PIONEER OF WEARABLE SPORTS TECHNOLOGY

White Paper

Polar Training Load Pro

November 12, 2019

Polar Research and Technology

CONTENTS

1 Introduction

Heart rate has been the most popular measure for quantifying objectively training load during the last decades. However, new wearable technologies including GPS and accelerometers as well as power sensors opened up various new possibilities. While measuring training load from heart rate is still the preferred method in some sports, athletes and coaches from other sports favor to quantify training load based on power measures (cyclists) or combine heart rate with distance, speed or acceleration tracking (running, swimming, and team sports). Moreover, recent literature emphasizes the benefits of using subjective feeling to define training load and recovery.[1,2]

Up to date, no gold standard exists to quantify training load. A recent consensus statement of the International Olympic Committee on load in sport and risk of injury[2] recommended using internal and external load measures that are relevant and specific to the nature of each sport.

The term 'external load' refers to any external stimulus applied to the athlete that is measured independently of their internal characteristics (e.g. independent of fitness, age, gender, and body composition). 'Internal load' is needed in order to achieve external load and is a result of physiological and psychological responses. These responses are individual and depend on physiological characteristics (e.g. fitness, training background, age, gender, body composition) and environmental factors (e.g. higher effort needed in altitude or heat). Based on this recommendation, Polar Training Load Pro offers both, most popular internal and external training load measures instead of giving training load based on a single method. Selected loads for internal measures are Cardio load (based on HR measures) and Perceived load (based on RPE). From an external point of view, load will be measured with Muscle load, and determined from total power. In addition, the user still has the possibility to monitor other external load measures such as training time, frequency, type, speed, and distance.

2 Why measure

Polar Training Load Pro provides the user the possibility to:

- Quantify and monitor how much strain is placed on the cardiovascular and the musculoskeletal system and how the training session was perceived.
- Compare training with previous sessions (after training).
- Compare the Polar provided training loads with each other to track progress and detect early onset of fatigue (described in more detail in 3.4).
- Analyze training, e.g. to see which training periods/weeks were harder and which were easier.

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3 Description of Training Load Pro

3.1 Cardio load

Description

Cardio load – measured by heart rate - shows your cardiac response to a training session.

Advantages of use

- The user can assess and compare Cardio load from all sports from which heart rate recordings are available and use them for training planning and analysis.
- Cardio load takes into account the daily variations in effort needed to conduct exercise. Those daily variations depend on variables including hydration and nutrition status, fitness level, fatigue, mood, and environmental conditions which are not taken into account in Muscle load.

Calculation and interpretation

Cardio load is determined by a training impulse (TRIMP) calculation, which is a popular and scientifically accepted[2] way to quantify training load. It takes into account the duration and intensity of the session and can be calculated for all sports from which heart rate recordings are available. Several formulas exist how to calculate TRIMP. Based on a survey among scientists and practitioners, we figured out that the traditional Banister TRIMP formula[3] is still the preferred method to calculate TRIMP. The TRIMPS are computed each second and then the sum is calculated (Figure 1). The weighting factor is based on the relationship between heart rate and blood lactate as observed during incremental exercise.

$$W = \sum_{t0}^{tfinal} \frac{HR_{(t)} - HR_{(rest)}}{HR_{(max)} - HR_{(rest)}} \cdot 0.64 \cdot e^{1.92 \frac{HR_{(t)} - HR_{(rest)}}{HR_{(max)} - HR_{(rest)}}} \qquad \text{eq.1}$$

$$W = \sum_{t0}^{tfinal} \frac{HR_{(t)} - HR_{(rest)}}{HR_{(max)} - HR_{(rest)}} \cdot 0.86 \cdot e^{1.67 \frac{HR_{(t)} - HR_{(rest)}}{HR_{(max)} - HR_{(rest)}}} \qquad \text{eq.2}$$

Figure 1. Calculation of TRIMP with the Banister method.

$HR_{(t)}$: Heart rate at a given time

$HR_{(rest)}$: Resting heart rate (from user settings)

$HR_{(max)}$: Maximal heart rate (from user settings)

eq1 for males and eq2 for females

The higher the Cardio load, the more strenuous was the training session for the cardiovascular system. As TRIMP depends on the user settings, resting and maximal heart rate and gender, TRIMP will slightly differ between users, even if they would exercise with the same heart rate and duration. For the same external load (e.g. Muscle load described later), fitter athletes show a lower TRIMP compared to their counterparts with a lower fitness level. This is because they are able to exercise with a lower heart rate.

Limitations

There are two main limitations in using Banister TRIMP. Firstly, the well-known limitations of heart rate to quantify training load in sports with short bouts of very high intensity (anaerobic energy supply) e.g. during strength training and some team sports. Secondly, the use of generic weighting equations for modeling, only separating between males and females. It seems obvious that gender is not the only factor making athletes different. As such, the TRIMP calculation does not necessarily take into consideration all individual differences that affect training load.

3.2 Muscle load

Description

Polar Muscle load is an external load measure and shows the amount of mechanical energy (kJ) that you produced during exercise. This reflects your energy output, not the energy input it took you to produce that effort. Power measurements are a popular and scientifically accepted method to quantify training load.[2]

Advantages of use

- User can assess the work of the musculoskeletal system during training and use it for training planning and training analysis.
- User can make work of the musculoskeletal system comparable between training sessions, no matter what the slope is (this is not possible to do with speed or distance as external measure)
- As Muscle load is measured by power, it responds to an increase in rate of change of work almost instantaneously. It is therefore well suited for interval training due to its fast response time while heart rate may take several minutes to reach steady-state.
- The measurement range of Muscle load is substantially wide. Muscle load can measure aerobic and anaerobic intensities whereas the measurement range of heart rate is limited to aerobic intensity.

Calculation and interpretation

Muscle load is sports-specific because different muscles are used in each sport and thus a comparison between sports is not possible to do. Muscle load will be provided for sports where power is available and is calculated with following formula:

Muscle load = average power during training session * duration of training session

It requires the direct measurement of power (e.g. through power pedals in cycling) or estimation of power based on biomechanical formulas.

The higher the Muscle load within an individual, the more strenuous was the training session for the musculoskeletal system. However, the same Muscle load can be achieved with a high or low perception of effort or heart rate, depending on the fitness level of the user and numerous other factors including hydration and nutrition status, mood and environmental conditions.

Limitations

Muscle load does not take into account the effort needed to exercise. When comparing Muscle loads within a user, one shall be aware that effort needed to achieve the same power (either absolute power on flat terrain or power-to-weight ratio on an uphill slope) depends, among others, on fitness level, fatigue, and environmental conditions, e.g. altitude or heat.

3.3 Perceived load

Description

One of the most frequently used simple measures of load is the session rate of perceived exertion (RPE).[2] RPE is a measure of subjective exercise load and Perceived load is derived from session RPE and duration. RPE is defined to be a measure of internal load and is a valid method to quantify exercise training during a wide variety of types of exercise.[4] It is particularly common in team sports and has also been shown to be useful for training load calculation from strength training in a number of studies.[5,6]

Advantages of use

- The user can assess and compare Perceived load from all sports and use them for training planning and analysis.

Calculation and interpretation

Perceived load is calculated using the following formula:

Perceived load = RPE * duration

The higher the Perceived load, the more strenuous was the training session experienced by the user. Perceived load is comparable between and within individuals.

A score for RPE will be given after the training session on a scale from 1–10 (Figure 2).[7]

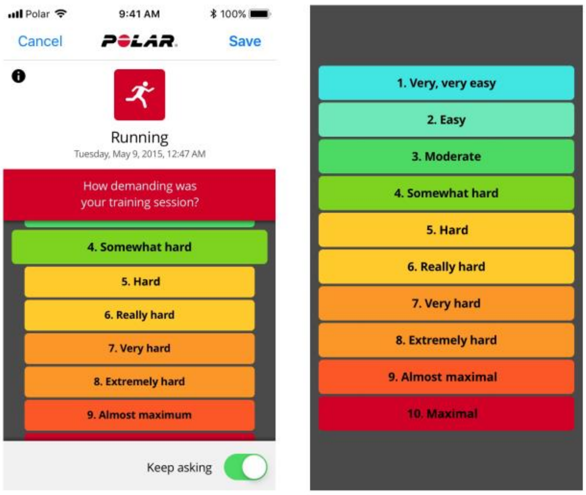

Figure 2. Session RPE scale

Limitations

Perceived load is a subjective and not an objective measure and can therefore be manipulated by the user. Perceived exertion is also likely a product of cardio and muscle effort and does therefore not divide the different physiological systems, which would be beneficial for optimizing training (e.g. do swimming or paddling when muscular load on legs was high).

3.4 Comparing different training loads

Description

As described previously, power measures the work done by muscles and is independent of effort (external load measure) while heart rate and RPE are measures of effort needed to generate power (internal load measures). Comparing internal and external measures as well as following the relationship between RPE and heart rate opens up valuable new possibilities to monitor training.

Advantages of use

- User can track sports-specific performance progress after each training session (if power and heart rate are available).

Calculation and interpretation

Example:

Runner X wants to check his/her running performance development after 10 training sessions. Let's assume (s)he generated the following data shown in Table 1:

Table 1. Data from 10 training sessions

Training session	Average heart rate [bpm]	Average power [W]	Ratio avg.HR/avg. power
1	178	385	0.462
2	150	330	0.455
3	132	291	0.454
4	138	305	0.452
5	144	326	0.442
6	168	385	0.436
7	180	415	0.434
8	160	378	0.423
9	130	310	0.419
10	155	380	0.408

The ratio of average heart rate/average power of each running session can be plotted as in Figure 3. The lower the ratio, the less effort (measured by average heart rate of the training session in this example) was needed to achieve training performance (measured by average power of the training session). This indicates improved running performance. On the other hand, an increase in the ratio of average heart rate/average power would indicate a decrease in submaximal running performance.

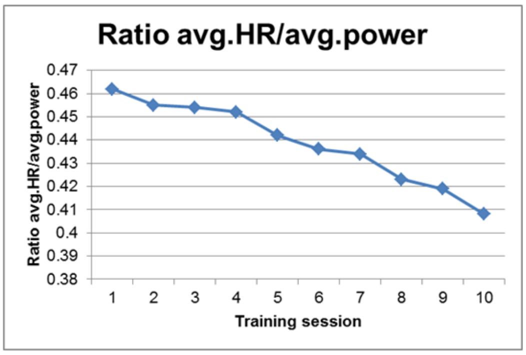

Figure 3. Improving running performance over 10 training sessions, measured by the ratio of avg. HR/avg. power. The lower the ratio, the better the performance.

avg. = average, HR = heart rate

In addition, it can also be helpful to compare RPE with heart rate, as the "normal" relationship between those variables may be inverted before sickness.[8]

Limitations

Variables such hydration, temperature, mood, sleep quality, and nutrition contribute to heart rate and RPE, both positively and negatively. As such, changes in the ratio of average heart rate/average power are not necessarily caused by lower fitness unless conducted under comparable conditions.

3.5 Training load and training load levels

Description

Training load quantifies the strenuousness of a single training session and makes different sessions comparable. It will be calculated for each of the three Training Loads separately.

- Cardio load (based on heart rate)
- Muscle load (based on power)
- Perceived load (based on rate of perceived exertion (RPE))

Polar Training Load Pro will be expressed in absolute numbers for all three loads (Figure 4). In order to make the user better understand the absolute load number, (s)he can also see the Cardio, Muscle and Perceived load relative to his/her own previous loads on a 5-scale interpretation. These relative training loads are called Cardio load level, Muscle load level and Perceived load level.

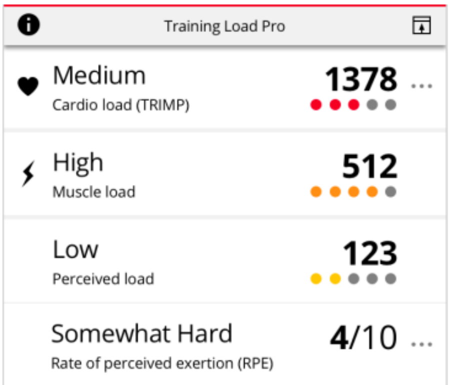

Figure 4. Mobile view of Training Load Pro. Each load is shown in absolute numbers and on a 5-scale interpretation with bullets and text.

Advantages of use

- The user can use absolute numbers for training planning and analysis.
- Training Load levels help the user to better understand the absolute training load number as load is shown in relation to own training history.

Calculation and interpretation

Calculation of absolute loads is described in the above chapters. The higher the absolute number, the more strenuous was the training session.

Load level will be calculated by comparing the absolute Cardio load, Muscle load and Perceived load of the new training session to the average session training load from the previous 90d. Table 2 describes which interpretations are given and how they are calculated.

Table 2. Training Load Levels

Very low	New session load is <0.5 * average of all training sessions conducted within last 90 days
Low	New session load = 0.5–0.75 * average of all the training sessions conducted within the last 90 days
Medium	New session load = 0.75–1.25 * average of all training sessions conducted within the last 90 days
High	New session load = 1.25–2 * average of all training sessions conducted within the last 90 days
Very high	New session load is ≥ 2 * average of all training sessions conducted within last 90 days

The algorithm for Training Load levels starts to work after 3 training sessions. If later on, less than 3 training sessions were done within the sliding 90 days, the 90 days average values will not be updated, and the latest valid average will be used.

Limitations

Limitations for absolute loads were described in previous chapters. Limitations for load levels are that the limits between very low, low, medium, high and very high were defined based on best practice from analyzing training loads from our customers and are therefore not based on firm scientific background.

3.6 Strain and Tolerance

Description

In addition to Cardio load, Muscle load and Perceived load for each training session, Cardio load is also shown as short-term and long-term training load. In scientific literature, short-term training load is often referred to as acute training load and long-term as chronic training load. In Polar terminology, we use Strain for short-term and Tolerance for long-term load.

Advantages of use

- The user can follow how Strain varied over the past months in order to know at which times training weeks were harder and when lighter.
- The user can see how Tolerance varied over the past weeks/months in order to know whether training has been progressive (needed to increase fitness).

Calculation and interpretation

Strain is defined as the rolling average of the most recent 7 days daily average Cardio load (in scientific literature also described as acute load), while Tolerance reflects the rolling average of the most recent 28 days daily average Cardio load (in scientific literature also described as chronic load). Based on the recommendation by Gabbet et al.,[9] Polar selected 1 week of training (7d) as default for Strain and 28 days as default for Tolerance. However, Tolerance can vary between 3–6 weeks of training. Strain is analogous to a state of \`fatigue\` (the more training has been done within the past week, the more fatigued/strained is the body) and Tolerance is analogous to a state of \`fitness\` (the more training has been done in the past month, the fitter the user is expected to be and the more (s)he is prepared to endure/tolerate training).[10] Banister et al.[10] proposed that the performance of an athlete in response to training can be estimated from the difference between a negative function (\`Strain\`) and a positive function (\`Tolerance\`).

Limitations

The interpretation of short-term loads being analogous to a state of “Strain“ and long-term Training Loads are analogous to a state of “Tolerance” are only an estimate and depend on the individual response to training, which also depends on lifestyle outside training. Moreover, these interpretations are not applicable during block training where highly concentrated training workloads are focused on carefully selected fitness components compared to traditional training periodization, which usually tries to develop many abilities simultaneously.

3.7 Injury & illness risk

Description

If you have been training more than usual, you have an increased risk of getting injured or sick and for this reason you will receive an injury risk alarm.

Advantages of use

- The user gets an alert when injury & illness risk is high and can accordingly adjust training to avoid injuries and/or getting sick.

Calculation and interpretation

Injury & illness risk is calculated from Strain divided by Tolerance and is based on scientific literature.[2,9] If Tolerance has been progressively and systematically increased to high levels (e.g. the athlete has developed fitness) and Strain is low, the athlete is considered well prepared. Conversely, if Strain exceeds Tolerance (i.e., loads within the past week have been rapidly increased, resulting in \`fatigue\`, or training over the last 4 weeks has been inadequate to develop \`fitness\`), then the athlete is considered underprepared and is

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likely to be at an increased risk of injury. The “Sweet Spot” for training is defined as the zone when acute/chronic load ratio is between 0.8 and 1.3 (Figure 5). This model has currently been validated in Australian rules football, cricket and rugby[11], demonstrating that injury likelihood is low (<10%) when the acute to chronic load ratio (Strain divided by Tolerance) is within the range of 0.8–1.3 and that the likelihood of injury doubles when the ratio exceeds 1.5 (i.e. the load in the most recent week is 1.5 times greater than the average of the last 4 weeks).[11,12] Injury & illness risk alert is showing up when the ratio of Strain divided by Tolerance is above 1.5. For former Polar users, the minimum requirement for the calculation of injury and illness risk is 3 days with Cardio load, of which at least one load day is outside the 7 day load window. For new users, the minimum requirement is 3 days with Cardio load. The algorithm requires that at least 3 training sessions are available within the past 28 days.

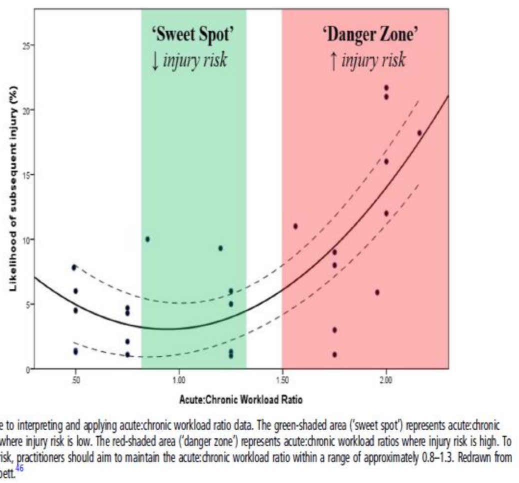

Figure 5. “Sweet Spot” for training according Blanch and Gabbett (2016).

Limitations

It is thought that the same principles are applicable in athletes participating in individual endurance sports[13] and technical sports, even though confirmation through research is missing. It has not been investigated how injury risk calculated from acute to chronic load ratio behaves if users are often changing sports mode (switch between various sports). Varying sports is thought to reduce injury risk. Thus, this feature may work less precisely in users doing a variety of sports.

3.8 Cardio load status

Description

Cardio load status shows how your current Strain relates to Tolerance (Cardio load status= Strain divided by Tolerance). You can quickly see if your status is detraining, maintaining, productive, or overreaching.

Advantages of use

- The user is able to follow estimated training adaptation/response: detraining, maintaining, productive, overreaching.
- The user can see the training status before training in order to decide whether and how to train or to rest.
- The user can see how training status changes after exercise in order to understand how much load was caused by the training.
- The user can see how the training status is estimated to behave for coming days in order to decide when to do next key training session.
- User can see whether there has been enough training load in the past weeks/month in order to ensure training has been productive and increased fitness.
- If the user is overreached, (s)he can see when in the future the training status drops back to productive/maintaining in order to continue training and not lose fitness by waiting too long.
- The user can see how Cardio load status has varied for past weeks/months in order to know at which times training was harder and when it was lighter.

Calculation and interpretation

Cardio load status is calculated from Strain divided by Tolerance. It uses a similar approach as the Injury & illness risk, but limits are not exactly the same (Table 3). In short, the ’Sweet Spot` will be separated into ’maintaining` (when Strain was slightly lower than Tolerance) and ’productive` (when Strain was slightly higher than Tolerance, reflecting a progression). The algorithm requires that at least 3 training sessions are available within the past 28 days.

Table 3. Cardio load status logics

Strain divided by Tolerance	Textual interpretation	Supporting description
< =0.8	Detraining	You’ve been training less than usual. If you keep this up, your fitness level will start going down.
>0.8 -1.0<=	Maintaining	You’ve been training less than usual, but just enough to maintain your fitness level. If you keep this up for long, detraining will occur.
>1.0 -1.3<=	Productive	You’ve been training progressively which should be improving your fitness level. Keep it up!
> 1.3	Overreaching	You’ve been training much more than usual during the last few days. If you keep this up for long, your risk for sports related injuries will increase and your training may become counter-productive.
> 1.5	Overreaching with injury risk	If you keep on overreaching, you’ll increase your risk for overtraining. With this much training, you’re prone to sports related injuries. You may also fall ill more easily.

Limitations

It needs to be remembered that Cardio load status is only an estimate based on Cardio load without taking into consideration the capacity of an individual to cope with the load, while Polar Recovery Pro offers several possibilities to assess actual individual recovery status and training adaptation.

4 Validity

Calculations of Cardio load, Muscle load, Perceived load and injury & illness risk are based on scientifically accepted methods.[2,9]

5 Limitations

Even though Training Load Pro uses a unique holistic approach, it does not contain all possible aspects related al physiological and psychological systems of the body.

6 References

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7 Glossary

Table 4. Polar Terminology related to Training Load Pro and Recovery Pro

Polar Terminology	**Definition**
Cardio load	Cardio load (training impulse, TRIMP) shows your cardiac response to a training session. Cardio load levels indicate how hard a training session was compared to your session average from the past 90 days.
Cardio load status	Cardio load status shows how your current Strain relates to Tolerance (Cardio load status= Strain divided by Tolerance). You can quickly see if your status is detraining, maintaining, productive, or overreaching.
cardio system	The circulatory system, also called cardiovascular system.**; Example:** E.g. the Orthostatic test gives a test result "Your cardio system is not fully recovered" and "Your cardio system is recovered.
cardio training	In cardio training you use large muscle movement over a sustained period of time and keep your heart rate to at least 50% of its maximum. Cardio training gives your heart, lungs and circulatory system a good workout.
detraining	Detraining Cardio load status. You've been training less than usual intentionally or unintentionally. If you keep this up, your fitness level will start going down.
injury & illness risk	**Definition:** If you have been training more than usual, you have an increased risk of getting injured or sick and for this reason you will receive an injury risk alarm.
maintaining	Maintaining Cardio load status. You've been training less than usual, but just enough to maintain your fitness level. If you keep this up for long, detraining will occur.
Muscle load	Muscle load shows the amount of mechanical energy (kJ) that you produced during a running or cycling session. This reflects your energy output, not the energy input it took you to produce that effort. In general, the fitter you are, the better the efficiency between your energy input and output. Muscle load is calculated based on power and duration. In case of running, also your weight counts. Muscle load levels indicate how hard a training session was compared to your session average from the past 90 days.
overreaching	Overreaching Cardio load status. You've been training more than usual. If you keep this up for long, your risk for sports related injuries increases and your training may become counterproductive.
Perceived load	Perceived load is calculated from training duration and your subjective feeling, i.e. ‘how demanding was your training session’. It is useful for sports where measuring training load based on heart rate alone has its limitations, for example, strength training, short intervals and sprints. Perceived load levels indicate how hard a training session was compared to your session average from the past 90 days.
productive	Productive Cardio load status. If you've been training progressively long enough, the chances are that you're getting fitter.

RPE	The abbreviation 'RPE' stands for 'rate of perceived exertion'. This estimate allows you to keep track of how hard your sessions felt. If your estimates of similar sessions are getting lighter, your performance is probably improving. Unexpectedly hard estimates can reveal that something's interfering with your recovery.
Strain	Strain describes how much you have strained yourself with training lately. It shows your average daily load from the past seven days. Your Cardio load status shows how Strain relates to Tolerance. (Cardio load status= Strain divided by Tolerance)
Tolerance	Tolerance describes your readiness to endure cardio training. It shows your average daily load from the past 28 days. Your Cardio load status shows how Strain relates to Tolerance. (Cardio load status= Strain divided by Tolerance)
Training Load Pro	Training Load Pro includes Cardio load, Muscle Load and Perceived load. It helps you understand the ways that your training sessions are straining your body.
your estimate	This estimate, RPE, allows you to keep track of how hard your sessions felt, and also whether reality met your plans in this respect. The abbreviation 'RPE' stands for 'rate of perceived exertion'. If your estimates of similar sessions are getting lighter, your performance is probably improving. Unexpectedly hard estimates can reveal that something's interfering with your recovery.