The Problems with Training Stess Score (TSS)

Drew Shardlow

email shardlow.a@gmail.com

September 30, 2021

Introduction

The Training Stress Score (TSS) was developed by Dr. Andrew Coggan Ph.D. and is used on the web platform Training Peaks. He is an accomplished athlete (cycling) and exercise physiologist. It has its origins in cycling power. The ambition behind it was to account for the experience that workouts with varying power were harder than those with a constant power even if mean power was the same (and by implication over and above that which naturally arises from using a power squared function as an indication of intensity).

The Equation

He arrived at the following:

$$TSS = 100 \times \frac{t \times NP^{\circledR} \times IF^{\circledR}}{FTP \times 3600}$$

where "normalized power" $\quad NP^{\circledR} = \sqrt[4]{\frac{\sum_{i=0}^{n-1} p_i^4}{n}}$

and "intensity factor" $\quad IF^{\circledR} = \frac{NP^{\circledR}}{FTP}$

with smoothed power sample elements p_i

which constitue the vector $\quad \boldsymbol{p}$

This equation can be considerably simplified allowing us to get more insight into what is going on:

$$TSS = \frac{1}{36} \times t \times IF®^2$$

$$TSS = \frac{1}{36FTP^2} \times t \times \sqrt[2]{\frac{\sum_{i=0}^{n-1} p_i^4}{n}}$$

$$1.\ \boxed{TSS = \frac{1}{36} \times t \times RMS\left(\frac{\boldsymbol{p^2}}{FTP^2}\right)}$$

For a steady value the RMS is simply equal to that value and we get the simplified equation:

$$2.\ \boxed{TSS = \frac{1}{36} \times t \times r^2 \text{ where } r = \frac{p}{FTP}}$$

A steady power output at FTP for 60 mins gives a TSS of 100 as expected.

At first sight this makes intuitive sense as we have a power squared function of intensity to account for the much higher workload of exercising at higher power outputs. It also predicts a higher workout load where there is variation in power output.
I have two significant problems with this result:

1. The RMS of smoothed power does not properly account for this variability.

2. TSS scores don't add up.

1. Say power varied as a sinusoidal wave going up and down throughout the workout. Say it varied between 200 and 300 Watts over 60 minutes. It we had two workouts, one with a single cycle during the workout, and one with 10 cycles during the workout, the $RMS(\boldsymbol{P^2})$ and therefore the TSS are the same for both. It therefore fails in its ambition to properly account for any increased workload arising from variability in power.
2. We will re-express our simplified TSS equation. If the sampling rate for power is r time per second then the seconds $t = n/r$ where n is the number of samples. $\boldsymbol{p^2}$ is simply the vector formed from each element of $\boldsymbol{p}$ where ${p^2}_i = (p_i)^2$

$$TSS = K \times \frac{n}{r} \times RMS(\boldsymbol{p^2})$$

$$\frac{TSS \times r}{K \times n} = RMS(\boldsymbol{p^2})$$

$$\left(\frac{TSS \times r}{K \times n}\right)^2 = \frac{\sum_{i=0}^{n-1} p_i^4}{n}$$

$$\frac{TSS^2 \times r}{K^2 t} = \boldsymbol{p^2} \cdot \boldsymbol{p^2} = \sum_{i=0}^{n-1} p_i^4$$

The r.h.s is the sum of the fourth power of smoothed power values used in any TSS calculation. For two back to back workouts we can write:

$$3. \quad \boxed{\frac{TSS_{ab}^2}{t_{ab}} = \frac{TSS_a^2}{t_a} + \frac{TSS_b^2}{t_b}}$$

where TSS_{ab} is the TSS calculated for both workouts, considered as a single workout, and TSS_a and TSS_b are the TSSs calculated individually for the two consecutive workouts.

Now 3. is an odd equation. The TSS of workouts calculated individually do not (in general) add up to the TSS of the whole. The the form is similar to how you find the length of the hypotenuse of a right angled triangle using Pythagoras' theorem. This creates bizarre anomalies. Imagine two back to back workouts of 30 minutes, both at a steady power output, the first at FTP, the second at 0.5 FTP (we might take a really short break between them). From equation 2 above we see that the TSS for the first (TSS_a) is 50, and the TSS for the second (TSS_b) is 12.5. The simple sum of $TSS_a + TSS_b$ is 62.5. But if we use the above equation we get:

$$\frac{TSS_{ab}^2}{60} = \frac{50^2}{30} + \frac{12.5^2}{30}$$

$$TSS_{ab} = \sqrt{2 \times 50^2 + 2 \times 12.5^2} = 72.887$$

But for all intents and purposes it can be considered a single workout. That is odd! What if the second workout was at zero power (a rest). The equation should still work reliably. We would expect no additional TSS from this rest period.

$$\frac{TSS_{ab}^2}{60} = \frac{50^2}{30}$$

$$TSS_{ab} = \sqrt{2 \times 50^2} = \sqrt{2} \times 50$$

So TSS increases by doing nothing. This is clearly nonsense! Although extreme, we can see that periods of very low intensity activity during a workout artificially increase calculated TSS. Unfortunately TSS fails in its primary objective, to account for workload arising from variability in power output, and in trying to achieve this breaks the simple rule that the workout load calculated from consecutive workouts should add up.

In general, I believe a measure of training load of whatever metric needs be of the form:

$$l = k \times t \times \sum_{n=0}^{qt-1} f$$

where q is the sampling frequency

t is the duration in seconds

and k is a suitably chosen constant

The fact that it is a simple sum ensures the load calculated for consecutive workouts add together. We might choose a value of k to ensure a load $l = 100$ for exercise at threshold value for a particular sport and metric. Most calculated values of workload follow this pattern. There is incomplete evidence and little consensus on the exact form this function should take for a particular sport and metric. This is because there is no gold standard measure of workload. A simple first attempt at f might be something like:

$$f(p_i) = k \times p_i^2$$

If we wished to add in an additional component to account for variation (I personally don't see a rationale for this) we can do this in a way that does not break summation. We quantify variation by using differences between values but if we sum these they add up to zero. We could overcome this by using the absolute value of the differences:

$$f(p_i) = \alpha \times p_i^\gamma + \beta \times |p_i - p_{i-1}|^\delta$$

TSS is well established and deeply embedded in many training platforms and so there is very strong resistance to the acceptance that it is flawed. This resistance fails to provide a counter argument, other than the bald assertion that it is of value. It may well have value, as indeed the Borg scale does, but it is not optimal. Competitive athletes deserve a tool that is.