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ANALYSIS OF ANNUAL TRAINING IN ADOLESCENT SPRINTERS IN RELATION TO BIOLOGICAL MATURATION AND SPRINT MECHANICS

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Abstract: Annual improvements in performance among adolescent sprinters reflect the combined effects of training adaptation, biological maturation, technical changes, and measurement conditions. This article aims to develop a literature-based framework for annual analysis that enables these factors to be considered together when interpreting performance changes. The critical narrative review compared longitudinal observations of young sprinters, seasonal biomechanical studies, and methodological work on measurement reliability in sport. The principal analysis concerns adolescent preparation for the 100 m and 200 m events; findings on 60 m performance were considered supporting evidence. The literature indicates that sprint times, step mechanics, and strength measures do not change at the same rate. The framework integrates multidimensional recording of training load, standardized sprint tests, individual developmental trajectories, and evaluation of changes relative to measurement error for annual monitoring. The proposed framework is an evidence-informed analytical protocol, rather than a prescribed training dose or an experimentally validated new method. The central conclusion is that annual training effectiveness should be assessed through repeated measurements of performance and its mechanical components in the context of growth, rather than through a single personal-best performance.

Keywords: adolescent sprinters, annual training cycle, periodization, biological maturation, acceleration, maximal sprint speed, training load, longitudinal analysis, measurement error.

Introduction

Subtracting an adolescent sprinter’s performance at the beginning of the year from that at the end is computationally straightforward but scientifically complex to interpret. Within a year, the athlete’s stature, body mass, muscular strength, movement coordination, training experience, and competition conditions may change. Attributing the entire improvement in performance to the coach’s chosen program without accounting for these factors introduces a causal inference error. Conversely, a temporary decline in speed does not automatically indicate an absence of long-term adaptation.

This article focuses on the annual analysis of preparation for the 100 m and 200 m events during adolescence. Within this scope, acceleration, maximal sprint speed, and the ability to maintain speed are monitored separately. The specific endurance demands of the 400 m require a separate analysis; consequently, training volume or intensity guidelines for that event are not generalized here. Studies of 60 m performance in children and adolescents help explain the development of short-sprint performance, but their findings cannot be transferred directly to the 200 m.

The research question was formulated as follows: which data should be collected throughout the annual training process to support a well-founded interpretation of performance changes in relation to biological development, mechanical adaptation, and measurement uncertainty? The scientific

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objective is to connect analytical criteria supported by the available evidence, rather than to derive a ready-made universal training program from the literature.

Materials and Methods

The study was conducted as a critical narrative review of the literature. Sources were checked through PubMed, J-STAGE, and journal publisher websites as of October 7, 2026. The search used combinations of the terms adolescent sprinters, longitudinal sprint performance, annual training season, biological maturation, sprint monitoring, and training load. Selection prioritized direct relevance to the topic, clarity of study design, and the ability to distinguish findings from limitations. This search is not presented as a comprehensive systematic review or meta-analysis.

Three types of evidence were distinguished: original studies directly observing young sprinters; studies conducted in highly trained sprinters or young children, with limitations on transferability; and methodological sources concerning measurement, maturation, and training load monitoring. When the full text was unavailable, only information explicitly reported in the publisher's or PubMed abstract was used. Findings concerning different ages, sexes, race distances, and follow-up periods were not pooled into a single overall effect size.

For each source of evidence, the sample, age or performance level, follow-up duration, measured variables, and limits of interpretation were identified. The equations below are mathematical definitions for processing observational data or components of the proposed analytical model. No new cohort of athletes was examined, no statistical model was fitted, and no experimental effect estimate was calculated in this article.

Direct Evidence and Its Interpretive Limits

Katoh et al. followed eight male sprinters annually from 12 to 15 years of age. Between ages 12 and 14, sprint speed increased from 8.79 to 9.61 m/s; between ages 12 and 13, step length increased from 1.95 to 2.08 m, whereas no significant age-related increase in step frequency was found. At baseline, skeletal age was approximately three years ahead of chronological age [1]. These observations concern a small, early-maturing group: the recorded speeds cannot be treated as normative values for all adolescents, nor can the improvement be attributed solely to training.

Miyamoto and Yanagiya assessed 11 male and 7 female track and field athletes at three seasonal time points. Mean 100 m times in the male athletes were 12.2, 12.2, and 11.9 s, whereas differences between seasonal assessments in the female athletes were not statistically significant [2]. Participants included both sprinters and jumpers. The absence of a control group, the small sample, and measurements based on a single attempt preclude interpreting this study as definitive evidence of the effectiveness of an annual training program.

Aerenhouts et al. compared sprint-start and countermovement jump (CMJ) performance in 28 female and 25 male adolescent sprinters at assessments one year apart. In both sexes, block-exit velocity and performance over 5–10 m improved; absolute jump power increased, whereas power relative to body mass did not [3]. This observation indicates that an increase in absolute power should not be equated

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with a sprint-specific adaptation in relative power. However, the separate causal contributions of growth and training were not established.

Romann et al. analyzed 41,123 season-best 60 m performances from 8,732 female athletes aged 6–15 years; the analysis included athletes with results from at least three seasons [4]. Such data are important for demonstrating variation in individual development. However, without direct measurements of training dose or biological maturation in the database, the results do not establish the effectiveness of a coach's program. The underrepresentation of athletes who left the sport early also limits the generalizability of the findings.

Table 1. Key empirical evidence for annual analysis

Source and design	Study population	Contribution to the analysis	Main limitation
Katoh et al. [1]	8 male sprinters, aged 12–15 years	Maturation and step mechanics were monitored together	Small, early-maturing sample
Miyamoto and Yanagiya [2]	Adolescent track and field athletes; seasonal follow-up	Physical fitness attributes were compared across the season	Small, uncontrolled sample; training load was not measured in detail
Romann et al. [4]	8,732 female athletes, 60 m, aged 6–15 years	Individual trajectories across multiple seasons	Training effects were not directly measured
Bezodis et al. [5]	4 trained sprinters, 5 months	Sprint speed and step frequency changed together	Small observational study without a control group
Loturco et al. [6]	13 highly trained sprinters, 14 months	Distinction between group mean and individual changes	Does not provide normative values for adolescents

In a five-month observational study of four sprinters, Bezodis et al. recorded decreases in running speed and step frequency during phases involving high volumes of strength training and running, followed by increases during phases involving lower-volume, higher-intensity sprinting [5]. This finding does not contradict the age-related changes in step length reported by Katoh et al.: development over several years and responses to training load within a single season represent different timescales.

In a study assessing 13 sprinters at four training camps over 14 months, Loturco et al. found no statistically significant changes in many variables at the group level, but meaningful differences emerged when individual changes were compared with test variability [6]. Thus, a stable group mean does not demonstrate that no individual athletes improved or declined. This evidence does not establish an expected percentage improvement for young athletes.

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Distinguishing Biological Maturation from Training Effects

Chronological age indicates elapsed time, whereas biological maturation describes the stage of development. These two indicators may not correspond among athletes in the same age category. Comparing sprint times without recording changes in stature, body mass, and strength overlooks influences beyond training. Maturation information should provide context for interpreting performance, rather than serve as a decisive criterion for athlete selection.

Mirwald et al. developed a model using anthropometric measurements to estimate maturity offset, the time relative to peak height velocity (PHV). The standard error of estimate in the original model was 0.49 years for males and 0.50 years for females [7]. These figures do not guarantee that an individual athlete's maturation timing can be determined to within half a year; they represent statistical errors associated with the sample used to develop the model.

Using longitudinal data from 58 young soccer players, Malina et al. found that anthropometric predictions tended to place PHV later in early-maturing individuals and earlier in late-maturing individuals [8]. This validation study in soccer players does not provide evidence about sprint-training outcomes; it demonstrates a limitation of the measurement method. Caution is therefore required when entering maturity offset into a model as an error-free measure of biological age or using it to assign an athlete to a fixed developmental category.

Annual monitoring should record stature, sitting height, and body mass measured using consistent methods, together with measurement dates, training experience, and the athlete's sex. Growth velocity is calculated by dividing the difference in stature between successive measurements by the elapsed time. A small short-term difference may result from instrument or postural error; a single pair of measurements therefore does not justify a definitive conclusion about the timing of PHV.

Baseline performance level should also be considered when comparing an athlete's changes with those of peers. An athlete starting at a higher performance level may show a smaller percentage improvement, but this does not imply lower-quality training. Nor is it justified to use male developmental trajectories as normative standards for female athletes. Analysis should be based on individual baseline status and changes over time within each sex [1,4].

Sprint Mechanics and Adaptation Across the Year

Over the same interval of motion, mean running velocity is expressed as the product of step length and step frequency. Here, a step denotes the distance from ground contact by one foot to ground contact by the opposite foot; it should not be confused with a complete cycle comprising two steps.

$$v = L \cdot f \quad (1)$$

Here, v is velocity (m/s), L is step length (m), and f is step frequency (steps/s). The equation is a kinematic identity, not a coaching instruction that deliberately lengthening a step will increase velocity. L and f are interdependent: changing one may alter the other and affect braking during ground contact. Therefore, video-derived measures should be compared within the same phase of the sprint and over the same segment.

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During a straight-line acceleration segment, the dynamics of the body's center of mass in the direction of motion are described by Newton's law. Aerodynamic drag is treated as a positive magnitude acting opposite to the direction of motion.

$$m\frac{dv}{dt}=F_h-F_d, P_{net}=(F_h-F_d)v \quad (2)$$

Here, m is body mass (kg); Fh is the signed horizontal component of the ground reaction force along the direction of motion (N), which may be negative during braking; Fd is aerodynamic drag (N); and Pnet is the instantaneous net mechanical power associated with horizontal motion of the body's center of mass (W). Pnet is neither metabolic energy expenditure nor the sum of the power produced by all muscles. No ground reaction force acts during the flight phase. Average power is calculated from the instantaneous products of force and velocity; multiplying their separate averages may not yield the same value. Running on a bend requires the tangential and centripetal force components to be distinguished.

Morin and colleagues identified associations between measures of effective force application in the direction of running and sprint performance in 12 physically active men; only two participants were sprinters [9]. This study supports the distinction between the magnitude of maximal force and its orientation during sprinting. The correlational design does not establish the causal effect of a training-induced technical change, nor does it imply that vertical force is unimportant at maximum velocity.

Two implications follow for annual analysis. First, improvements in 0–10 m and 0–30 m times should not be equated with improvements in maximum velocity. Second, to establish whether an increase in the load lifted during a strength exercise represents an adaptation that has transferred to sprinting, running performance itself must be assessed. When body mass increases, monitoring measures relative to body mass alongside absolute force helps clarify interpretation; however, a simple ratio does not automatically eliminate all effects of body size.

Tottori and Fujita's eight-week intervention examined 20 boys aged 9–12 years who were not engaged in specialized sports training. The 50 m time changed from 9.71 to 9.44 s in the plyometric training group and from 9.41 to 9.54 s in the control group; the group-by-time interaction was $p = 0.002$ [10]. This short-term evidence indicates that adaptations to jump training may transfer to sprinting. It does not establish the same dose or guarantee the same percentage improvement within an annual program for specialized adolescent sprinters.

Analytical Structure of the Annual Training Cycle

Periodization entails more than dividing the year into named phases: each phase requires a priority adaptation, a measure used to assess it, and a basis for progression to the next phase. Haugen and colleagues synthesized different approaches to periodization in sprint practice but noted the lack of evidence directly comparing the superiority of these models [11]. There is therefore no basis for declaring short-to-long, long-to-short, or block periodization the best approach for all adolescents.

Table 2 is an analytical synthesis developed for this article. It should not be interpreted as a validated prescription for the number of training weeks, distances, or repetitions. Phase duration should be

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determined in relation to the competition calendar, training history, growth status, and opportunities to attend training. Planning one or two competitive peaks also depends on these conditions.

Table 2. Questions to Be Examined Across the Phases of the Annual Training Cycle

Phase	Priority objective	Monitored measure	Basis for the next decision
General preparation	Motor skills and adaptation to training load	Technique records, attendance, strength test	Movement quality and load tolerance
Specific preparation	Development of acceleration and maximum velocity	0–10 m, 0–30 m, flying sprint segment	Identification of the sprint component that has changed
Precompetition	Expression of performance and fatigue management	Sprint testing under a consistent protocol, subjective well-being	Adjustment of volume while maintaining sprint quality
Competition	Performance in the target event and consistency	100 or 200 m, conditions, number of competitions	Balance between target competitions and recovery
Transition	Recovery and annual review	Missed training, pain records, annual trend	Priority objective for the next cycle

Completely discontinuing technical and speed skill practice between phases complicates the analysis: it becomes difficult to distinguish whether subsequent performance reflects adaptation to a new stimulus or restoration of a previously acquired skill. Planned training and work actually completed should therefore be recorded separately. Absence from training, school or examination demands, illness, and travel to competitions form part of the annual dataset.

Running velocity should also be monitored when training volume is reduced before competition. If performance improves as volume decreases, this may reflect reduced fatigue; however, if wind, footwear, or the starting procedure changes concurrently, no single explanation can be established. Specifying an exact percentage reduction or duration as a universal standard for adolescents goes beyond the evidence considered here.

Multidimensional Recording of Training Load

Two sprint sessions may have the same duration yet produce very different effects. Distance, velocity, recovery between repetitions, start type, running surface, and the presence of resistance determine the nature of the work performed [11]. Using total running distance as the sole load measure in an annual analysis does not distinguish acceleration work from maximum-velocity work.

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In the session rating of perceived exertion (session RPE) method proposed by Foster and colleagues, the subjective rating of exertion for a training session is multiplied by its duration [12]. This simple summary measure does not replace the assessment of velocity-specific mechanical load.

$$TL_{session}=RPE_{session}\cdot D, TL_{week}=\sum_{j} TL_{session,j} \quad (3)$$

TLsession is a proxy measure of internal training load expressed in arbitrary units; RPEsession is the subjective rating of exertion for the entire session on a 0–10 scale; and D is duration in minutes. The weekly total is calculated across all recorded sessions. RPE should be collected using a consistent procedure and time interval; the rules for including warm-up, rest, and cool-down activities in the calculation should remain unchanged throughout the season.

This article proposes retaining external training load as a vector of separate components rather than combining it into a single artificial number: acceleration repetitions and distance; the distance covered in flying sprint segments; the distance and time of longer sprint efforts; repetitions, load, and execution quality in strength exercises; and jump type and number of contacts. Directly adding values expressed in different units has no physical meaning.

Calculating relative intensity requires the same distance and starting protocol. When distance is unchanged, the ratio of mean velocities equals the inverse ratio of the corresponding times.

$$I=100\frac{v_j}{v_{ref}}=100\frac{t_{ref}}{t_j} \quad (4)$$

Here, I is relative velocity expressed as a percentage; tref is the standardized reference time for the same segment and start type; and tj is the time for the subsequent trial. This measure is not instantaneous maximum velocity. If the reference time is updated during the season, both the previous and new calculation baselines should be retained with their dates. Otherwise, work performed at the same actual velocity may be reclassified into a different intensity zone in the records.

Describing abrupt changes in training load is useful, but a single safety threshold based on a measure such as the acute to chronic workload ratio does not constitute causal evidence. Impellizzeri and colleagues examined problems linking the calculation, causal interpretation, and practical application of this measure [13]. Accordingly, a particular ratio should not be used to guarantee injury-free training for all adolescents.

Measurement Reliability and Meaningful Change

Sprint times are sensitive to small errors. Haugen and Buchheit show that differences in starting procedures, timing technology, and testing protocols affect the comparability of results [14]. A training time recorded using electronic timing gates is not the same measure as a fully automatic competition time initiated by the starting signal. Adding handheld stopwatch measurements to a time series otherwise based on electronic timing may distort the seasonal trend.

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Table 3. Minimum dataset for the proposed annual monitoring protocol

Domain	Core records	Standardization requirement
Sprint performance	0–10 m, 0–30 m; flying sprint segment; primary race distance	Consistent starting procedure, segment, device, and trial-selection rule
Movement mechanics	Step length and step frequency; ground contact time where required	Consistent camera position, frame rate, and analysis segment
External load	Distance, time, repetitions, recovery, resistance training, and jump training	Distinguish planned from completed training
Internal response	Session RPE and records of well-being and pain	Consistent scale, collection timing, and instructions
Growth and context	Stature, body mass, training age, attendance, and testing conditions	Consistent equipment and measurement procedures, with dates recorded

The typical error of repeated tests is estimated from paired measurements obtained under conditions in which the athlete is assumed to have remained unchanged. The standard deviation of the paired differences can be used after verifying the absence of consistent systematic bias and the comparability of the measurement errors [15].

$$TE=\frac{SD_{diff}}{\sqrt{2}} \quad (5)$$

SDdiff is the standard deviation of the differences between the retest and the initial test; TE is the typical error of a single measurement. If the errors of the two tests are independent, their variances are equal, and the differences are approximately normally distributed, the minimum detectable change at 95% confidence for the difference between two individual measurements can be approximated as follows, provided that systematic test–retest bias is absent or has been corrected.

$$MDC_{95}\approx 1.96\sqrt{2}\cdot TE\approx 2.77\cdot TE \quad (6)$$

MDC95 is a statistical detection threshold; it is distinct from the smallest worthwhile change in sporting terms. The coefficient 1.96 is based on a large-sample approximation; in small samples, uncertainty in the TE estimate and the appropriate critical value must be considered separately. A difference below this threshold does not justify concluding that the athlete has not changed: the available test may be unable to distinguish such a change reliably. A difference exceeding the threshold likewise does not establish that training caused it.

Estimating TE requires a sufficient number of repeated measurements under stable conditions. Pooling athletes with different performance levels and obtaining a high test–retest reliability coefficient from the resulting large between-athlete variance does not guarantee measurement precision for an

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individual athlete. The best trial from one test must not be compared with the mean of another. If the analysis uses the mean of several trials, the error estimate must correspond to that same aggregation procedure.

The sign convention for percentage change is specified in advance so that a reduction in time is expressed as a positive change.

$$\Delta_{imp}=100\frac{t_0-t_1}{t_0}\% \quad (7)$$

Here, t0 is the baseline time and t1 is the subsequent time; a positive Δimp indicates a reduction in time. This is a purely descriptive change. It must not be interpreted as a training effect adjusted for biological maturation, a prediction, or a guarantee. The difference in seconds and its uncertainty should be reported alongside the percentage change.

Statistical analysis of repeated measurements

In annual monitoring, successive tests from the same athlete are not independent observations. Athletes who complete more training may also differ from other athletes in baseline performance, training age, and opportunities. To avoid conflating between-athlete differences with within-athlete changes over time, each athlete's mean load is separated from deviations from that mean. Romann and colleagues used mixed-effects models to analyze repeated performance outcomes [4].

The following expression is a proposed model specification for future observational data. It has not been fitted in this article. The natural logarithm of sprint time is used as the outcome; negative coefficients indicate an association with shorter times.

$$y_{ij}=\beta_0+b_i+g(A_{ij})+\beta_W(U_{ij}-\overline{U}_i)+\beta_B\overline{U}_i+\gamma^T X_{ij}+\varepsilon_{ij} \quad (8)$$

In the model, yij is the log-transformed time of athlete i at test j; β0 is the overall intercept at the specified reference values of the covariates; bi is the athlete-specific random intercept; and g(Aij) is a prespecified function of age or time. Uij is one prespecified measure of training load completed in the preceding period, and $\bar{U}i$ is the athlete's mean load over the observation period. βW represents the association with deviations from the athlete's own mean, whereas βB represents the association with between-athlete differences. Xij contains selected covariates such as sex, training age, growth measures, and measurement conditions; εij is the residual. The unit of measurement for U and the time window preceding the test are specified in advance. For example, the distance covered in standardized high-speed segments or the sum of session RPE values may be used; other types of load require separate terms.

This model does not guarantee complete separation of training effects from natural development. Coaches adjust training load according to the athlete's condition: an athlete whose speed has declined may be assigned lighter training. In this situation, the co-occurrence of low training load and poor performance does not imply that lighter training caused poor performance. Relating preceding load to a subsequent test clarifies temporal ordering, but does not convert an observational design into a randomized experiment.

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A model with many parameters is unstable in a small sample. The primary outcome and a limited set of covariates should be selected in advance, and collinearity between age and proxies for maturation should be examined. If residual serial correlation is present, an appropriate correlation structure should be considered. Athlete-specific time slopes may also be incorporated if sufficient data are available; otherwise, this added complexity does not improve inference. Model assumptions concerning random effects, residual variance, and covariates are assessed using diagnostic procedures.

Reporting should not rely solely on p-values. Differences in seconds, percentage changes, confidence intervals, and individual trajectories should be presented together. Highlighting only favorable results from several tests increases the risk of selective reporting. Accordingly, the roles of performance over the primary race distance, supplementary sprint segments, and strength tests should be specified before monitoring begins.

Interruptions in participation and missing tests should also be analyzed. Missing values due to pain, illness, or withdrawal from sport may not represent purely random missingness. Including only athletes who complete the entire year can create an excessively favorable impression of the program. Reasons for missing data, the number of athletes included in the analysis, and sensitivity analyses should be reported transparently.

Discussion and practical interpretation

The synthesis of the evidence indicates that the principal units of annual analysis are the athlete, time, and task. If an athlete's acceleration improves while maximal speed remains unchanged, the conditions under which maximal speed is attained become a focus for investigation in the next cycle. If jump or strength performance improves while sprint performance remains unchanged, the transfer of general physical adaptations to running should be examined. These situations identify directions for further investigation; they do not constitute ready-made diagnoses or an automatic algorithm for exercise selection.

A decline in performance may be associated with excessive training load, measurement conditions, technical changes, or other factors. Coaching decisions should not be based on a single session rating, jump test, or percentage decline. In particular, pain and persistent fatigue should not be dismissed as mere statistical noise; assessment by an appropriate professional should be sought when necessary. Considering health, education, and the opportunity for continued participation in sport together during youth athlete development is consistent with the general approach of the IOC consensus statement [16].

It is useful to summarize annual training effectiveness through two separate questions: how has the athlete's performance changed, and how convincingly can the observed change be explained by the available data? Time series and test results address the first question. Study design, maturation records, comparability of conditions, and measurement error address the second. Distinguishing these two levels helps prevent overconfident interpretation of complex data.

The limitations of this article include narrative source selection, differences in age and performance level across studies, and reliance on abstract information alone for some studies. The analysis does not

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claim to cover all available articles. Direct evidence relates primarily to 60 m, 100 m, and initial acceleration; specific evidence concerning bend running in the 200 m and maintenance of speed toward the end of the race is limited. Multiseason observations illuminate biological development, short-term experiments address the effects of particular exercises, and observations of elite groups reveal subtle within-season changes; these forms of evidence are not fully interchangeable.

For subsequent empirical evaluation, a one-year prospective study should collect data on sex, maturation, training age, completed training load, and standardized performance outcomes together. A prespecified analysis plan, consent procedures for participants who are minors, and protection of personal data are required. When the aim is to compare the causal effects of training programs, a controlled design and comparable groups are needed wherever feasible. The practical value of the analytical framework proposed in this article should also be evaluated using such data.

Conclusion

Scientific evaluation of adolescent sprinters' annual training requires the integration of biological maturation, completed training load, the mechanical components of sprinting, and measurement uncertainty. The literature does not support a single universal annual program or an identical expected percentage improvement for all athletes. The central methodological conclusion is that a personal-best performance, a physical capacity, and an individual trajectory should not be treated as interchangeable concepts.

Practical analysis rests on standardized timing, differentiation of sprint segments, distinction between planned and completed training loads, and comparison of observed changes with test error. A model for repeated observations helps account systematically for developmental factors, but does not automatically convert an observational association into a causal effect. Within these limits, an annual report can be used to define specific, testable objectives for the next training cycle.

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