From 1982 through 2006, "Measurement News" was the official newsletter of the USATF Road Running Technical Council, which oversees the USATF Course Certification Program. The following article was published in the March 1991, Issue #46 newsletter.

Understanding Aidedness – The effect of Drop

By Bob Baumel, Road Running Technical Committee

The purpose of this essay is to clarify the previous work by RRTC members on aided courses and to dispel some misconceptions regarding that work. I will set out what I believe is a useful definition of an aided course. I will explain how a course can be "tough" even though it is aided. And I will discuss the optimal pacing strategy for taking advantage of an aided course (or any other hilly course for that matter).

When is a Course Aided?

A course is aided if it requires ***less energy to run*** than a flat course of the same distance. This doesn't guarantee that any particular runner will run it faster, or even that the *average* times will be faster. It does offer a distinct advantage to any runner who is smart enough to pace the course properly.

Suppose, for example, that marathon X requires 99% as much energy to run as a flat marathon. Then a runner who maintains the *same rate of energy consumption as on the flat course* will inevitably cover marathon X in about 99% as much time as the flat course.

In reality, many runners receive less than the maximum benefit because they *don't* pace themselves optimally, i.e., when running up and down hills, they don't parcel out their energy at the same even rate as on a flat course. (More on this later.) But with just a little practice, runners can easily master the optimal pacing strategy and take full advantage of aided courses.

What do we mean by "Effective Length"?

I said that a course is aided if it takes less energy to run than a flat course. Energy cost can be measured in physical units such as joules, calories, etc. But it can be simpler to speak in terms of "effective length", which is just a shorthand way of stating the course's energy requirement *relative to the energy cost of a flat course.*

For example, I have written that the effective length of the Boston Marathon course is about 500 meters short of the marathon distance. What this means is that running Boston requires the *same amount of energy* as a flat course roughly 500 m shorter than a marathon. (Which *may or may not* translate into an equivalent time saving, depending on how runners pace the course.)

How Do We Know the Energy Cost of Running a Course?

The energy cost of running at any speed or incline is known from laboratory treadmill experiments. It has been argued that our results apply only to short races because they depend on laboratory tests involving short durations of running. Actually, when you realize that we used laboratory data ***only*** to tell us the energy cost of inclined running, it should become clear that our results were ***not*** limited by the duration of the experiments. I should point out also that these experiments were not "performance tests" in any sense.

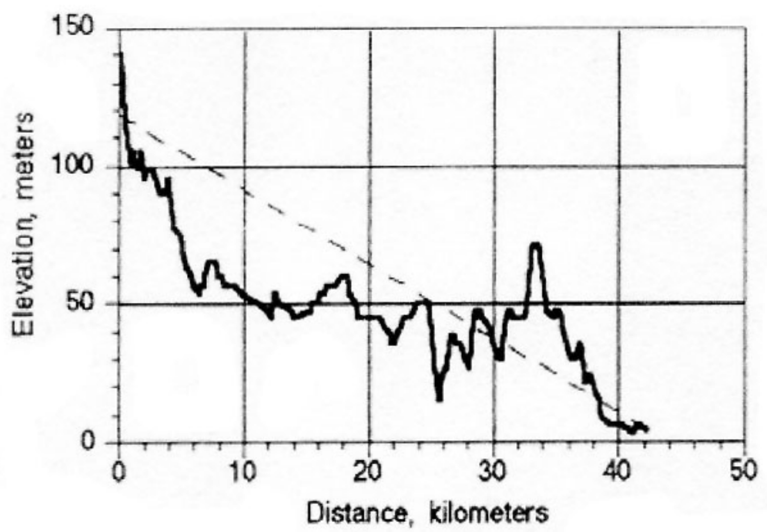
Let me explain. In an experiment to measure the energy cost of running, it is necessary only for the exercise to last long enough to attain an aerobic steady-state. Beyond that point, the result does not change with duration of the experiment. Also, the athlete should not be pushed near his limits in this type of experiment. If he does approach his limits, it results in anaerobic metabolism which reduces the accuracy of the energy cost measurement!

Once we know the energy cost of running any uphill or downhill grade, we can calculate the total energy requirement of any course with a known topographic profile by just adding up the energy needed for each individual level or sloping segment. This calculation is equally valid for courses of any length because the energy cost of running at a given speed and incline does not vary with time during a race (even though the runner's ability to *produce* energy may change).

And once we know the course's total energy cost, the rest of our argument follows by inexorable logic, and is equally valid for races of any length. If the total energy cost of the course is less than that of a flat course, and if a runner can maintain the same rate of energy consumption as on the flat course, then he will inevitably cover this course faster than the flat course.

Can an "Aided" Course Also be a "Tough" Course?

In the debates at the 1990 Convention, some runners said Boston is a "tough" course while others said it's an *easy* course. While these feelings are highly subjective, the definitions I've presented here permit a somewhat more objective treatment. I said that a course is aided if it takes less energy to run than a flat course. And this represents a *potential* time saving if the runner paces it smart enough.



Given this framework, one can easily imagine two courses that are equally aided (i.e. have equal energy requirements), but which differ in how smart the runner's pacing needs to be in order to realize that aid. The above graph displays the actual profile of the Boston Marathon course and also shows (with a dashed line) the profile of a hypothetical uniformly sloping course that would be equally aided.

The Boston course has a NET drop of 136 meters, although this is actually the result of 176 m of climb and 312 m of descent (with some of the individual uphills and downhills being fairly steep). The uniformly sloping course has a drop of 113 m, which occurs uniformly and gently throughout the course. Boston has an *average* downhill grade of 3.2 meters per kilometer, while the uniformly sloping course descends 2.7 meters *every* kilometer.

Both of these courses have the same energy requirement, equivalent to an “effective shortness” of about 500 m. But it’s fair to say that Boston is the “tougher” of the two because you need to be far more careful about your pacing strategy to take advantage of Boston’s aid. The uniformly sloping course allows runners to benefit with basically no strategy at all because constant energy consumption is identical to constant *speed* in that case.

Let’s Get Quantitative: How do Hills Affect Energy Cost?

Our data indicate that every meter of climb increases the energy cost by roughly the same amount as adding four meters to the course. In the same way, each meter of drop *decreases* the energy cost as much as *shortening* the course by four meters.

Another way to say this is that if you want to maintain a constant rate of energy consumption, then when you run up a 1% grade, you should run about 4% slower than on the level. And when you run *down* a 1% grade, you should run 4% *faster* than on the level. Similarly, when you run up (down) a 2% grade, you should run about 8% slower (faster) than on the level. And so on.

If the above figures were exactly correct, then the effective shortening due to one meter of drop would exactly balance the effective lengthening due to one meter of climb. Do the downhills really give you back everything that you lose on the uphills? Of course not. Nature would never be that kind! Nevertheless, the downhills do give back a *surprisingly large percentage* of the extra energy consumed on the uphills.

The precise degree of non-cancellation depends on the steepness of the hills. For example, if you have equal uphills and downhills with a 1% grade, our calculations indicate that the downhills return about 97% of the extra energy used on the uphills. On 2% grades, the downhills give back 94%. Even on 5% grades (roughly the slope of Heartbreak Hill), the descent still returns about 85% of the cost of the ascent.

These results help us understand why even though the Boston course climbs 176 m and drops 312 m, its total energy cost is nearly the same as one might predict knowing *only* the course’s net drop of 136 m. (As indicated earlier, Boston actually has the same total energy requirement as a uniformly sloping course that drops 113 m.)

The moral is that, in general, equal uphills and downhills *nearly* cancel out in terms of energy cost. What this means is that runners hurt themselves on hilly courses mainly because of poor pacing – not because there's a high energy cost.

(By the way, wind is rather different from slope in this regard. If you spend roughly equal time with and against the wind, you'll probably lose far more energy heading into the wind than you regain when it's at your back. Mathematically speaking, the difference is that the wind effect is much more *non-linear* than the slope effect.)

Let's Hear More About the Optimal Pacing Strategy:

Experience shows that on *flat* courses, the best performances tend to be very nearly evenly paced. Naturally, this even pace will differ for races of different lengths (You don't run as fast in a marathon as in a 5 km race), but within a single race, the pace is nearly constant.

If the course is *not* flat then, considering the importance of energy metabolism in determining distance running success, the correct generalization of the flat even-pacing strategy is to maintain a *constant rate of energy consumption* (not constant speed).

This idea is not new, as it has been expounded by many coaches and exercise physiologists. For example, Own Anderson recently advocated such a strategy in his article in the January 1991 *Runner's World*.

To parcel out your energy at an even rate, you must slow down on the uphills and speed up on the downhills. For example, when running up a 5% grade (roughly the slope of Heartbreak Hill), you should run about 20% slower than on the level. And on a 5% downgrade, you should go about 20% faster than on the level.

Almost every runner does naturally slow down on uphills and speed up on downhills *to some extent*. But ***not enough*** to maintain a consistent rate of energy consumption. The result is to increase energy consumption on the uphills and decrease it on the downhills. And this uneven energy consumption inevitably hurts performance.

For example, Owen Anderson wrote in his Jan 91 *Runner's World* article that by charging uphills too aggressively, runners build up lactic acid that significantly slows them down for the remainder of the race.

Why Don't Most Runners Follow the Optimal Pacing Strategy?

There are many reasons why most runners don't slow down enough on uphills, or speed up enough on downhills, to maintain constant energy consumption. One possibility is that once the runner settles into a certain rhythm, it produces an "inertia" to maintain *speed*, which works against the speed changes needed to maintain constant energy consumption.

Another possibility, referring specifically to uphills, is that the runner may view uphill running as painful and unpleasant, and therefore tries to get it over with as quickly as possible (so he runs it too fast). Or the runner might just be too "macho" to slow enough on the uphills.

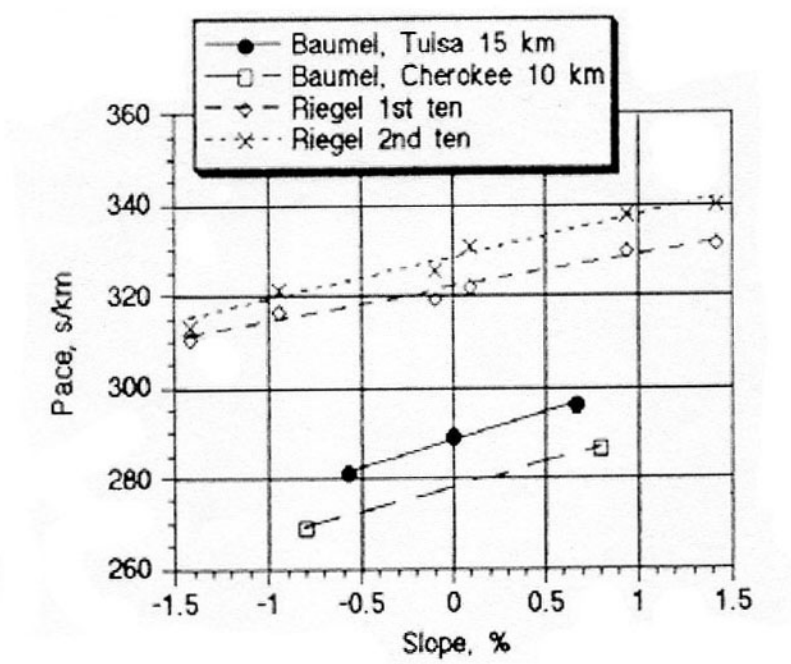
Referring to downhills, the runner may (consciously or unconsciously) use downhill segments to get some rest, or may be afraid of going too fast and getting 'out of control'. Owen Anderson's Jan 91 *Runner's World* article discussed a recent study of runners on hilly courses. This study found that although the runners increased their speed by 12% on downhill stretches, they *decreased* their rate of oxygen consumption (and thus their overall exercise intensity) by 10% on these stretches.

The optimal strategy on downhills is to run fearlessly and let gravity pull you along, while also continuing to exert your own energy just as hard as on the level sections.

Returning to uphills, perhaps the major reason why most runners don't slow down enough is *fear* that they will lose precious time that won't be regained later. Using the optimal strategy requires confidence that it *really is* the optimal strategy. You must slow down more than may seem 'natural' on the uphills, confident that you'll run fast enough on the downhills to gain back (nearly all of) the time lost on the uphills. If you are running alongside a competitor as you enter an uphill stretch, you must be prepared to let the other runner pull away, confident that you'll pass him back later.

Do Any Runners Actually Use the Optimal Pacing Strategy?

Considering that constant energy consumption pacing has often been recommended, I'm sure there are runners who use it, including some at the elite level. (And the number is bound to increase as the strategy is publicized.) Right now, my best example (clearly non-elite) illustrating use of the optimal strategy comes from my own running:



This graph displays data from my races in the 1989 Tulsa Run 15 km and 1990 Cherokee Strip 10 km (a local hilly race in Ponca City), and also some

Data collected by Pete Reigel. Pete's data were not collected in reaces, but were instead obtained during his noontime training runs.

The variables plotted are 'Pace' in seconds per kilometer, and 'Slope' in percent. (Just to be sure you have no illusions about the speed of these performances, I should point out that 300 seconds per kilometer is the same as five minutes per kilometer, or about eight minutes per mile.)

The data from my two races come from my times at the 5 km splits; i.e., each plotted point represents an average over a 5 km interval. That's why there are only three data points from the Tulsa Run 15 km and only two data points from the Cherokee Strip 10 km.

Pet's data are from splits recorded every mile during a six-mile run (actually he runs eight miles, but disregards the first and last miles). Pete has been doing these runs since the beginning of 1991, and already has 25-30 of them at this time (but so far, he's sent me the raw data from only the first 20 runs). What I have plotted are the average of his first 10 runs, and the average of his second 10 runs.

How can we tell if these performances were obtained with the optimal strategy? I said earlier that if you want to keep your energy consumption constant, then for every increase in slope of 1%, you should slow down about 4%. This suggest that we check the plotted data by figuring the percentage slowdown that occurs with each 1% slope increase. I will refer to this quantity as the "slowdown ratio".

The slowdown ratio was 4.18 in my Tulsa Run data, and was 3.89 in my Cherokee Strip data. In Pet's first 10 runs it was 2.26, while it was 2.83 in his second 10 runs.

As both of my races indicate slowdown ratios very close to 4, it seems likely that I came close to the optimal constant energy consumption strategy on both occasions. I must point out that the Tulsa Run has an early downhill and late uphill, while the Cherokee Strip course as the opposite pattern. Thus, I maintained the same uphill-to-downhill speed ratio in both cases, even though the order of uphill and downhill was reversed.

Pete apparently didn't come as close to constant-energy-consumption pacing, which isn't surprising since he recorded *training runs*. (I regard the optimal pacing strategy as a tool for *races*, and often depart from it in my training runs.) The increase in Pet's ratio between his first and second sets of 10 runs suggests that he may be getting more skilled at constant energy pacing.

Actually, if Pete's data indicate the way runners typically run (*without* any optimal pacing strategy), it suggests that an average runner might typically get about 2/3 of the benefit from an aided course that we compute by energy cost. This is consistent with statistical results that Ken Young obtained in 1984 by comparing times in the St. George and Fiesta Bowl Marathons.

In any case, I am convinced that constant-energy-consumption pacing is entirely practical, and allows you to obtain the entire potential benefit from an aided course (or indeed, to run as fast as possible on *any* hilly course).