Internal Load, External Load, and the Pole-force-ratio

Skisens white paper – April 2025

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There are several different ways to quantify the load the body is exposed to during physical exercise. These can be divided into measures of *internal load* and *external load*. Internal load refers to how hard the body is working, while external load refers to the work performed by the body.

Examples of metrics that reflect the body's internal load include heart rate, lactate, and oxygen uptake (VO_2). Of these, VO_2, unlike the other two, is also a measure of capacity (work capacity). Even though VO_2 is a measure of work capacity, it is not in itself a measure of performance. To compare performance we need measures of external load. The best measure of external load is work performed per unit time — i.e., power (watts). Power is proportional to VO_2 through the body's efficiency. Put simply, this means that external power can be increased either by increasing internal capacity as measured by oxygen uptake, or by improving efficiency.

Skisens power is computed by measuring the force in the pole and multiplying it by speed. Since the pole axial force is not aligned with the direction of travel, we also apply a factor that we call the *poling-efficiency index* (PFR), known in Swedish as *stavriktningsindex*. It is defined as the ratio between the force component in the direction of travel and the pole axial force. In general, PFR is not known on an individual level and is therefore set in the Skisens interface to a constant value, PFR=0.6, which is a typical value for a trained skier moving at controlled speed on gentle terrain. This is, of course, an approximation. In reality, PFR varies with technique and intensity, which means that the power measured by Skisens does not always coincide with external power as typically measured in cycling.

The fact that Skisens power does not perfectly overlap with external power means that we need to interpret the measured data somewhat differently than in cycling. It is not necessarily the case that a skier with higher Skisens power is a better skier. A contributing factor to high Skisens power can also be a lower Pole-force-ratio. However, it has been shown that Skisens power correlates extremely well with the body's internal load — in fact much better than external power, which in skiing depends strongly on whether one is skiing uphill or on flat terrain.

As an example, Figure 1 shows Skisens power overlaid with speed for a skier on a treadmill who maintains a constant external power of 200 W under different combinations of speed and incline. Note how heart rate is higher when Skisens power is higher, even though the external power is the same. To exclude the influence of accumulated fatigue, the test was performed in both directions, i.e., the skier first started at high speed (Figure 1) and then at low speed. In both cases it is clear that both heart rate and Skisens power depend on speed. In particular, both increase at high speed, but there is also a tendency for an increase in steep incline, suggesting a "sweet spot" where movement economy is best. Using Skisens power for intensity control instead of heart rate has a major advantage because the former responds much more quickly to changes in load.

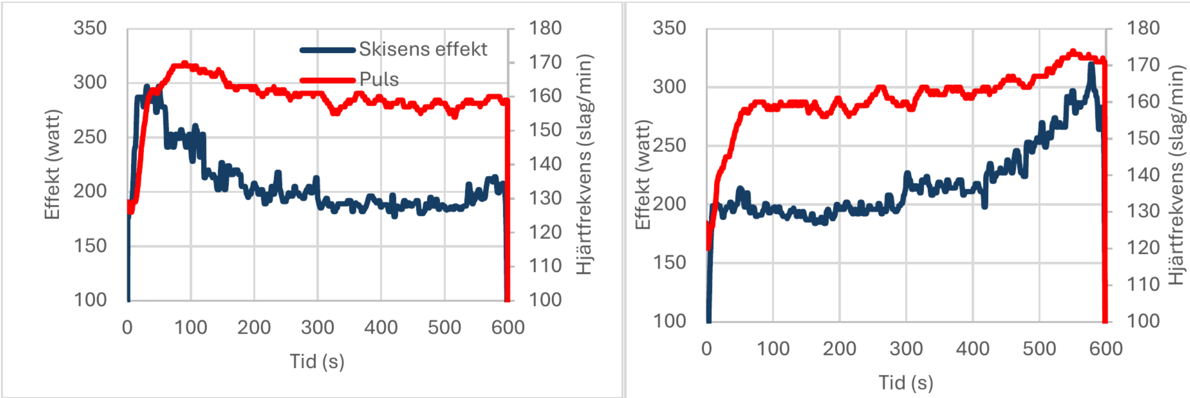

Figure 1: Skisens power and heart rate for a skier maintaining a constant external power of 200 W under different combinations of speed and incline.

The variations observed in Skisens power in Figure 1 can be translated into variations in PFR. This is illustrated in Figure 2, which also shows the protocol with variations in speed and incline. Underlying the PFR variations seen in Figure 2 are technique-related changes that can be reflected in Skisens key metrics: impulse, cycle rate, and ground contact time, shown in Figure 3.

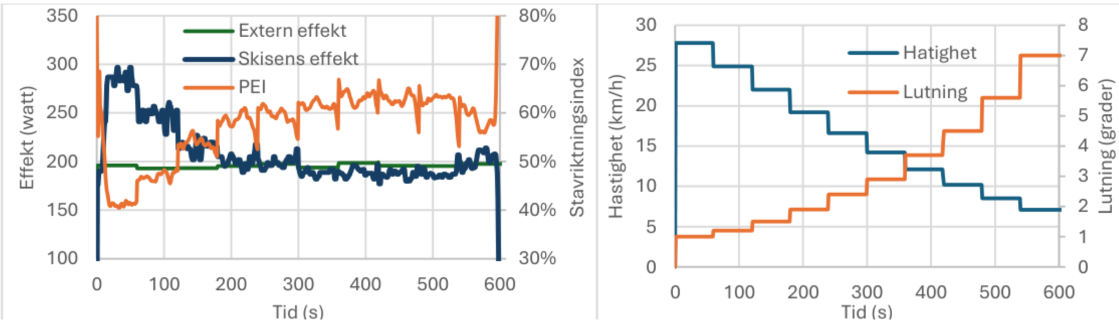

Figure 2: Variations in Skisens power with speed and incline during constant external power. (a) Skisens power and poling-efficiency index (PFR). (b) Speed and incline protocol throughout the test.

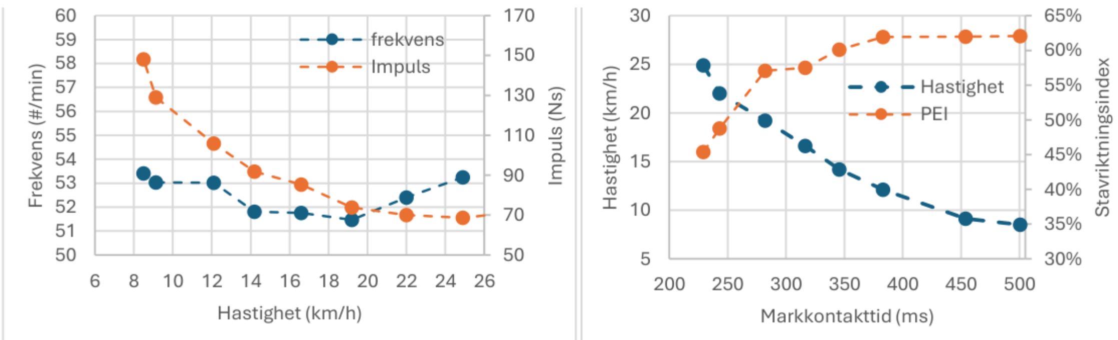

Figure 3: Variations in impulse and cycle rate with speed (a), and speed and poling efficiency as a function of ground contact time (b).

A notable observation in Figure 3 is that speed correlates strongly with ground contact time, and consequently poling efficiency also correlates with ground contact time, which enables the extraction of a model. Empirically, the model in Equation (1) has been found to fit well for describing the dependence of poling efficiency on ground contact time, as shown in Figure 3.

$$\mathrm{PFR}(T) = A \frac{\frac{T - T_{\mathrm{shift}}}{T_0}}{1 + \left(\frac{T - T_{\mathrm{shift}}}{T_0}\right)^{\alpha}} \tag{1}$$

where T is ground contact time, while A, T_{shift}, T_0, and α are fit parameters used to adjust the peak level, shift the curve along the x-axis, and control the relation between the initial PFR increase at short ground contact times and the subsequent decay at longer times.

Figure 4 shows the model in Equation (1) fitted to PFR for the test described above. By applying the model to Skisens power, it then becomes possible to estimate external power. Figure 5 shows the estimated external power. Note how, unlike Skisens power, it fluctuates around a constant value of 200 W (the external power) throughout the test.

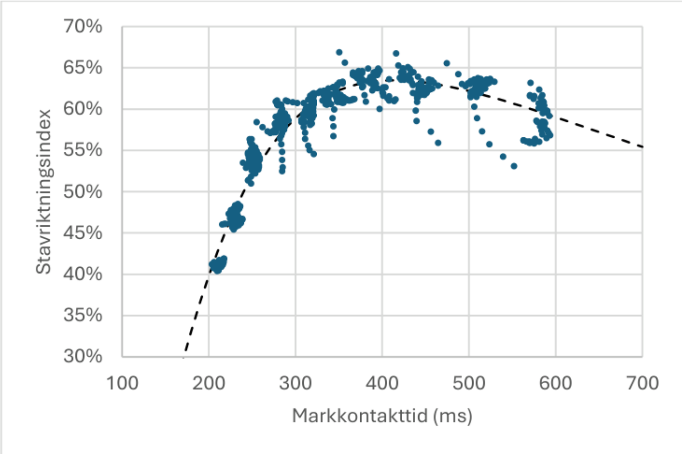

Figure 4: Measured ground contact time (.) compared with the model (–) in Equation (1).

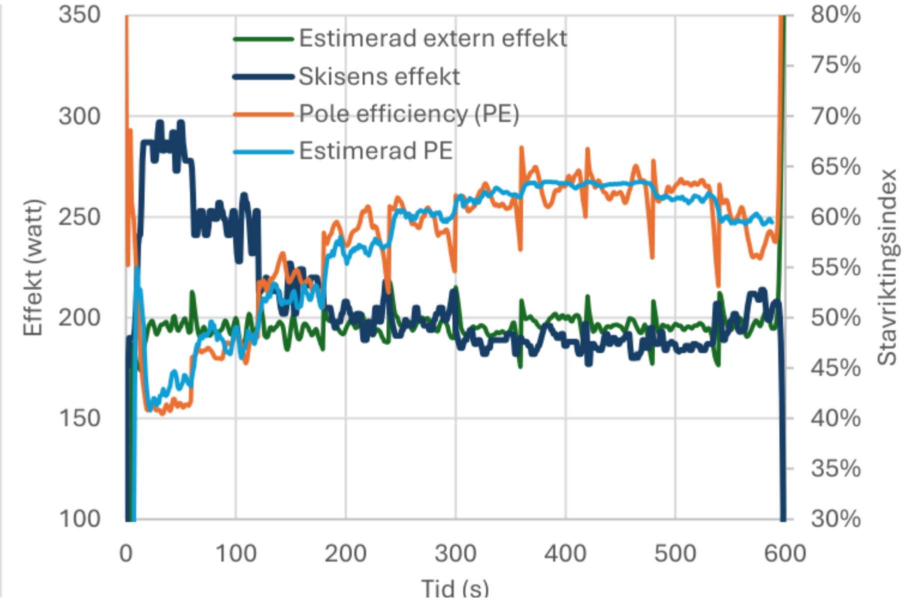

Figure 5: Comparison of measured and modeled PFR, as well as Skisens power and external power, during a 10-minute test following the protocol in Figure 2(b).

To further illustrate how external power can be obtained given knowledge of the Pole-force-ratio, Figure 6 shows metrics from a treadmill interval session. Note how Skisens power is below external power, and how they correlate very well. This indicates that, in this particular case, PFR is > 0.6, and that its variation over the session's speed range is moderate.

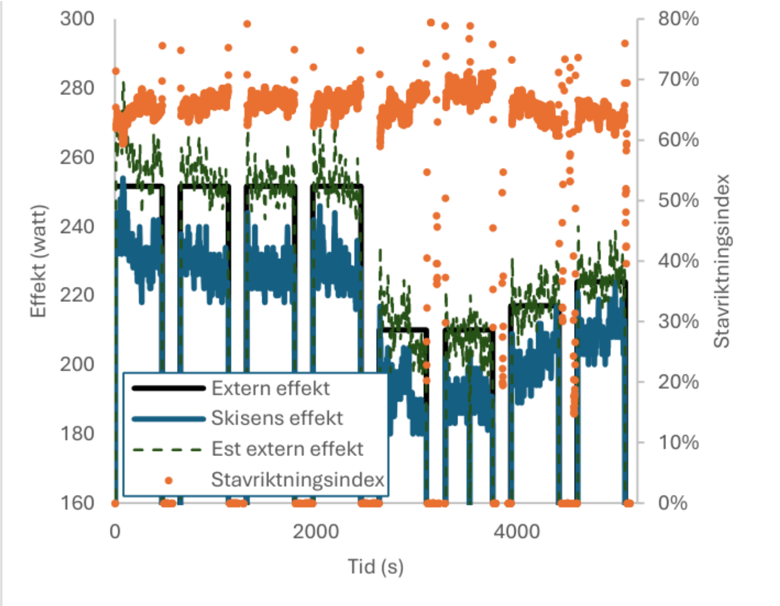

Figure 6: Power and Pole-force-ratio during a treadmill interval session. The first four intervals are at an incline of 5° and a speed of 12 km/h, followed by four intervals at 3° incline and 15, 15, 16, 16.5 km/h.

Discussion and Conclusions

In this text, we have discussed the interpretation of Skisens power in relation to how power is interpreted in cycling. First and foremost, both are measures of load. In this respect, training can be structured in essentially the same way at the individual level. One can use FTP expressed in Skisens power to prescribe and control interval training. For more detailed control of high-intensity intervals, a power profile can be employed.

However, we need to think somewhat differently when it comes to comparing performance. Skisens power is not a direct measure of external power in the same way as in cycling. The reason for this is that the Pole-force-ratio, i.e. the fraction of the applied force directed along the direction of travel, varies between different skiers.

Athletes who wish to better characterize their Pole-force-ratio can perform a treadmill protocol to derive a model of its variation with speed and ground contact time. Based on such a model, it is then possible to calculate the external power, which provides a direct measure of performance, analogous to cycling.