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**Original Article**

# Training load determining sports performance of swimmer at the 2012 London Olympics

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**Abstract**
Representative of the Slovak Republic M.S. in the years 2010-2016, she recorded a progressive growth of sports performance in swimming disciplines (50m butterfly 28.75 s, 100m butterfly 1:05.40 and 100m freestyle 55.86 s). In the 2012 annual training macrocycle, she achieved performances in the disciplines of 50m freestyle with a time of 25.53 and 100m freestyle with a time of 56.38. Retrospective analysis classified special and general training means that showed the highest tightness with sports performance in swimming. Non-parametric procedures such as Spearman's correlation coefficient and CHAID decision trees were used for interaction detection and prediction. When analyzing the data, we used the method of studying the training diaries from the 2012 annual training cycle. From the point of view of general training indicators, we focused on days of loading (GTI 110), the number of training units (GTI 111), the number of events (GTI 112), the total load time (GTI 113), regeneration time (GTI 114) and days of medical incapacity (GTI 115). Of the special training indicators, we focused on the total number of kilometers flown (STI 101), the volume of warm-up and swim-out (STI 102), the volume of aerobic endurance (STI 103), the volume of anaerobic endurance (STI 104), the volume of load swam in race pace (STI 105), elemental arm swimming (STI 106), elemental leg swimming (STI 107), technical exercises (STI 108). Among the special training indicators, the determinants of sports performance included the volume of warm-up and swim-out (STI 102) and elemental arm swimming (STI 106). Of the general training means, the number of events (GTI 112), days of loading (GTI 110) and the number of training units (GTI 111) determined the year-round sports performance. The exact identification of training means in terms of volume and intensity will allow us to rationalize the periodization of the training load, harmonize the conceptual starting points and improve the system of tuning the sports form of the observed swimmer for the next top world events.
**Keywords: Olympic Games, Swimming. Performance. Load. Predictors. Regression trees.**

## Introduction

Without the deliberate use and manipulation of the training load, it is impossible to imagine changes in the level of performance. As a result, sports performance is limited by factors that affect it during training to varying degrees. In addition, the load in sports training and the subsequent reaction is of decisive importance in the improvement of skills and characteristics (Yakovlev et al. 2018; Gussakov et al. 2023).

Based on the correctly chosen periodization of the training load, athletes can achieve an optimal level of preparation for top events (Platonov, 2019). By analyzing the training load, we can identify and assess general and specific training indicators. Based on this information, coaches are able to predict athletes' performance during the entire training process (Pretorius, 2020; Makar et al. 2023).

The primary goal for elite swimmers is to outdo their competitors by swimming faster and setting new personal, national or even world records (Kachaunov & Petrov, 2020). According to Bompa (1999), the training process is characterized by its complexity and multifacetedness, as it constantly changes depending on the application of the chosen load. The key goal of the training load is to influence the improvement of the level of specific activities, abilities and characteristics (Pla et al. 2019).

The swimming world has witnessed a steady increase in the performance of swimmers over the past few decades. Between 2008 and 2009, more than 130 world records were broken. The sports public mainly blamed drastic changes in swimwear for the high number of broken records. The sports public believed that the swimming records achieved in these swimsuits would remain unbeaten for a long time. In fact, to date, many of these records have been broken.

Precisely because of the constant increase in swimming performance, coaches are forced to invent new principles and training methods or to optimize existing training methods.

Each discipline in swimming is different in its specificity of training load, achieved volume in the aerobic zone, anaerobic zone and especially the volume in a special (race) pace. The sizes of individual characteristics can differ significantly even among swimmers with the same specialization in a given discipline.


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Many recommendations for the weekly volume of training load can be found in the literature, for example by Chatard & Stewart (2011), Hellard et al. (2019), Pollock et al. (2019), Solonenco et al. (2021), Gonzalez-Rave et al. (2021), Hermosilla et al. (2021) and Ravé et al. (2022). Based on these recommendations, we can create an exact structure of the training load for the microcycle. However, it should be kept in mind that these recommendations and the ratio of individual characteristics may not suit every swimmer, and the volumes will be different for each of them.

There is therefore no precise pattern or recipe for the unambiguous use of the training burden in sport training that is generally valid and we know knowledge and information that is only generalized.

**Problem**

The identification of the training load that limits the sports performance in swimming is an essential part of the management and rationalization of the training process in order to improve the quality of sports training and the system of tuning the sports form for top world events such as the European Championships, World Championships and Olympic Games.

The aim of the work is to point out the intra-individual periodization of the training load in the representative of the Slovak Republic in swimming and to identify the training indicators that determined the year-round level of sports performance in the annual RTC 2012 Olympic training cycle.

**Objective**

The aim of the work is to point out the intra-individual periodization of the training load in the representative of the Slovak Republic in swimming and to identify the training indicators that determined the year-round level of sports performance in the annual ATC 2012 Olympic training cycle.

**Material & Methods**

Representative of the Slovak Republic M.S. (born 1990) recorded a progressive growth in sports performance in swimming disciplines in the years 2010-2016 (50m butterfly 28.75 s, 100m butterfly 1:05.40 and 100m freestyle 55.86s). In the 2012 annual training macrocycle, she achieved performances in the disciplines of 50m freestyle with a time of 25.53 and 100m freestyle with a time of 56.38.

General (GTI) and special (STI) training indicators from the training diary (tab. 1) are the starting point for revealing the factors determining sports performance in the ATC 2012 annual training cycle. The basis of the analysis was the weekly - volume training indicators GTI 110-115, STI 101- 108 and year-round sports performance (SP) converted to point values according to FINA tables (table 1). The length of the annual time series was 52 weeks. Sports performance in individual weekly microcycles was converted to point values from swimming performances and tests for 50 m and 100 m in a 25 and 50 meter pool.

Table 1 Volume of general and special training indicators in the annual training cycle 2012

| Code | | Training indicators | M | Min | Max | Sum | SD |
|---|---|---|---|---|---|---|---|
| **SP** | | Sport performance (points) | 667.85 | 602.00 | 796.00 | 34728.00 | 56.87 |
| **GTI** | 110 | Days of loading (n) | 5.63 | 3.00 | 7.00 | 293.00 | 0.95 |
| | 111 | The number of training units (n) | 12.25 | 6.00 | 17.00 | 637.00 | 2.38 |
| | 112 | The number of events (n) | 0.71 | 0.00 | 4.00 | 37.00 | 1.45 |
| | 113 | The total load time (h) | 14.75 | 9.00 | 23.00 | 767.00 | 2.98 |
| | 114 | Regeneration time (h) | 3.40 | 2.00 | 5.00 | 177.00 | 0.93 |
| | 115 | The number of days of medical incapacity (n) | 0.29 | 0.00 | 3.00 | 15.00 | 0.78 |
| **STI** | 101 | The total number of kilometers flown (km) | 24.27 | 9.70 | 38.50 | 1262.10 | 5.86 |
| | 102 | The volume of warm-up and swim-out (km) | 6.00 | 3.70 | 10.10 | 312.25 | 1.41 |
| | 103 | The volume of aerobic endurance (km) | 10.09 | 1.40 | 18.20 | 524.80 | 3.41 |
| | 104 | The volume of anaerobic endurance (km) | 1.08 | 0.30 | 2.15 | 56.15 | 0.44 |
| | 105 | Volume of load swam in race pace (km) | 0.75 | 0.10 | 1.90 | 38.95 | 0.40 |
| | 106 | Elemental arm swimming (km) | 1.66 | 0.30 | 5.95 | 86.55 | 0.98 |
| | 107 | Elemental leg swimming (km) | 2.42 | 0.40 | 5.40 | 125.90 | 0.92 |
| | 108 | Technical exercises (km) | 2.28 | 0.20 | 4.70 | 118.50 | 1.08 |

Nonparametric procedures (Breiman et al. 1984, Lehmann 1975) were selected based on an assessment of the normality of the distribution of the sets. The interaction between sports performance and training indicators has been assessed by the Spearman correlation coefficient $r^s$. (Cohen 1988).

The non-parametric algorithm CHAID - Chi-squared Automatic Interaction Detector and Trees (Breiman et al. 1984) was used to construct decision trees. This technique can be used for prediction (an alternative to parametric multiple regression), classification and detection of interactions between variables.

Results are obtained by automatically detecting relationships between independent variables based on chi-square tests. The advantage of the CHAID (Classification and Regression Trees) technique is in a better summary, interpretation and presentation of binary trees. CHAID creates trees that tend to have multiple branches (options). In each step of the analysis, it searches for one predictor that has the greatest influence on the dependent variable categories (Camp & Slattery, 2002).

However, CHAID may not always find an optimal distribution for the variables. Once it finds that all remaining categories are statistically different, it stops merging categories. For the models, we also present the regression parameters (Linear Correlation R, Standard Deviation SD, Mean Absolute Error MAE; Mean Error ME). Using them, we can define the prediction reliability of a non-parametric model as in linear regression. The results were processed in MS Excel and IBM SPSS Modeler. The findings and conclusions are formulated on the basis of objective and logical evaluation of the obtained results.

**Results**

The intra-individual periodization of the training load enabled the Slovakian representative in swimming (M.S.) to achieve the highest point performance in ATC 2012 with a value of 796 points in the 50 m freestyle discipline with a time of 25.53. In RTC 2012, the swimmer completed a total flown of 1262.10 km, which represents an average of 24.27 km per week (Min 9.70 km; Max 38.50 km). The number of training units reached the number of 637 with 293 days of loading (Min 6; Max 17 training units per week). During the training cycles, the swimmer spent 177 h. regeneration, which represents 23.07% of the total load time.

Out of the total load, the volume of warm-up and swim-out (STI 102) reached 312.25 km (24.74%) in the calendar year. The largest volume of the swimmer was realized in aerobic endurance (STI 103) at the level of 524.80 km (41.58%). Anaerobic endurance (STI 104) with its volume of 56.15 km was part of the load at the level (4.45%).The volume swam in race pace band (STI 105) was the smallest part with a level of 38.95 km (3.08%). The elemental arm swimming (STI 106) reached volume level of 86.55 km (6.86%) and the elemental leg swimming (STI 107) had a level of 125.90 km (9.97%). The last part was technical exercises (STI 108) at the level of 118.50 km (9.39%).

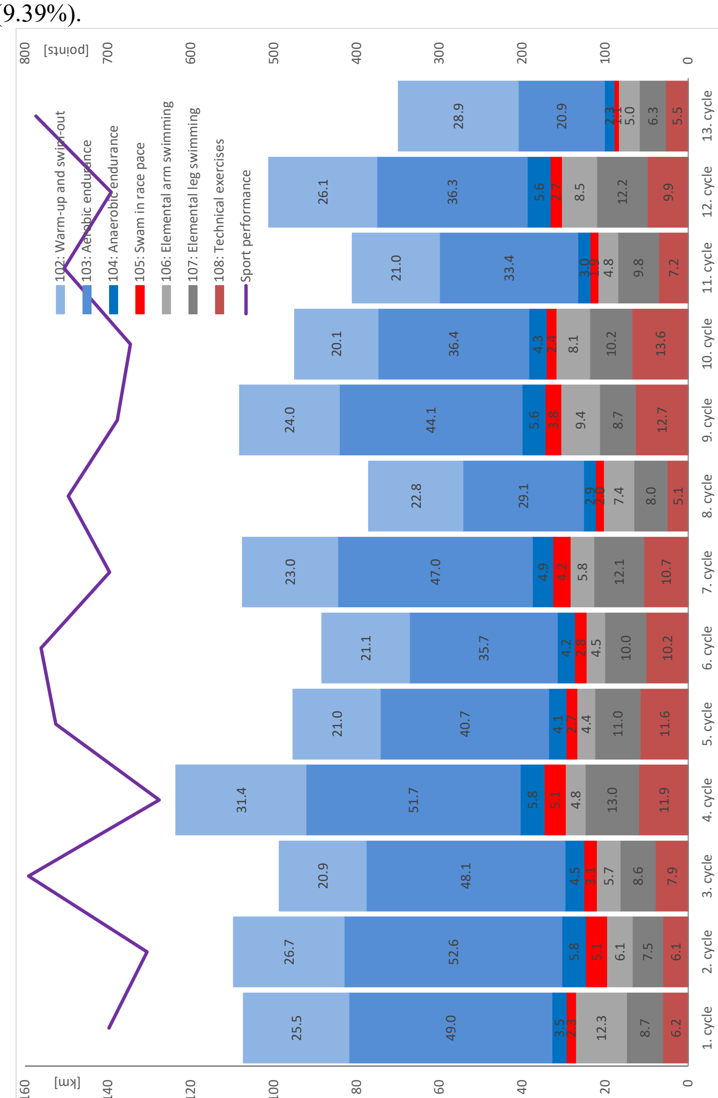


Figure 1. Periodization of training load in annual training cycle 2012 (mesocycles)

Table 2 Correlation of sports performance and training indicators

| Code | | Training indicators | $r^s$ | p |
|---|---|---|---|---|
| GTI | 110 | Days of loading (n) | 0.292 | 0.036 |
| | 111 | The number of training units (n) | 0.124 | 0.382 |
| | 112 | The number of events (n) | 0.672 | 0.000 |
| | 113 | The total load time (h) | -0.003 | 0.984 |
| | 114 | Regeneration time (h) | 0.331 | 0.016 |
| | 115 | The number of days of medical incapacity (n) | -0.197 | 0.161 |
| STI | 101 | The total number of kilometers flown (km) | 0.028 | 0.844 |
| | 102 | The volume of warm-up and swim-out (km) | -0.158 | 0.263 |
| | 103 | The volume of aerobic endurance (km) | 0.006 | 0.965 |
| | 104 | The volume of anaerobic endurance (km) | 0.228 | 0.104 |
| | 105 | Volume of load swam in race pace (km) | 0.178 | 0.208 |
| | 106 | Elemental arm swimming (km) | -0.255 | 0.068 |
| | 107 | Elemental leg swimming (km) | 0.062 | 0.662 |
| | 108 | Technical exercises (km) | 0.137 | 0.332 |

Through non-parametric procedures, we have been able to classify the interactions between sport performance and training indicators, or to detect the predictors that most significantly affected the swimmer's average sport performance in ATC 2012.Statistically significant correlations (tab. 2) of general training indicators with sports performance were demonstrated with the number of days of loading (GTI 110, $r^s$= 0.292, p= 0.036), number of events (GTI 112, $r^s$= 0.672, p<0.01) and regeneration time (GTI 114, $r^s$= 0.331, p= 0.016).

As we mentioned in the methodology, the CHAID algorithm creates trees that tend to have multiple possibilities. The algorithm created a tree with multiple branches. Based on a factual and logical evaluation, we interpret the branches of the regression tree that predict a higher variability of sports performance when training indicators are combined.The non-parametric CHAID algorithm built prediction models that achieve high reliability with reasonable prediction error (Figs. 2 and 3, Tables 3 and 4). Training indicators were introduced into the models, which showed low to high tightness with sports performance in swimming. Training indicators are nodal variables with indication of volume limit values for the possibility of predicting the number of performances at higher and lower load volumes.Among the predictors of swimming performance (Fig. 2, Tab. 3), **special training indicators** were selected: warm-up and swim-out (STI 102) and elemental arm swimming (STI 106).

**First branch:** For the lowest predicted sports performance, the sufficient volume of warm-up and swim-out per week is lower than or equal to 4.550 km (STI 102; F= 9.271; p= 0.014; 624 points; n= 5) and in combination with the volume of elemental arm swimming lower or equal to 1.100 km (STI 106, F= ∞; p<0.01; 629 points; n= 1).

**Second branch:** With the variability of the volume of swimming and swimming in a week from 4.550 to 5.100 km (STI 102; F = 9.271; p = 0.014; n = 11) we can expect the highest sports performance with 721 points.

**The third branch:** Warm-up and swim-out volume with a weekly volume higher than 5.10 km (STI 102; F = 9.271; p = 0.014; 657 points; n = 36) predicts sports performance with 657 points.

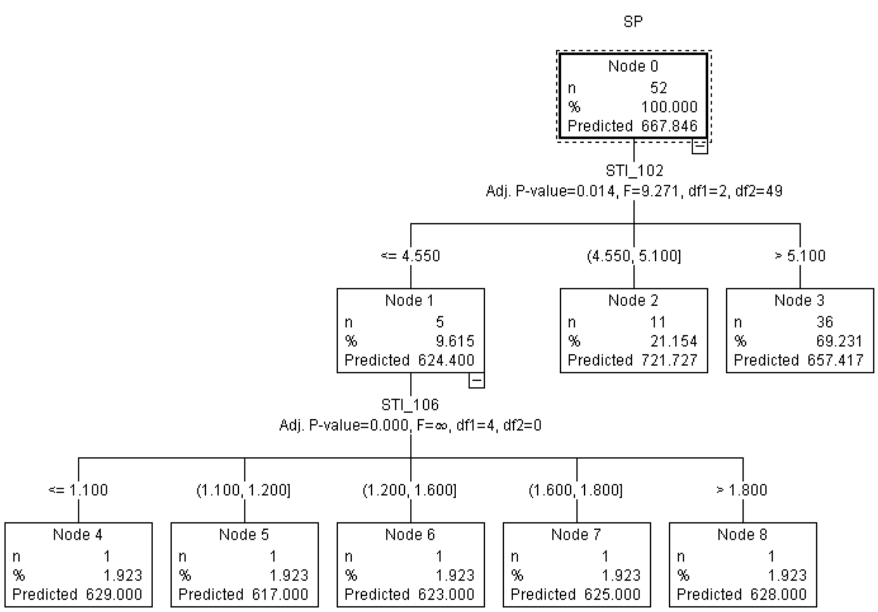


Figure 2 Regression tree of selected special training indicators STI 101-108 to sports performance by the CHAID method
(R: 0.524; SD: 48.42; MAE: 36.39; ME -0.0)

**Legend to special training indicators: SP** Sport performance. **STI_102** Warm-up and swim out (km). **STI_106** Volume of load swam in race pace (km).

Table 3 Prediction model of special training indicators for sports performance in swimming using the CHAID method

| Node | | Criterion | Prediction | Effect | N | % |
|---|---|---|---|---|---|---|
| 1 | | STI_102 <= 4.550 | 624.4 | -43.446 | 5 | 9.615 |
| | 4 | STI_106 <= 1.100 | 629 | 4.6 | 1 | 1.923 |
| | 5 | STI_106 > 1.100 and <= 1.200 | 617 | -7.4 | 1 | 1.923 |
| | 6 | STI_106 > 1.200 and <= 1.600 | 623 | -1.4 | 1 | 1.923 |
| | 7 | STI_106 > 1.600 and <= 1.800 | 625 | 0.6 | 1 | 1.923 |
| | 8 | STI_106 > 1.800 | 628 | 3.6 | 1 | 1.923 |
| 2 | | STI_102 > 4.550 and <= 5.100 | 721.727 | 53.881 | 11 | 21.154 |
| 3 | | STI_102 > 5.100 | 657.417 | 53.881 | 36 | 69.231 |

From the point of view of **general training indicators** (Fig. 3, Tab. 4), predictors of sports performance were selected: the number of events (GTI 112), days of loading (GTI 110) and number of training units (GTI 111).

**Second branch:** The predicted average sports performance of 667 points (for 52 performances) is determined by at least one event per week (GTI 112; F= 103.171; p<0.01; 757 points; n= 11), the days of loading less than or equal to 6 (GTI 110; F= 35.600; p<0.01; 770 points; n= 9).

If the number of days of loading per week will be higher, we can expect a performance of 699 points with a higher number of training units per week >12 (GTI 111; F= ∞; p<0.01; n= 1).

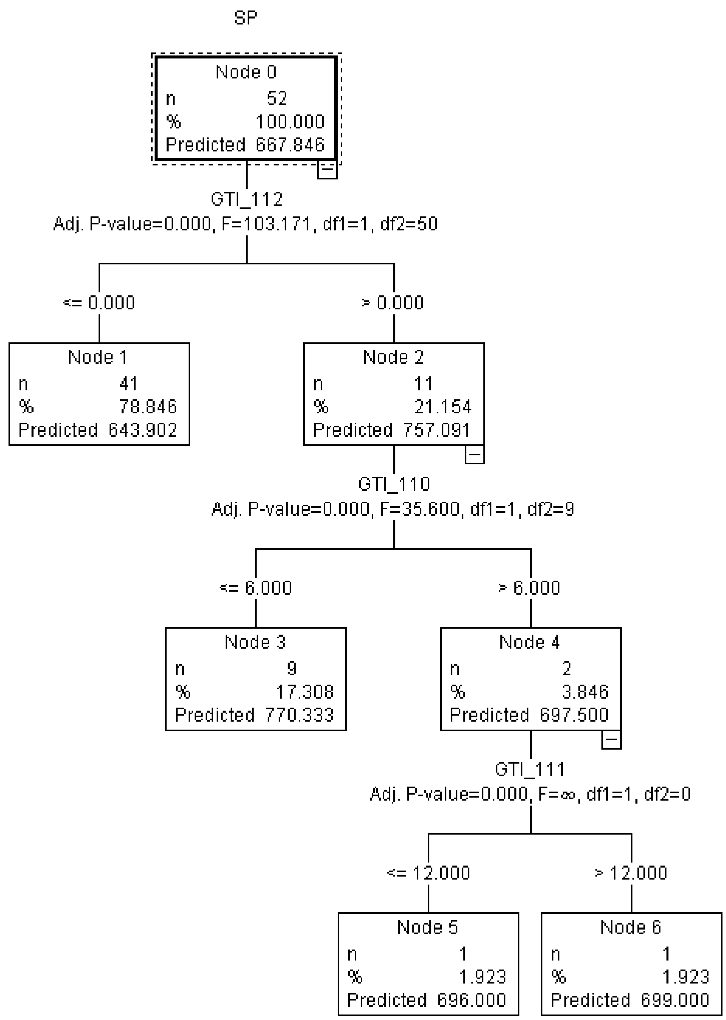


**Figure 3** Regression tree of selected general training indicators GTI 110-115 to sports performance by the CHAID method
(R: 0.852; SD: 29.76; MAE: 23.29; ME 0.0)

**Legend to general training indicators: SP** Sport performance. **GTI 110** Days of loading (n). **GTI_111** Training units (n). **GTI_112** Competitions/Starts (n).

Table 4 Prediction model of general training indicators for sports performance in swimming using the CHAID method

| Node | | | Criterion | Prediction | Effect | N | % |
|---|---|---|---|---|---|---|---|
| 1 | | | GTI_112 <= 0 | 643.902 | -23.944 | 41 | 78.846 |
| 2 | | | GTI_112 > 0 | 757.091 | 89.245 | 11 | 21.154 |
| | 3 | | GTI_110 <= 6 | 770.333 | 13.242 | 9 | 17.308 |
| | 4 | | GTI_110 > 6 | 697.5 | -59.591 | 2 | 3.846 |
| | | 5 | GTI_111 <= 12 | 696 | -1.5 | 1 | 1.923 |
| | | 6 | GT_111 > 12 | 699 | 1.5 | 1 | 1.923 |

**Discussion**

Accurate timing of peak form for key competitions requires careful planning that should take into account a multi-year period. Of course, this vast task had to be divided into smaller and manageable units (Maglisho, 2003).

The structure of the swimmer's training load was based on a model for a three-peak season. The first peak of the season was in the third mesocycle (Figure. 1), where the goal was to meet the qualification limit for the Olympic Games. The second peak of the season is the Olympic Games in the eighth mesocycle, and the last peak was the World Championships in the thirteenth mesocycle.

In the literature, we can find the recommendations of Hermosilla et al. (2021) for the most commonly used pyramid model of periodization of training load with a decrease in volume towards the event.

Based on the annual training cycle, we are able to point out the individual periodization of the training load. This periodization involves tailoring the training load to the swimmer's specific needs or goals. It can include a combination of several types of periodization that are adjusted according to the swimmer's progress or recovery needs (Bompa & Haff, 2009).

From general training indicators, the swimmer completed 637 training units with a total load time of 767 hours in the RTC 2012 annual training cycle and a total of 1262. 10 flooded km. For comparison, in the work of Vaňková (2010), Czech elite swimmers completed 423 training units with a total load time of 780 h. and with a volume of 2511.7 km. In her work, Krčková (2013) mentions an Olympic swimmer with the number of 518 training units in the annual cycle and a total volume of 2873 km.

In the weekly microcycle, the swimmer completed min. 6 and max. 17 training units. Finney (2003) recommends 10-11 training units per week regarding the number of training units. Meeusen et al. (2013) describe reducing the number of training units in a weekly microcycle in British swimmers to 9 to avoid overtraining.

The total load time in the microcycle ranges from min. 9 and max. 23. In the publication, Finney (2003) describes a weekly microcycle with a maximum load time of 23 hours.

Chatard & Stewart (2011); Hellard et al. (2019); Solonenco et al. (2021); Gonzalez-Rave et al. (2021); Hermosilla et al. (2021); Ravé et al. (2022); Rushall, 2018; Sylta et al. (2016) dealt with the issue of the influence of training load on sports performance

According to the volume of the training load, we compared our achieved results with the recommendations of professional literature. Chatard & Stewart (2011) put the total load in a weekly microcycle in the range of 45-60 km. Bonifazi et al. (2000); Mujika et al. (2002) report a weekly load volume of 50–60 km that was established for the Italian national team and the Australian Olympic team. Meeusen et al. (2013) describe a prescribed volume of 43–53 km for British swimmers to reduce the risk of overtraining. For comparison, Gonzalez-Rave et al. (2021), who recommend 25–90 km total in a microcycle for swimmers with sports performance at the level of 850–900 points (FINA). Rădulescu et al. (2017) recommend a maximum training load of 80 km in the microcycle.

After several or months of high-volume training should be followed by a short period in which the volume of the training load is gradually reduced for four weeks. This reduction leads to a significant improvement in sports performance in order for the swimmer to reach peak performance at the desired moment (Chatard & Stewart, 2011), which corresponds to our results, as in the mesocycles where the peak events were located, the load volume was reduced (mesocycles 3, 8 and 13) (Figure. 1).

Solonenco et al. (2021) describe that during the period of general preparation in the macrocycle, they mostly devoted themselves to improving aerobic endurance, strength, flexibility, technique, starts, turns and coping with psychological stress. Training units during this period consisted mainly of elemental swimming of arms, elemental swimming of legs, technical exercises and resistance with light intensity. Subsequently, in the competition period, the swimmers had their most important events planned. The content of the training units consisted of high-intensity resistance and sprints for all swimmers. In Figure 1, we can see that the swimmer has a constant race pace level in all mesocycles during the entire annual training cycle, which can suit short distance swimmers.

In the results section, we present the volume of the race pace in the weekly microcycle at the level of M= 0.75 km and max 1.90 km. Pollock et al. (2019) in their publication states a race pace recommendation for mid-distance swimmers of 1.3 ± 3.5 km. From the point of view of the annual cycle, the swimmer swam 38.95 km at a race pace. In the analysis of her work, Krčková (2013) states the annual volume of a swimmer at a competitive pace at the level of 70 km, which is also a significantly higher value than in our results.

In the prediction models mentioned above, the special training indicators of warm-up and swim-out (STI 102) and elemental arm swimming (STI 106) were introduced. We believe that short-distance swimmers need a longer warm-up and swim-out to get up to speed, as they must be able to develop maximum speed and stay at it as long as possible. With arms, it is essential that swimmers have the best technique and arm strength to have an effective stroke.

This is an example of a highly intraindividual periodization of the training load in relation to the athlete being monitored. We note that the obtained results correspond to recommendations from swimming and professional practice, however, Pollock et al. (2019) recommend higher weekly training load volumes compared to ours.

**Conclusions**

In our contribution, we were able to point to the intraindividual periodization of the exercise load of the Slovak representative in swimming (M.S.) in the ATC 2012 annual training cycle. Using regression trees with the CHAID method, training indicators were selected that demonstrated high tightness with year-round sports performance. The optimal load was characterized in terms of volume and intensity, or variability of sports performance prediction.

The influence of the volume of the warm-up and swim-out was demonstrated (STI 102) and elemental arm swimming (STI 106) played an essential role in the preparation, as short-distance swimmers need longer warm-up and return to get up to speed and must be able to develop maximum speed as possible the longest duration. Elemental arm swimming also plays an important role so that swimmers have the best technique and arm strength for an effective stroke.

Of the general training indicators, the influence of the number of events (GTI 112), the days of loading (GTI 110) and the number of training units (GTI 111) was proven.

Retrospective analysis classified the training means that were most involved in improving the swimmer's sports performance. Their exact identification will make it possible to rationalize the periodization of the training load, to harmonize the conceptual starting points of sports training and to improve the system of tuning the sports form of the swimmer himself towards the top events.

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