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Quantification Method and Training Load Changes in High School Cross-Country Runners Across a Competitive Season

Micah C. Garcia, MS*; Brett S. Pexa, PhD, ATC†; Kevin R. Ford, PhD‡; Mitchell J. Rauh, PhD, MPH§; David M. Bazett-Jones, PhD, ATC*

*College of Health and Human Services, Motion Analysis and Integrative Neurophysiology Lab, University of Toledo, OH; †Department of Athletic Training and ‡Department of Physical Therapy, Congdon School of Health Sciences, High Point University, NC; §Doctor of Physical Therapy Program, San Diego State University, CA

Context: Running programs traditionally monitor external loads (eg, time and distance). Recent efforts have encouraged a more comprehensive approach to also account for internal loads (eg, intensity, measured as the session rating of perceived exertion [sRPE]). The combination of external and internal loads accounts for the possible interaction between these loads. Although weekly changes in training loads have been reported between external loads and the combination of external and internal loads during 2- and 4-week training cycles, no authors have indicated whether these differences occur during an entire cross-country season in high school runners.

Objective: To compare changes in training loads, as measured by (1) external loads and (2) combined external and internal loads in high school runners during an interscholastic cross-country season.

Design: Case series.

Setting: Community-based setting with daily online surveys.

Patients or Other Participants: Twenty-four high school cross-country runners (females = 14, males = 10, age = 15.9 $\pm$ 1.1 years, running experience = 9.9 $\pm$ 3.2 years).

Main Outcome Measure(s): Week-to-week percentage changes in training load were measured by external loads (time, distance) and combined external and internal loads (time $\times$ sRPE [timeRPE] and distance $\times$ sRPE [distanceRPE]).

Results: Overall, the average weekly change was 7.1% greater for distanceRPE than for distance ($P = .04$, $d = 0.18$). When the weekly running duration decreased, we found the average weekly change was 5.2% greater for distanceRPE than for timeRPE ($P = .03$, $d = 0.24$). When the weekly running duration was maintained or increased, the average weekly change was 10% to 15% greater when external and internal loads were combined versus external loads alone, but these differences were nonsignificant ($P = .11–.22$, $d = 0.19–0.34$).

Conclusions: Progression in the training load may be underestimated when relying solely on external loads. The interaction between internal loads (sRPE) and external loads (distance or time) appears to provide a different measure of the training stresses experienced by runners than external loads alone.

Key Words: adolescent athletes, workload, training monitoring, rating of perceived exertion

Key Points

- Running distance or time alone may underestimate training stress, as the average progression in training load was $\geq$10% lower for external loads than for the combination of an external and internal load.
- We suggest that high school cross-country coaches may implement their preferred external loads, as no differences were found between the average change in distance or time.

Cross-country is a popular sport among adolescents, as nearly 500 000 high schoolers participated in interscholastic cross-country during the 2018–2019 academic year.[1] Coaches typically monitor running volume to estimate the training loads that their athletes experience during training. Running programs are then designed to gradually progress training loads (ie, manipulating variables to generate a training response[2]) to improve performance while trying to minimize the risk of running-related injuries (RRIs) that are associated with sudden increases in running volume.[3] These programs manipulate running duration, frequency, and intensity of running sessions,[4] each of which contributes to training loads.[5] The progression of training loads is necessary to strengthen the musculoskeletal structures and enhance running performance; however, excessive progression without adequate recovery may be detrimental to the load capacity of musculoskeletal structures and result in overuse injury.[5,6]

Coaches and runners traditionally monitor training loads according to external loads such as running distance or time[7] (ie, the physical component of the training program[8]). Although external loads are simple to prescribe and measure, external loads alone fail to encompass a comprehensive approach to the stresses experienced by long-distance runners.[7,9] Relying solely on distance or time fails to account for *internal loads* (ie, the psychological or physiological response to an external load[10]) that may vary across running sessions (eg, intensity).[11] Running intensity can also be easily quantified in long-distance runners using a 10-point scale (1 = *very easy*, 10 = *maximal effort*)[12] to measure the session rating of perceived exertion (sRPE). Prior investigators have reported that sRPE correlated with blood lactate,[13] a finding that was validated in adolescent long-distance runners.[14] Monitoring external and internal loads individually limits the ability to consider the potential interaction between time or distance and intensity for these loads. Combining an internal and external load has been purported to provide a more comprehensive and individualized approach to monitoring training loads,[9,15,16] and this measure may be easily quantified by multiplying an internal load (sRPE) by an external load (distance or time).[15,16]

Changes in external loads are often measured on a weekly basis (eg, percentage change over a 2-week period). Recently, researchers[15,16] assessed the weekly change in training load according to external load and combined external and internal loads in adult and high school long-distance runners. In both studies,[15,16] the training load progression was lower for external loads than for the combination of an external and internal load, suggesting that external loads alone may underestimate the actual stresses experienced by long-distance runners. However, the study in high school runners was limited to boys and was conducted only during a 2-week period, in which the weeks were designed to reflect low and high training loads.[16] A limitation of this work might be an inability to generalize the results to an entire cross-country season when the weekly training load varies. Therefore, the purpose of our investigation was to compare the training load progression as measured by external loads (distance, time) and combined external and internal loads (sRPE) in male and female high school cross-country runners during a competitive cross-country season. We hypothesized that the training load progression during the season would be greater with the combination of an external and internal load than that of external loads alone.

METHODS

Participants

Cross-country runners from 2 local high schools (1 all-boys school, 1 all-girls school) were invited to participate in our study for the fall 2020 cross-country season. Volunteers were excluded if they had a current self-reported RRI. Runners with a history of RRI were eligible for the study if they did not self-report a current RRI at the time of enrollment. Written consent (or parental permission and assent if age <18 years) was obtained from all participants before enrollment, and the study procedures were approved by the university's institutional review board.

Procedures

Demographic information (sex, race and ethnicity, and stage of physical maturation[17]) and running history (age of starting to run long distances, age of first competition in long-distance running, sport specialization,[18] and average number of runs per week and miles run per week over the last month) were collected for each participant before the start of the cross-country season. During the season, participants followed their usual running program as designed by their coach. After each running session, participants recorded their run using an electronic running log (Qualtrics XM). The running log included self-reported running distance (miles), time (hours, minutes, and seconds), and sRPE (10-point scale; 1 = *very easy*, 10 = *maximal effort*). A custom interactive heatmap (Figure 1) was used to self-report sRPE, and the participant clicked the region within the image that corresponded to the perceived exertion during the running session. Each region had a numeric value.

Figure 1. Session rating of perceived exertion (sRPE)[12] interactive heatmap scale used for the study. Participants clicked the region that corresponded with their perceived exertion for the running session.

Analyses

The primary outcomes of interest were the weekly changes in training loads during the cross-country season. Training loads were quantified by external loads (time [minutes], distance [miles converted to km]) and combinations of an external load with an internal load (timeRPE = time × sRPE, distanceRPE = distance × sRPE) for each running session. For each week during the 8-week season, we calculated the cumulative sum of each training load variable. If a participant sustained an RRI during the season, data from the weeks after the RRI were excluded from the analysis. An *RRI* was defined as pain in the low back or lower limbs that caused either a restriction or end of running (distance, speed, duration, or training) for ≥7 days or 3 consecutive scheduled sessions or required the participant to consult a physician or other health care professional.[19]

Weekly change was calculated as the percentage change from the cumulative sum of the current week (*Week1*) relative to the cumulative sum of the previous week (*Week0;* Equation 1).[20] We could not calculate weekly change for the first week in the season, resulting in a maximum of seven 2-week cycles of weekly change data points for each participant. Each weekly change data point was classified in 1 of 3 progression subgroups: (1) decrease in training duration (>4% decrease in time), (2) no change in training duration (–4% to 4% change in time), or (3) increase in training duration (>4% increase in time).[15] If a participant stopped completing the electronic running log during the season, we averaged only the weeks with at least

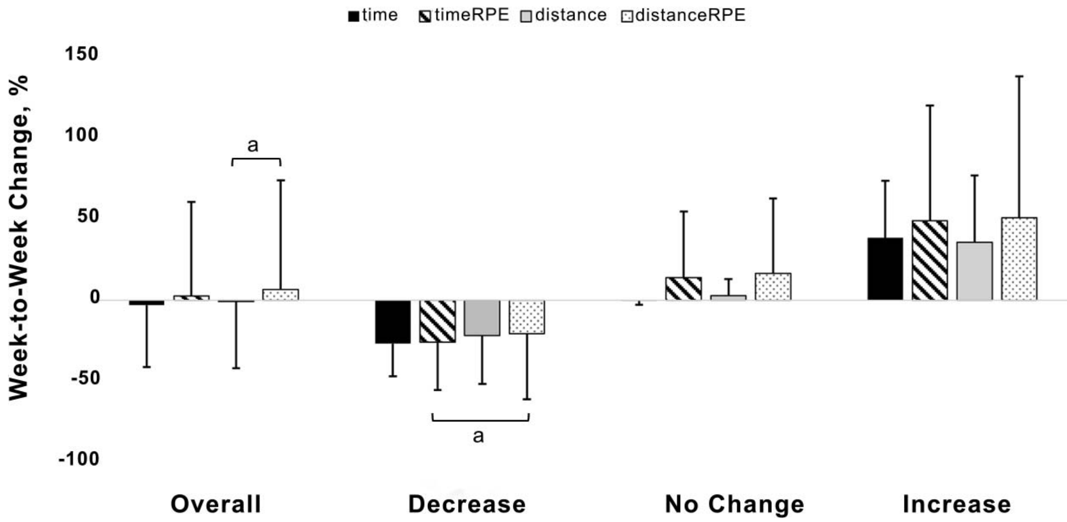

Figure 2. Average weekly change for training load variables. Displayed as mean ±SD. Abbreviation: RPE, rating of perceived exertion. [a] Significant difference ($P \leq .05$).

1 run recorded for their average weekly change. The weekly change had to be within 2 SDs of the average of the participant's weekly change to be included in the analysis.[15]

$$\text{Weekly change}(\%) = \frac{(\text{Week 1} - \text{Week 0})}{\text{Week 0}} \times 100 \qquad (1)$$

The analysis was conducted in R (version 3.6.3; RStudio, Inc). Consistent with the statistical design of a prior study,[15] we used paired *t* tests to compare the average weekly change between load variables (time versus timeRPE, distance versus distanceRPE, time versus distance, and timeRPE versus distanceRPE) for all data points (overall) and within progression subgroups (decrease, no change, increase) and assessed effect size with the Cohen *d* (*small* = 0.2, *medium* = 0.5, *large* = 0.8).[21] Statistical significance was set at $P \leq .05$.

RESULTS

Of the 28 runners who enrolled in the study, 4 were excluded due to incomplete data from not self-reporting their running sessions, leaving 24 runners in the final analyses (females = 14, males = 10, age = 15.9 ± 1.1 years, running experience = 9.9 ± 3.2 years) and 148 weekly change data points. Of the 148 weekly change data points, 6 were outliers (>2 SD from the participant's average weekly change) and removed from the analysis. Of the 142 remaining weekly change data points, 79 (55.6%) reflected a decrease in running duration; 19 (13.4%), no change in running duration; and 44 (31.0%), an increase in running duration.

Overall, the average weekly changes for time, timeRPE, distance, and distanceRPE were –3.0% ± 37.9%, 2.6% ± 57.7%, –0.7% ± 40.8%, and 6.5% ± 66.9%, respectively (Figure 2). A difference was noted between distance and distanceRPE ($P = .04$, $d = 0.18$; Table). No differences were observed between time and timeRPE ($P = .08$, $d = 0.15$), time and distance ($P = .20$, $d = 0.11$), or timeRPE and distanceRPE ($P = .09$, $d = 0.40$).

For weeks with a decrease in running duration, the average weekly changes for time, timeRPE, distance, and distanceRPE were –26.5% ± 20.1%, –25.7% ± 29.2%, –21.7% ± 29.6%, and –20.5% ± 40.0%, respectively (Figure 2). A difference was identified between timeRPE and distanceRPE ($P = .03$, $d = 0.24$; Table), but no differences were demonstrated between time and timeRPE ($P = .73$, $d = 0.04$), distance and distanceRPE ($P = .63$, $d = 0.05$), or time and distance ($P = .06$, $d = 0.22$).

For weeks with no change in running duration, the average weekly changes for time, timeRPE, distance, and distanceRPE were –0.4% ± 2.3%, 13.8% ± 40.6%, 2.8% ± 10.2%, and 16.5% ± 45.8%, respectively (Figure 2); no differences were seen for any of the comparisons (*P* values $\geq .15$, *d* values ≤ 0.34; Table).

For weeks with an increase in running duration, the average weekly changes for time, timeRPE, distance, and distanceRPE were 38.1% ± 34.9%, 48.6% ± 70.6%, 35.5% ± 40.9%, and 50.6% ± 86.5%, respectively (Figure 2). None of the comparisons differed (*P* values $\geq .11$, *d* values ≤ 0.25; Table).

DISCUSSION

To our knowledge, we are the first to report the comparison of weekly change in training load between external loads and the combination of an external and internal load for male and female high school cross-country runners during an entire competitive season. Unlike previous results in adults and male high school long-distance runners,[15,16] we found that the weekly change in training load was not different when an external load was combined with an internal load (distanceRPE and timeRPE) versus an external load alone (distance and time) when running duration increased (>4%). However, the weekly change in training load was greater for distanceRPE than for distance for the overall data and greater for distanceRPE than for timeRPE when running duration decreased (<–4%). We also found that the change in training load was similar between external loads (distance versus time) and the combination of an external and internal load (distanceRPE versus timeRPE).

When weekly running duration was maintained or increased, changes in distance and time were approximately 10% to 15% lower than changes in distanceRPE and

Table. **Paired Differences Between Progressions in Running Loads for High School Cross-Country Runners**

Comparison	Overall (n = 141) MD (95% CI)	Overall *P* Value (Cohen *d*)	Change in Running Load Decrease (<–4%; n = 79) MD (95% CI)	Decrease *P* Value (Cohen *d*)	No Change (–4% to 4%; n = 19) MD (95% CI)	No Change *P* Value (Cohen *d*)	Increase (>4%; n = 44) MD (95% CI)	Increase *P* Value (Cohen *d*)
Time vs timeRPE	–5.6 (–11.8, 0.6)	.08 (0.15)	–0.8 (–5.1, 3.6)	.73 (0.04)	–14.2 (–34.1, 5.7)	.15 (0.34)	–10.5 (–27.6, 6.5)	.22 (0.19)
Distance vs distanceRPE	–7.1 (–13.9, –0.4)	.04[a] (0.18)	–1.1 (–5.8, 3.6)	.63 (0.05)	–13.8 (–34.1, 6.6)	.17 (0.33)	–15.1 (–33.6, 3.4)	.11 (0.25)
Time vs distance	–2.3 (–5.9, 1.2)	.20 (0.11)	–4.8 (–9.8, 0.1)	.06 (0.22)	–3.2 (–8.5, 2.1)	.22 (0.29)	2.5 (–4.5, 9.6)	.47 (0.11)
TimeRPE vs distanceRPE	3.9 (–0.6, 8.4)	.09 (0.14)	–5.2 (–10.0, –0.4)	.03[a] (0.24)	–2.7 (–8.6, 3.2)	.35 (0.22)	–2.0 (–13.8, 9.7)	.73 (0.05)

Abbreviations: MD, mean difference; RPE, rating of perceived exertion.

[a] Significant difference ($P \leq .05$).

timeRPE. Although these results were nonsignificant, small effect sizes (d = 0.19–0.34) were present and may be clinically meaningful.[22] During a competitive season, a continual underestimation of training loads by relying solely on external loads may have an additive effect that influences performance and the risk of sustaining an overuse injury. For example, if training loads are underestimated by 10% for 4 consecutive weeks, the cumulative training load would be underestimated by 40% during that period. Therefore, a clinically meaningful difference in training load progression may occur when quantified by external loads alone versus the combination of an external and internal load. This finding supports the belief that monitoring weekly distance or time alone may underestimate the training stresses experienced when high school long-distance runners maintain or increase weekly running duration. Including the intensity of the run may be a more comprehensive representation of training stress.[15,16] Running programs often manipulate running duration[23] and intensity[4] (eg, interval splits and recovery runs), and running at faster speeds increases the landing force of each step.[24] Increasing duration, intensity, or both increases the cumulative landing force applied to musculoskeletal structures, and relying solely on external loads may be an oversimplified way of estimating training stress, as this method fails to account for variations in internal loads.[7]

Progressively increasing training stress is necessary to improve performance.[25] However, researchers and clinicians are concerned that a sudden change in training stress (ie, "too much, too soon, too fast") increases the risk of sustaining an injury.[6,26] In our study, time in almost one-third of the weekly progression data points increased by more than 4%. Running programs often follow the "10% rule" that recommends not increasing running volume by more than 10% over a 2-week training cycle to reduce the risk of sustaining an RRI.[27] Interestingly, the 10% rule is not currently supported by research, as no differences in the risk of sustaining an RRI were found between adult running programs that progressed running volume by <10% and those that progressed running volume by 10% to 30%.[20,28,29] Here, we observed that the average progression in running duration group was 35.5% to 50.6%, depending on the training load variable. These results suggest that high school runners may experience weeks of excessive progression in running volume. We did not assess the interaction between RRIs and progression in running volume, but excessive progression in running volume was previously noted to increase the risk of sustaining an RRI.[20] Thus, high school runners may be at a heightened risk of incurring an RRI after a week of an excessive progression in running volume. Prospective studies with large cohorts are needed to better understand the relationship between progression in training load and the risk of sustaining an RRI in high school long-distance runners.

Running programs are prescribed according to running time or distance, and to our knowledge, it is unclear if these variables measure a similar construct as an external load. We found no differences in the weekly change between time and distance, and the only difference between timeRPE and distanceRPE was during weeks of decreasing running duration. Although this difference had a small effect size ($d = 0.24$), the mean difference was only 5.2%, which is likely not clinically meaningful. Similarly, a small effect size ($d = 0.22$) was seen between the change in time and the change in distance during weeks with a decrease in running duration, but the mean difference was only 4.8%, which again questions the clinical meaningfulness. Therefore, it appears that either time or distance may be used for monitoring external loads as the small effect sizes coupled with mean differences of ~5% are likely not clinically meaningful. Overall, our results suggest that using time or distance provides a similar measure of external loads, and coaches may choose their preferred external load when developing running programs for high school runners.

Our findings should be interpreted in the context of the study limitations. First, the runners self-reported time, distance, and sRPE using an electronic running log; this device may pose a burden on runners and provide incomplete data. However, our purpose was to compare the differences in the magnitude of training load change among external loads and the combination of an external and internal load within participants and not between participants. Because we used paired data for our analysis, incomplete data (eg, not reporting a running session) do not weaken our results, as the same running sessions were included for weekly change data points for all training load variables to allow for comparison among quantification methods. Second, sRPE is a subjective measure of intensity and may be interpreted differently by participants. Although sRPE has been validated in adolescent long-distance runners,[14] a physiological measure of intensity (eg, heart rate) may be more appropriate and less of a burden. With the increased availability and decreased cost of wearable technology for monitoring time, distance, and heart rate, applying wearable technology and incorporating a physiological measure of intensity may reduce both the reporting burden on runners and the likelihood of incomplete data. Third, the cutoffs used to determine the categorization of change in progression followed methods from recent research.[15] However, larger cutoffs (eg, 10%) may provide a more accurate categorization for the change in progression. Fourth, we were unable to assess sex differences in load progression, as the sample size did not offer sufficient power for sex-specific analyses. Lastly, the progression in training load was not compared with injury risk. We recommend that future investigators recruit large samples of male and female runners and follow them prospectively to assess how training loads interact with training stress and injury.

In conclusion, incorporating internal loads (sRPE) in combination with external loads (distance or time) provided a similar representation of training stresses experienced by high school cross-country runners for the season. However, when maintaining or increasing weekly running duration, progression in training loads was 10% to 15% lower when measured by external loads alone than when measured by the combination of an external and internal load. Although these differences were nonsignificant, the small effect sizes and mean differences of >10% suggest a clinically meaningful difference may exist between the progression in training loads when measured by external loads alone versus the combination of an external and internal load. Relying solely on external loads may therefore underestimate the stresses that runners experience during each training session. No clear distinction was seen between distance or time, so coaches may use their preferred measure of external load monitoring when developing training programs.

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Address correspondence to Micah C. Garcia, MS, College of Health and Human Services, Motion Analysis and Integrative Neurophysiology Lab, University of Toledo, 2801 W Bancroft St, Health and Human Services Building 2505E, Toledo, OH 43606. Address email to micah.garcia@rockets.utoledo.edu.