energy of the two legs varies little throughout the pedaling cycle, so it may be ignored in comparison to the kinetic energy, which increases rapidly as the thighs swing into motion and decreases just as rapidly when they come to rest. (See Hull, Kautz, and Beard 1991 for specific numerical examples.) On a free-wheel-equipped bicycle (or a fixed-wheel bicycle on which the cyclist strives to keep the chain taut), the cyclist's muscles must supply the power required to accelerate the legs. The muscles could also absorb that energy to keep chain tension from varying, but it is far more efficient to allow the chain to slow the legs, so that their kinetic energy is transmuted into propulsive work. There is no obvious inefficiency in this pedaling style: the cyclic interchange of energy transmits a specific average power (proportional to the cube of pedaling rpm) to the rear wheel, on top of which one may perform additional work.

But now imagine the case of the rider's wishing to pedal more gently (after entering a paceline, for example). If the required pedaling power happens to be lower than the average dictated by the pedaling cadence and the rider's leg mass,[14] any excess of power will have to be absorbed by the brakes or by the rider's muscles through eccentric contraction. These are both very inefficient, so the cyclist is better advised to pedal only intermittently or to shift to a higher gear.

As another example, consider stand-up pedaling. If all the cyclist's body weight during stand-up pedaling is applied to each pedal in turn, then crank torque is a simple rectified (i.e., positive-only) sinusoidal function with a fixed amplitude. Even if the rider's arms share in the work by tipping the bicycle (this is a good example of a nonmechanism way to add arm work), power is easily calculated from body weight times average speed of pedal descent (i.e., revs/s times twice the pedal-circle diameter). How can one change the stand-up pedaling torque so as to adjust pedaling speed? To increase pedaling speed, it is obvious that one can pull up on the rising pedal, adding more force to the other pedal and increasing crank torque to any level. But pedaling more slowly is a problem: if the rider fixes her center-of-mass (CoM) height (as if sitting on a seat) then any downforce applied by the rising leg is immediately translated into eccentric contraction (negative work) that absorbs output from the other leg.

Actual stand-up pedaling involves a hearty range of vertical body motions. One option is for the cyclist to let the lower of her two legs remain straight while she straightens the upper. This motion exerts no net crank torque, as the body is lifted half the diameter of the pedal circle. Then the downward-moving leg, now straight, is held rigid while the body falls (no muscular work performed). By this means, the power output of the legs can be halved without any negative work. The contributing author has been unable to think of any stand-up pedaling scheme that could reduce

energy expenditures still further while still supporting all the rider's weight on the pedals.

Effects of pedaling motion, body position, and rpm

Up to this point, the chapter has been concerned with the overall physiology of muscles and exercise and some general background on pedaling. Now we take up a variety of questions related to the specifics of pedaling. There is almost no theory to guide us in this area, so the main thrust will be to report on efforts to devise improved pedaling mechanisms.

Pedaling and rowing motions

Harrison's (1970) curve for short-duration pedaling or cycling (figure 2.15, curve 1) was developed based on measurements taken from a group of active men, not record athletes. The significance of his results lies, therefore, in measurements of the relative power produced by the same individuals using different motions and mechanisms. Harrison's findings seem to be particularly significant because his subjects produced, in some cases,

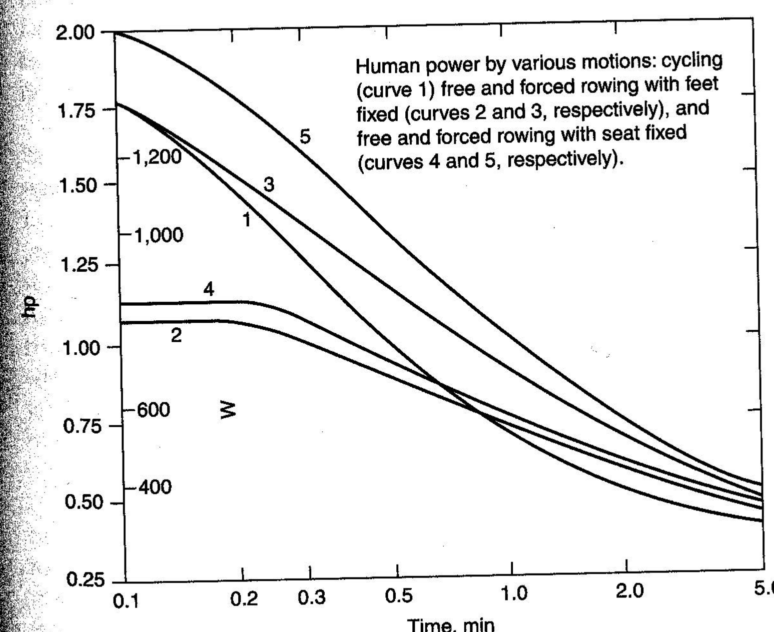

Figure 2.15
Peak human power output by various motions. (From Harrison 1970.)