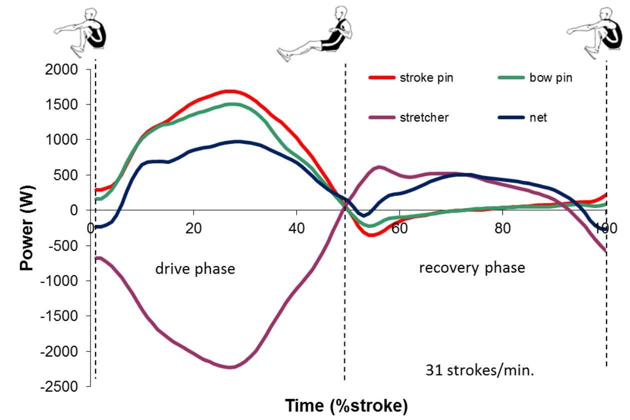


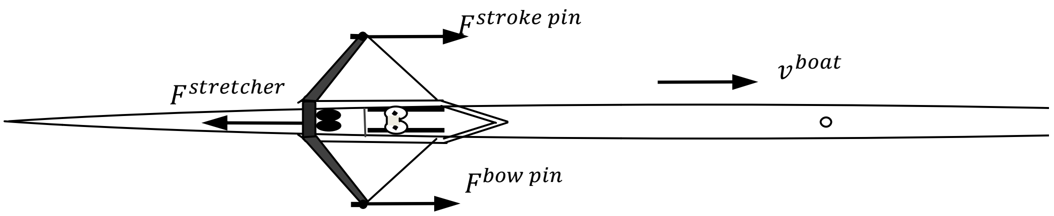

**Figure 2: Power delivered to the boat pins, stretcher and net power. The area under the power-time curve is the energy expenditure for that time.**

### *Case Two: On-water rowing*

**BACKGROUND:** In the case of a single sculler the forces applied to the boat in the propulsive direction by the rower are:

$$F^{boat} = F^{bow\ pin} + F^{stroke\ pin} + F^{stretcher} + F^{seat}$$
$$= F^{bow\ pin} + F^{stroke\ pin} + F^{stretcher}$$

neglecting the seat force as it is on wheels.




Then the power delivered to the boat by the rower will be:

$$P^{boat} = F^{boat} \cdot v^{boat} = F^{bow\ pin} \cdot v^{boat} + F^{stroke\ pin} \cdot v^{boat} + F^{stretcher} \cdot v^{boat}$$

The purpose of this experiment was to examine the power delivered to a single scull throughout the whole stroke.

**METHODOLOGY:** For this case study a world champion female sculler rowed an instrumented single scull at 32 strokes per minute. Scull velocity was measured with a magnetic turbine and pickup coil, pin force with multi-component force transducers, stretcher force with strain gauge transducers, and oar angle with servo potentiometers. This information was sampled at 100 Hz for twenty consecutive strokes. Power delivered to the boat by the rower was calculated as the product of boat velocity and the pin and stretcher forces.

**RESULTS:** Immediately after the catch for 5% of the stroke the rower was absorbing power from the stretcher at a greater rate than was delivered to the pins via the oars. From that time on power was delivered to the boat until a peak of 974 W was reached during the drive phase. After another minimum at the finish of the drive phase power was again delivered to the boat during the recovery reaching a peak of 505 W before the rower again absorbed power from the boat leading up to the next catch. The total energy delivered to the boat was 816 J/stroke. Thirty percent of this energy was delivered during the recovery phase (Figure 2).

**DISCUSSION AND CONCLUSION:** The on-water observation that 30% of the power of power delivered to the boat was during the recovery phase has focussed attention on movement technique during the recovery phase. Certainly the rower is expending the great majority of rower-generated energy during the drive phase. However, most of this energy is absorbed by the rower's body during the drive phase due to the stretcher reaction force. Hence the perception of the rower is that little energy is transferred to the boat by comparison during the recovery phase. Focussing on recovery technique can optimise the 'run of the boat' during this phase in which the boat velocity reaches a maximum.

***Case Three: Foot dynamics during running***

**BACKGROUND:** The foot is a complex structure with 26 bones and wide range of other tissues active and 'passive'. The myth still abounds that "… as the subtalar joint supinates, the midtarsal joint's motion decreases until it eventually locks the forefoot on the rearfoot in preparation for its rigid lever function during the propulsive phase of gait."

**METHODOLOGY:** Ten healthy males (height 1.78 ± 0.12m, weight 74 ± 2.1kg, age 24 ± 7 yrs, shoe size US 10 ± 2) gave their informed consent to participate in the study and ran overground through the data collection area of the laboratory. The 3D trajectories of 18 retroreflective markers (skin-mounted for both conditions) were tracked by a ten camera motion capture system synchronised with the recording of ground reaction force data at 200 Hz. The forefoot was modelled by the navicular and metatarsal head markers (Wrbaski & Dowling, 2007) and the rearfoot by a three-marker wand attached to the calcaneus.

**RESULTS:** The dorsi-plantarflexion range of motion of the midfoot joint was comparable with ankle dorsi-plantarflexion (Figures 3 and 4) in the barefoot condition while shoe-wearing made a differential change to these angles. After heel rise (~60% stance phase), the peak power from the midfoot joint in the sagittal plane during running (0.37 W/BW) was reduced by 30% when wearing shoes ($p < 0.001$) (0.23 watts/BW) (Figure 5). On the other hand, the power at the ankle joint when wearing shoes (0.73 W/BW) was increased by 22% ($p = 0.043$) compared with the power developed when barefoot (0.60 W/BW) (Figure 6). The total amount of power from this region remained relatively constant between the footwear conditions (Table 1).

**Table 1.** Energy expenditure (J) after heel rise in the sagittal plane during running.

| | | Footwear | |
|---|---|---|---|
| | | Barefoot | Shod |
| Joint | Midfoot | 24 | 14 |
| | Ankle | 50 | 58 |
| | Total | 74 | 72 |

**DISCUSSION AND CONCLUSION:** The wide range of motion exhibited by the midfoot joint during propulsion while generating a significant fraction of total power output suggests that a single segment model of the foot during running oversimplifies lower limb function during running. If the function of footwear is to facilitate movement that mimics barefoot gait while providing comfort and protection for the foot, then the prevailing paradigm for footwear needs to change. For example, a traditional Oxford style school shoe has a relatively rigid upper and sole which often has “arch support”. The long term effects such a shoe has on movement function should be studied in comparison with a shoe that allows barefoot action.

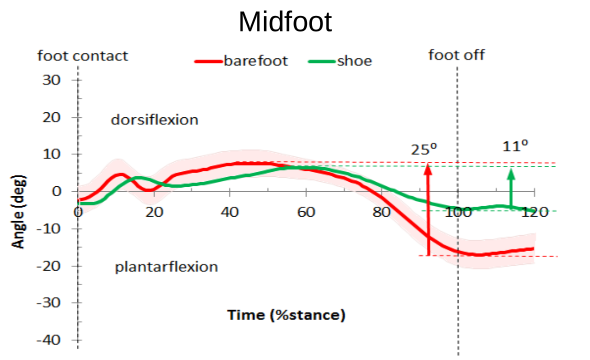



**Figure 3: Mean midfoot dorsi-plantarflexion for the stance phase during running.**

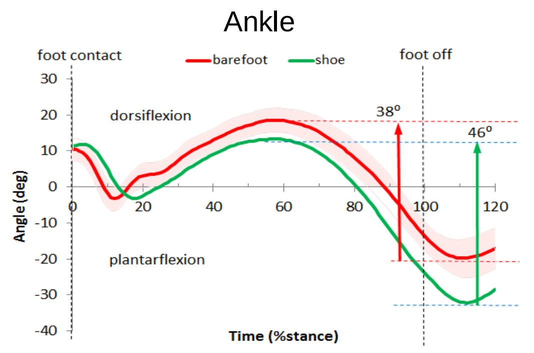



**Figure 4: Mean ankle dorsi-plantarflexion for the stance phase during running.**

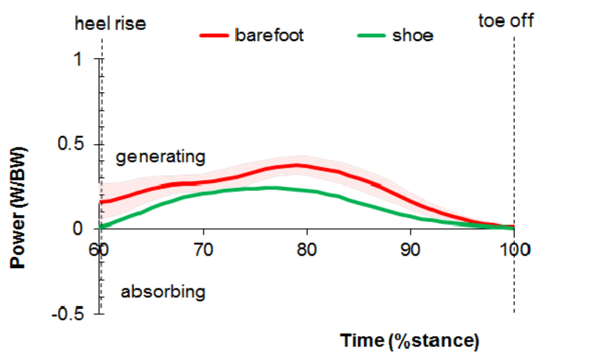



**Figure 5: Mean midfoot dorsi-plantarflexion joint power post heel-rise during running.**

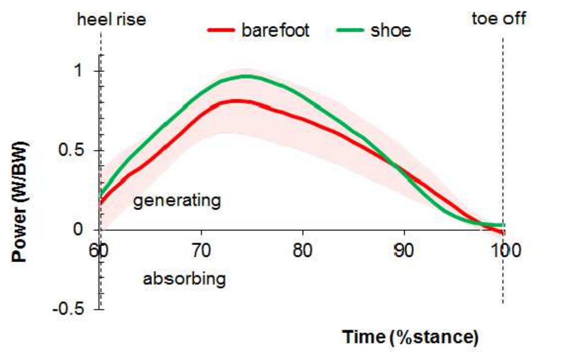



**Figure 6: Mean ankle dorsi-plantarflexion joint power post heel rise during running.**

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