Journal of Athletic Training 2020;55(12):1285–1291
doi: 10.4085/1062-6050-573-19

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Original Research

Session Rating of Perceived Exertion Combined With Training Volume for Estimating Training Responses in Runners

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Context: Historically, methods of monitoring training loads in runners have used simple and convenient metrics, including the duration or distance run. Changes in these values are assessed on a week-to-week basis to induce training adaptations and manage injury risk. To date, whether different measures of external loads, including biomechanical measures, provide better information regarding week-to-week changes in external loads experienced by a runner is unclear. In addition, the importance of combining internal-load measures, such as session rating of perceived exertion (sRPE), with different external-load measures to monitor week-to-week changes in training load in runners is unknown.

Objective: To compare week-to-week changes in the training loads of recreational runners using different quantification methods.

Design: Case series.

Setting: Community based.

Patients or Other Participants: Recreational runners in Vancouver, British Columbia.

Main Outcome Measure(s): Week-to-week changes in running time, steps, and cumulative shock, in addition to the product of each of these variables and the corresponding sRPE scores for each run.

Results: Sixty-eight participants were included in the final analysis. Differences were present in week-to-week changes for running time compared with timeRPE ($d = 0.24$), stepsRPE ($d = 0.24$), and shockRPE ($d = 0.31$). The differences between week-to-week changes in running time and cumulative shock were also significant at the overall group level ($d = 0.10$).

Conclusions: We found that the use of an internal training-load measure (sRPE) in combination with external load (training duration) provided a more individualized estimate of week-to-week changes in overall training stress. A better estimation of training stress has significant implications for monitoring training adaptations, resulting performance, and possibly injury risk reduction. We therefore recommend the regular use of sRPE and training duration to monitor training load in runners. The use of cumulative shock as a measure of external load in some runners may also be more valid than duration alone.

Key Words: running, training load, monitoring, training response, inertial sensors

Key Points

- Training duration in combination with the session rating of perceived exertion provided a better estimate of training stress than duration alone.
- Cumulative shock may be a more sensitive measure of external load in some runners.

In order to change a training stimulus and ultimately influence performance and fitness levels, coaches and athletes manipulate multiple factors that affect the training stimulus, such as the frequency, intensity, volume, and duration of a training session.[1,2] Manipulating these variables results in an overall physiological training stress on the athlete that, with proper recovery, will lead to adaptation and improved physical performance.[3] In distance running, coaches and athletes have historically monitored and quantified training primarily by using volume, either as weekly distance (measured in miles or kilometers) or duration (in minutes). Running volume is considered an *external training load* as it contributes to the mechanical loads applied to athletes. Given that running distance can be a good predictor of performance in distance running[4,5] and has been used almost exclusively by most North American coaches and runners for many decades, it is unsurprising that many coaches and runners use only this method to quantify running training.

Although external training loads in runners have traditionally been measured using duration or distance, the emergence and availability of consumer-grade wearable technology has made it increasingly practical to assess external loads applied to a runner using more specific and individualized biomechanical measures. Because a 30-minute running session might not yield the same external loads on runners with different biomechanical characteristics, biomechanical measures from wearable devices could provide more in-depth and individualized assessments of external loads during a running session, training cycle, or both. For example, currently available wearable technology allows the user to collect the number of steps (as the total count per session or via calculations from the average cadence and run duration) and peak accelerations of the lower limb (eg, tibia, feet or shoes, pelvis), among other measures.[6,7] However, a major limitation to quantifying running training using solely external loads is that these loads alone do not fully quantify the training stress experienced by an athlete. This simplification of training monitoring in runners is evidenced by the fact that in many sports, prescription or monitoring of training volume alone does not always yield the intended training adaptations and positive performances.[8–10] If an athlete does not respond to training as intended (ie, more or less training stress than planned) and if the training stress is not quantified appropriately, an athlete could experience too little (undertraining) or too much (nonfunctional overreaching) training stress,[11,12] resulting in performance decrements or, at the least, a plateau in performance. More experienced coaches and runners might have developed their own effective training-monitoring approaches to quantify week-to-week changes in training stress based on day-to-day observations of, and input from, their athletes, yet less experienced coaches and runners without the guidance of a coach might not be able to adequately quantify training stress. Thus, for most coaches and runners, it is important that the methods used to monitor running training adequately quantify the training stress resulting from the training stimuli.

In sport science practice, training stress is often referred to as the *training load*, measured as the product of an athlete's external and internal training loads.[13] In this context, running volume (eg, distance or duration) is considered a simple measure of the external training load. Although external training loads quantify the external mechanical loads placed on the body, they cannot account for how runners feel during a given training session. This is not only influenced by the external loads applied but also by the runner's state of recovery and daily stresses (eg, sleep, nutrition, illness).[14,15] As such, interpreting external loads in isolation is an oversimplified quantification of a runner's training stress because it fails to account for the physiological and psychological responses (ie, internal training loads) that are influenced by daily stress and lifestyle factors.[13,16–18] The session rating of perceived exertion (sRPE; often rated using a numeric scale between 1 and 10) is a practical measure of the internal training load in distance runners because it is simple to understand and administer. Other common measures of internal load in runners, such as heart rate and blood lactate concentration, introduce some logistical and financial challenges for most coaches and athletes. Thus, considering that the sRPE is practical and correlates well with blood lactate threshold,[19] it is most often used by distance runners and their coaches to assess internal training load. The combined monitoring of training volume (external load) and sRPE (internal load) may provide a more complete assessment of the training stress a runner experiences and may allow coaches to better identify sudden, or week-to-week, changes in training load that are not appreciated when only external loads, such as training volume, are monitored. With practice and experience, changes in week-to-week training loads can be manipulated to optimize training adaptations. Importantly, sudden changes in training load may also indicate an increased risk of injury.[20] Therefore, the sensitivity of the measures used to monitor training load is likely important from the perspectives of performance and injury risk management.

To date, whether different measures of external loads, including biomechanical measures, provide more valuable information regarding week-to-week changes in the external loads a runner experiences is not well understood. In addition, although monitoring the sRPE is practical and simple, it still requires additional time and effort for athletes and coaches. Thus, it would be valuable to understand the importance of combining the sRPE with different external-load measures to monitor week-to-week changes in training load in runners relative to a commonly used external-load measure, such as training duration. Therefore, the purpose of our study was to compare week-to-week changes in training stress using different quantification methods compared with running duration in recreational runners. We hypothesized that methods that incorporated internal loads (sRPE) to quantify running training would yield different week-to-week changes in training load than running duration alone. A secondary hypothesis was that using more specific variables (steps or cumulative shock) would yield differences in week-to-week changes in training stress compared with training duration.

METHODS

Participants

Data presented in this study are from a larger longitudinal study of running-related injury incidence over a 7-month self-guided running program (unpublished data, 2020). A sample of recreational runners between the ages of 18 and 60 years who had been running for at least 3 months was recruited from the local running community via running clubs and social media posts. Participants were excluded if they had experienced (1) a lower extremity injury in the previous 3 months, (2) any previous lower limb surgery, or (3) any current low back or lower extremity pain while running. Written consent was obtained from all participants, and ethics approval was granted by the institutional research ethics board.

Procedures

Each participant was outfitted with 2 RunScribe inertial measurement units (IMUs; version 3; Scribe Labs Inc, San Francisco, CA). Authors of a previous study[21] demonstrated that these sensors accurately measured peak accelerations at a range of speeds compared with a research-grade accelerometer. Each IMU included a triaxial accelerometer (range $\pm$ 16g) and a triaxial gyroscope (range $\pm$ 2000°/s) and sampled at a rate of 500Hz. The sensors were mounted according to company recommendations on the laces of each shoe using the provided lace clip (Figure 1). Demographics and a detailed training and injury history were collected for each participant before the start of the study. Participants were followed for 7 months (or until injury or dropout, whichever occurred first) and uploaded their training data after each run. Biomechanical measures automatically recorded by the sensor included running time, steps, vertical impact, braking, shock, foot-strike type,

Figure 1. Illustration of the position of an inertial measurement unit sensor on a running shoe.

pronation excursion, maximum pronation velocity, step rate, ground contact time, and flight ratio. As our intent was to determine the ability of different methods to monitor training load relative to duration, we were only concerned with external-load metrics measured by the sensors. These were running time, steps, and cumulative shock. *Cumulative shock* was defined as the vector sum of the peak braking and vertical accelerations per step multiplied by the total number of steps per run. Participants were also asked to report their sRPE after each run on a 10-point scale with descriptors ranging from *very, very easy* to *maximal*.[22] Participants ran in their preferred running shoes and followed their usual training program for the duration of the study.

Data Analyses

The primary outcome of interest was the change in week-to-week training expressed as a percentage. The 6 variables used to quantify training were running time (time), steps, and cumulative shock (shock), as well as the products of each of these variables and the corresponding sRPE scores (timeRPE, stepsRPE, and shockRPE) for each run. Time is a typical measure of training volume among runners, which is why we chose to compare all other methods with this variable. For each week, the cumulative value for each variable was calculated, and the percentage change from the previous week was determined. We assessed the week-to-week percentage changes for all training measures relative to training duration for the entire group and 3 subgroups: participants with an increase in training duration (>4% increase in time), participants with a decrease in training duration (>4% decrease in time), and participants with no change in training duration (<4% change) from week to week. The 4% cutoff threshold was chosen as the week-to-week percentage changes in running time within this range (–4% to +4%) that produced an average of 0% (ie, no change), and it was within the often used 10% rule of week-to-week changes in training. Data from these subgroups were analyzed to determine whether the direction in week-to-week change in training duration influenced the differences among training measures.

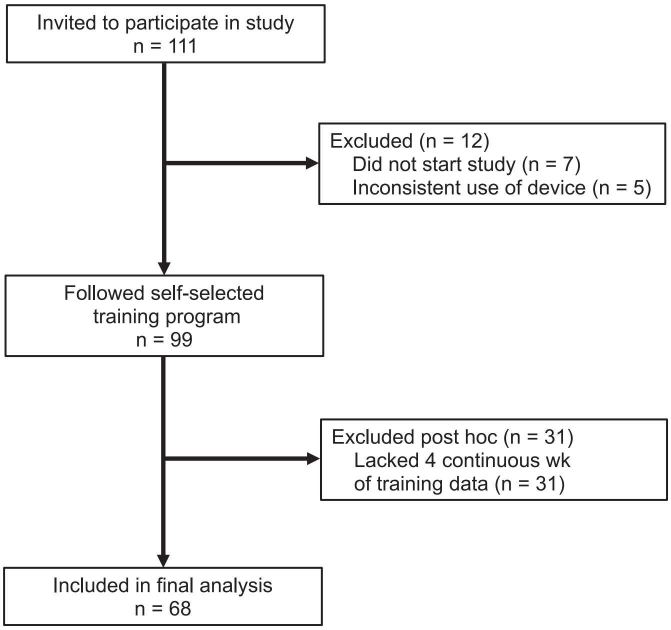

Figure 2. Flow chart demonstrating the sample of runners initially invited to participate in the study and the runners included in the final analysis.

Statistical Analyses

Because of missing data from unreported sRPE scores and weeks during which participants did not run, post hoc inclusion criteria included only the weeks during which the participant ran and no data were missing. A minimum of 4 continuous weeks of training data were necessary to be included in the analysis. Four weeks of continuous data resulted in three 2-week training cycles for analysis per participant. In addition, for each person, week-to-week duration differences had to fall within 2 standard deviations of the mean of the three 2-week cycles to be included in the statistical analyses. Paired *t* tests ($P \leq .05$) and Cohen d effect sizes were used to compare the week-to-week percentage changes in weekly running time with those of all other measures of training load (steps, shock, timeRPE, stepsRPE, and shockRPE).

RESULTS

In total, 111 volunteers met the inclusion criteria and were invited to participate in the study. Seven did not start the study, and 5 did not consistently use the IMUs to record their training. After further exclusion of recruits who did not meet the post hoc criteria, 68 participants (30 women and 38 men) were included in the final analysis (Figure 2; Table 1).

Table 1. Participant Demographics[a]

Characteristic	Mean ± SD
Age, y	40.1 ± 10.4
Height, m	1.73 ± 0.10
Body mass, kg	66.7 ± 11.5
Body mass index (calculated as $\text{kg} \cdot \text{m}^{-2}$)	22.2 ± 2.6
Running experience, y	12.3 ± 9.5
Prior weekly volume, km	48.8 ± 29.6

[a] N = 68: 30 women, 38 men.

Table 2. Week-to-Week Changes (%) in Training Load Measured in Time, Steps, Cumulative Shock, Time × RPE (timeRPE), Steps × RPE (stepsRPE), and Cumulative Shock × RPE (shockRPE), Mean ± SD

Week-to-Week Volume Change	Time	Steps	*P* Value	*d*	Shock	*P* Value	*d*	TimeRPE	*P* Value	*d*	StepsRPE	*P* Value	*d*	ShockRPE	*P* Value	*d*
Overall (n = 68)	11.6 ± 20.9	12.0 ± 21.7	.61	0.02	13.9 ± 25.0[a]	.05	0.10	18.9 ± 38.9[a]	.02	0.24	19.4 ± 41.2[a]	.03	0.24	22.9 ± 47.1[a]	.01	0.31
Decrease (n = 13)	−15.3 ± 6.5	−15.6 ± 8.6	.84	0.04	−14.6 ± 9.2	.60	0.09	−22.0 ± 10.4[a]	.01	0.80	−22.2 ± 11.2[a]	.01	0.78	−20.8 ± 12.1[a]	.04	0.59
No change (n = 14)	0.8 ± 1.9	0.0 ± 3.6	.39	0.29	1.9 ± 6.1	.53	0.25	7.7 ± 14.8	.09	0.68	6.2 ± 5.5	.19	0.51	8.6 ± 18.0	.12	0.63
Increase (n = 41)	23.9 ± 17.0	24.8 ± 17.2	.37	0.05	27.1 ± 22.6	.08	0.16	35.7 ± 39.4[a]	.02	0.39	37.1 ± 42.3[a]	.02	0.41	41.6 ± 50.1[a]	.01	0.48

Abbreviations: *d*, Cohen d effect size; RPE, rating of perceived exertion.

[a] $P \leq .05$ different from time. *Overall* = across all participants and 2-week cycles; *decrease* = >4% decrease; *increase* = >4% increase; *no change* = <4% change.

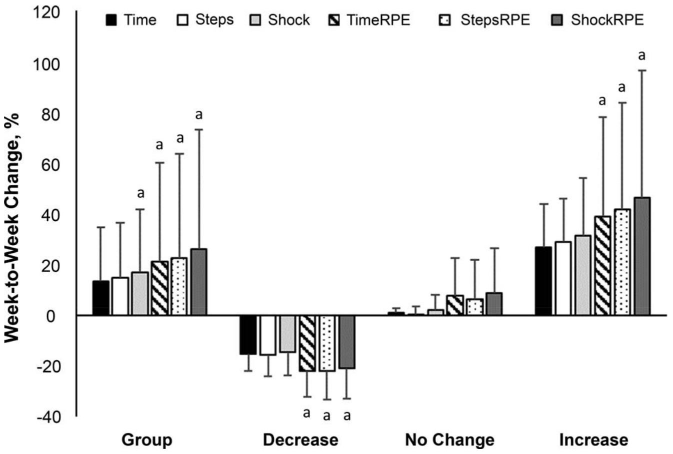

Figure 3. Week-to-week change (%) in training load measured in time, steps, cumulative shock, and the following training-load measures: time × rating of perceived exertion (timeRPE), steps × RPE (stepsRPE), and cumulative shock × RPE (shockRPE) for the whole group (group), those who showed an average decrease in week-to-week change in running time (decrease), those who showed no change in average week-to-week running time (no change), and those who showed an average increase in week-to-week change in running time (increase; mean ± SD). [a] Denotes a statistically significant difference from time at $P \leqq .05$.

We found significant differences between week-to-week changes in running time compared with timeRPE (*d* = 0.24), stepsRPE (*d* = 0.24), and shockRPE (*d* = 0.31; Figure 3; Table 2). These changes were seen when week-to-week changes were positive (progression) or negative (regression) but not when running time did not change from week to week. The difference between week-to-week change in running time and cumulative shock was also significant at the overall group level (*d* = 0.10).

DISCUSSION

The purpose of our study was to compare week-to-week changes in recreational runners' training stress using different quantification methods with running duration. We also assessed week-to-week changes in training stress and training duration among subgroups to determine whether the direction of the latter influenced the differences among training measures.

Our primary hypothesis—that incorporating an internal load (ie, sRPE) to compute running training load would yield different week-to-week changes in training stress relative to training duration alone—was proven true. Training duration (time) consistently underestimated the change in week-to-week training stress compared with the use of training loads that incorporated a measure of internal load (ie, sRPE). These changes were consistent regardless of whether training duration increased or decreased from week to week. When analyzing the whole group, we determined this underestimation was as little as 7.3% (time versus timeRPE), but when week-to-week training loads increased, this difference grew to 11.8% to 17.7% (time versus timeRPE and shockRPE). These differences could have meaningful implications in terms of improperly quantifying week-to-week changes in training stress and, ultimately, performance outcomes, among runners who are not incorporating sRPE in their weekly training-load monitoring. For instance, many runners and coaches follow

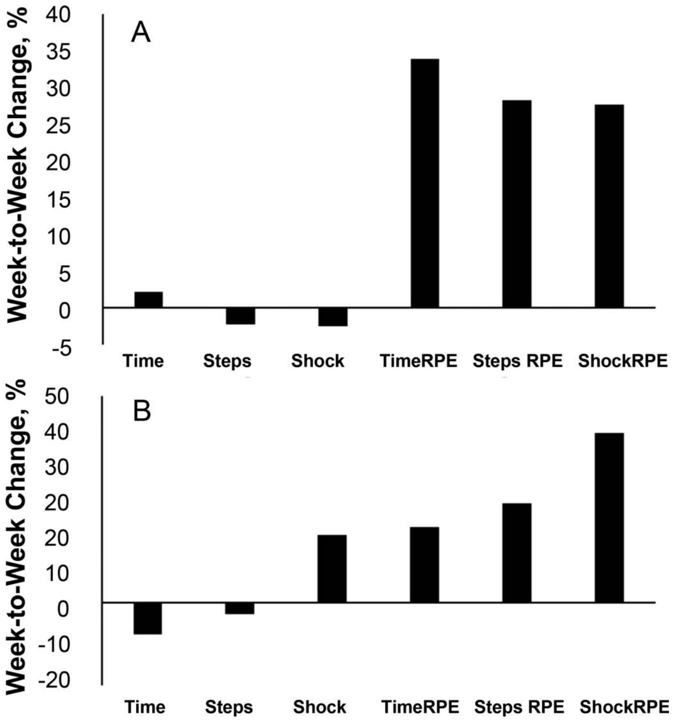

Figure 4. Individual examples demonstrating a case of A, large (>25%) week-to-week changes (%) in training loads (time rating of perceived exertion [RPE], stepsRPE, shockRPE) despite small changes (<4%) in external-load metrics (time, steps, cumulative shock), and B, decrease in week-to-week changes (%) in training time despite increases in some external-load metrics (shock) and all training-load metrics.

the 10% rule, whereby they do not increase training volume by more than 10% per week to reduce the risk of nonfunctional overreaching (ie, chronic fatigue associated with decrements in performance) or injury. Although this rule has been refuted in the literature,[23–26] our results suggest that a 10% increase in training volume may not represent true week-to-week changes in training and, in fact, could be equivalent to much larger changes in training stress.

Large week-to-week changes in training load have been anecdotally linked to increased injury risks, but little evidence supports this claim.[27] However, most investigators[23,25,26] have used only external-load measures to quantify the training load. One recent group[20] that monitored both internal and external training loads identified an association between changes in training load and new injury in an endurance sporting population, indicating that this combined method might more accurately gauge injury risk. Ultimately, injury occurs when the structure-specific cumulative load exceeds the load capacity of the tissue.[28] Given the complexity of structure-specific load capacity, it is not surprising that external loads alone do not appear to be sufficient for monitoring running training in order to assess injury risks or development.[23,25] Although wearable technology makes it easier to measure cumulative external loads during running, it is still difficult to accurately assess structure-specific internal tissue mechanical loads and capacity. More research that includes measures of training load, internal mechanical loads, and tissue capacity is needed to improve our ability to detect the risks of developing running injuries.

Importantly, when observing our data at an individual level, it is clear that the specific method used can uncover (1) vastly different week-to-week percentage changes in training load and, in some cases, (2) yield a different direction of week-to-week training-load changes. Practically, this suggests that the intended goal of a training period may not match the actual training stress a runner experiences (see Figure 4). Monitoring both external and internal loads allows the runner to accurately assess the overall training stress experienced, whereas this may be overlooked if only external loads are monitored.[13,16–18] Finally, it is interesting to note that week-to-week changes had greater variability when sRPE was included in the assessment of training stress due to the increased variability in sRPE among individual runners. Future authors should assess the variability in week-to-week changes among various training-load measures.

Our secondary hypothesis was that using more individualized external-load variables (steps or cumulative shock) from a shoe-worn IMU sensor would yield differences in week-to-week changes in training stress compared with training time alone. Our hypothesis was partially supported as the week-to-week change for the whole group measured with cumulative shock—the vector sum of the peak braking and vertical accelerations per step—was greater than time, even though this difference showed only a small effect ($d = 0.10$). However, this difference did not exist for the 3 subgroups. Further, week-to-week changes in steps were not different than changes in training time for the whole group and all 3 subgroups. Some evidence supports the hypothesis that cumulative shock may be a more sensitive measure of external load in certain contexts. Increased running speed,[29,30] running on harder surfaces,[30] and running downhill[31] have been associated with higher levels of peak tibial acceleration. Peak tibial acceleration also increases throughout a prolonged run.[32] Therefore, runners who have more variability in their training routine—incorporating different surfaces, speeds, length of runs, and slopes—would likely experience different external loads when measured by cumulative shock versus time. For example, it is not uncommon for runners to spend more time running on softer surfaces and at slower speeds during a recovery week. Training duration alone cannot quantify the step-by-step external-load differences when running on different surfaces and may underestimate or overestimate the weekly external load, depending on the training surface. Our analysis did not discriminate between these runners, but further investigations are necessary to determine if the use of cumulative shock to quantify external load would benefit runners who vary their training factors (eg, surface, pace, slope) from week to week compared with the duration alone.

Limitations

We used sRPE as our measure of internal training load, but better measures may be available to assess the physiological and psychological responses to external training load. Different interpretations of perceived exertion may lead some runners to rate fatigue, whereas others rate discomfort.[33] Standardizing the definition of RPE is important for maintaining the external validity of the measure. Assessing other perceptions, such as fatigue or discomfort, may prove more valid as an indicator of internal training load.[33] Finally, given the self-guided nature of the training program, the intention of week-to-week changes in training for our participants was unknown. Therefore, it is difficult to truly understand whether the specific training-load measures assessed provide more valuable information than training duration alone. However, the clear differences in week-to-week changes among the various measures of training and training duration at least suggest that including sRPE to quantify week-to-week changes in training load provides vastly different information.

CONCLUSIONS

Our findings suggest that the use of an internal training-load measure (sRPE) in combination with an external-load measure (training duration) provided a more individualized estimate of week-to-week changes in overall training stress. A better estimation of training stress has significant implications for monitoring training adaptations and resulting performance and possibly injury risk reduction and return to running after injury. Thus, we recommend the regular use of the sRPE and training duration to monitor training load in runners. Future researchers should investigate the influence of such training loads (1) when the goal of a training cycle (week-to-week changes) is known to better understand the significance of training loads relative to coach- or program-prescribed training and (2) on resulting running performance and injury incidence in runners at all levels. The use of cumulative shock as a measure of external load in runners who vary the surface, speed, and terrain of their training more regularly should also be further studied.

ACKNOWLEDGMENTS

This study was partially funded by the Canada Research Chair (C.M.), Natural Sciences and Engineering Research Council (C.N., C.M.), and Canadian Institutes of Health Research (C.M.). Dr Menon reported grants from the National Sciences and Engineering Research Council of Canada, Canadian Institutes of Health Research, and Canadian Research Chairs Program during the study.

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