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Relationships Between Different Internal and External Training Load Variables and Elite International Women's Basketball Performance

Original Investigation

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Relationships Between Different Internal and External Training Load Variables and Elite International Women's Basketball Performance

ABSTRACT

Purpose: To investigate the relationships between internal and external training load (TL) metrics with elite international women's basketball performance.

Methods: Sessional ratings of perceived exertion, PlayerLoad™/minute and training duration were collected from thirteen elite international level female basketball athletes (29.0 ± 3.7 years, 186.0 ± 9.8 cm, 77.9 ± 11.6 kg) during the 18 weeks prior to the International Basketball Federation (FIBA) Olympic qualifying event for the 2016 Rio Olympic Games. Training stress balance (TSB), differential load and the training efficiency index (TE_I) were calculated with three different smoothing methods. These TL metrics and their change in the last 21 days prior to competition were examined for their relationship to competition performance as coach ratings of performance.

Results: For a number of TL variables, there were consistent significant small to moderate correlations with performance and significant small to large differences between successful and unsuccessful performances. However, these differences were only evident for external TL when using exponentially weighted moving averages to calculate TL. The variable that seemed most sensitive to performance was the change in TE_I in the last 21 days prior to competition (performance r=0.47-0.56, p<0.001 and difference between successful and unsuccessful performance p<0.001, f^2=0.305-0.431)

Conclusions: Internal and external TL variables were correlated with performance and distinguished between successful and unsuccessful performances amongst the same players during international women's basketball games. Manipulating TL in the last 3 weeks prior to competition may be worthwhile for basketball players' performance; especially in internal TL.

KEYWORDS

Monitoring, Simple Moving Average, Exponentially Weighted Moving Average, Periodization

INTRODUCTION

Basketball is a five versus five open skill team sport that involves intermittent high intensity efforts regardless of sex.[1] Competitions at an international level (i.e. country versus country) normally culminate every four years at the Olympic Games. There are a number of matches and tournaments prior to the Olympic Games that are necessary for qualification and/or seeding. These matches and tournaments are characterized by a high number of basketball games within a few days which could lead to poor performance and increases in illness and injury risk.[2] As such, monitoring and adjusting training loads (TL) to reduce likelihoods of poor performance or injury/illness is considered important for practitioners.[3,4] Although there appears to be research available in amateur[5], NCAA Division I[6] and European professional[7] women's basketball, there seems to be a knowledge gap on the practice and competition TL demands in elite international women's basketball.

There are a number of different measures used to monitor TL in basketball.[3] These different measures are used to assess either internal load (i.e. the athlete's response to the training) or external load (i.e. the actual work performed in training).[8] It is recommended that both these constructs are monitored, along with their relationship, to optimize the training of athletes.[4,8,9] For instance, a consistent trend of greater external TLs with lower internal TL responses over time in an athlete may represent a positive adaptation to training and vice versa for a negative adaptation.[10] The training efficiency index (TE_I), which is an allometric log-transformed ratio of external to internal TL, is one method of quantifying the relationship between internal and external TL in team sport athletes.[10] In regards to internal TL, one of the most widely reported measures in basketball is sessional ratings of perceived exertion (sRPE),[3] which is generally recommended as a primary TL measure in most team sports.[11] There is also evidence for a relationship between sRPE and in-game performance in other open skill team sports (e.g. Australian Rules football).[12,13] In regards to external TL, tri-axial accelerometry, and in particular PlayerLoad™ (PL), is a validated commonly used measure that seems well suited to monitor external loads in basketball.[3,5,14] However, the evidence for a relationship between sRPE or tri-axial accelerometry with in-game performance in basketball is limited (potentially due to the complexity of team sport performance)[4] and bears further investigation.

Despite there being a variety of athlete monitoring measures used in basketball, TL models are generally constructed using training impulse (TRIMP) data.[15,16] TRIMP is the product of an intensity factor and a volume/duration factor.[16] An athlete's response to training can then be quantified (to an extent) from TRIMP values as the difference between longer-term chronic positive "fitness" and shorter-term acute negative "fatigue" functions.[15,16] Recently, this concept has led to the development of the acute to chronic workload ratio (ACWR), which is a measure of relative change in TL.[17] The ACWR is calculated as the ratio between the simple moving averages (SMA) of TL over acute and chronic periods.[17] However, significant concerns have been recently presented on the ACWR. Although the effects of mathematical coupling on the ACWR had trivial effect in one study[18], there may be critical statistical issues with the ACWR (e.g. failure to normalise correctly)[19] and the previous literature using the ratio.[20] For practitioners concerned with these issues but still wishing to measure changes in TL, alternatives include training stress balance (TSB)[21] and differential load.[13,22] TSB is calculated as the difference between the chronic and acute periods and differential load is an exponential smoothing of week-to-week rate of change in TL.[13,21] Regarding smoothing of TL, there have also been discussions over the most suitable moving average methods.[23] Exponentially weighted moving averages (EWMA) have been endorsed as a more suitable smoothing method to SMA.[23,24] However, like SMA, there are also conceptual issues with EWMA (e.g. individual "fitness" and "fatigue" gain and decay rates)[9] and there have also been different EWMA calculations presented in the available TL research.[13,24] These different smoothing methods all produce different TL values for acute and chronic periods. It is also not established which smoothing method produces TL metrics that have superior relationships to performance.

In light of the lack of available research on elite international women's basketball practice and competition TL and the call for more work on understanding how TL metrics relate to performance in all team sports, not just basketball[4]; further investigation in these areas is warranted. Therefore, the three primary aims of this study are to: i) provide data of common sRPE and tri-axial accelerometry TL metrics used in basketball for practitioners working in elite international women's basketball; ii) examine whether different external/internal TL metrics and their relationship to one another were correlated to in-game performance; and iii) determine if meaningful differences existed in these TL metrics between successful and unsuccessful in-game performances in elite international women's basketball. We hypothesized that there would be correlations between TL metrics and performance and significant differences in TL metrics between higher and lower performers. Due to the debate over the different smoothing methods for TL metrics and the criticisms of the ACWR, this investigation has presented alternative change in load measures (TSB and differential load) and the three main smoothing methods used in previous literature to add to the evidence base for practitioners.

METHODS

Participants

Thirteen elite international level female basketball athletes participated in this study (age 29.0 ± 3.7 years, stature 186.0 ± 9.8 cm, body mass 77.9 ± 11.6 kg). All athletes were part of the final squad selected for the 2016 Rio Olympics and had previously competed in senior professional competitions and/or internationally at the Olympic, World Championship or World Junior Championship levels. The data for this study was initially collected within the athletes' training environment and was released de-identified from the athletes and respective National Olympic Committee. Approval for this investigation was granted by the University Human Ethics Committee (Approval #19521) and conforms to the *Code of Ethics of the World Medical Association* (Declaration of Helsinki).

Design

This investigation was a retrospective observational study. TL data were collected from the participants for 18 weeks prior to the International Basketball Federation (FIBA) Olympic qualifying event for the 2016 Rio Olympic Games. Illness or injury incidents that caused an athlete to modify technical training or seek medical attention were also noted throughout the data collection period.[25] Correlations of different TL metrics with competitive performance were examined. Differences in the TL metrics of higher and lower performers were also investigated.

Methodology

Training impulse (TRIMP) was calculated from internal and external TL and included competition workloads i.e. games/tournaments. Internal TRIMP was the product of sRPE and session duration (t).[26] External TRIMP was the product of PlayerLoad™/minute (PL/min) derived from Catapult Sports (Melbourne, Australia) accelerometers and session duration (t).[5] PlayerLoad™ is an arbitrary unit derived from triaxial measures of rate of change in acceleration and is validated for use in basketball.[14] The following metrics were calculated daily from the internal and external TRIMP data: i) acute TL (7 day average), ii) chronic TL

(21 day average); iii) TSB (chronic - acute TL), iv) differential load, v) TE_I average over 5 days (TE_I5) and vi) TE_I average over 7 days (TE_I7) using established methods.[10,13,15,27] The TE_I was smoothed over 5 and 7 days to reduce measurement noise (similar to current recommendations for heart rate variability)[28] and give an overall indication of the athletes' internal response to the external TL for the last week. These variables were calculated and presented as SMA, EWMA as per Williams et al (EWMA-W)[23] and EWMA as per Lazarus et al (EWMA-L)[13]. The key difference between SMA and EWMA methods is that EWMA will give an increased weighting to the most recent TL an athlete completes in a period whereas SMA will provide an even weighting of the TL over the period.

The acute and chronic periods were set at 7 and 21 days respectively. Differential load was also assessed using 7- and 21-day exponential decays. The period length determination was based on the typical training micro-mesocycle combination employed by the head coach.[9] Based on research in elite weightlifting performance[29], TSB was assessed as: i) absolute values, which represented the value on the day of the competition; ii) the value 21 days prior to competition subtracted from the value on the day of the competition (CH21); and iii) the volatility (calculated as the standard deviation) of values in the last 21 days prior to competition (VOL21). The change in TE_I5 and TE_I7 over the 21 days prior to competition was also examined. The last 21 days prior to competition was chosen for the time period of interest based on the results of existing performance modelling research and tapering research in a basketball setting.[30-32] Lastly, the percentage of training burdened by injury/illness compared to total training time was considered in the last 21 days before competition.[25] This percentage of burdened training to total training was based on any injury or illness that affected an athlete's training (e.g. a shoulder injury may have limited shooting volume in training) or required medical intervention. Any injury or illness incidents were identified by the team doctor or physical therapist and their respective lengths were noted by the research team. If athletes were absent from training due to injury/illness, TRIMP was recorded as zero to enable continuous calculations.

TL and injury/illness metrics were then compared against performance expressed as coach ratings of performance. Coach ratings of performance have been used in other open skill team sports[33] and in this investigation, were the average of three different 1-10 scales (physical, mental and technical performance). All ratings were collected individually from the head coach and assistant coach within 24 hours of team performance. The final coach rating represented the average of both coaches' ratings across all three performance dimensions (physical, mental and technical). Efficiency, which is a common overall basketball value statistic, was also calculated where available from individual player's box scores.[34] Coach ratings were used in preference over the efficiency statistic to adequately capture an athlete's holistic individual contribution to team performance and strategy bearing in mind the complexity of team sport performance, playing positions, line-up and strength of the opposition.[4,9] To account for coaches' biases towards certain players and factors like playing positions, the coach ratings were converted into z-scores for each individual player. Then the allocation into either the successful performances (better than average, n=96) or unsuccessful performances (worse than average performances, n=61) was determined by whether the coaches' rating z-score was greater or lesser than 0.2; representing the smallest worthwhile change.[35]

Statistical Analysis

Statistical analyses were performed using statistical software (R statistics packages: *lmerTest, rmcorr, and performance;* https://www.r-project.org) or purposefully designed Excel spreadsheets (Microsoft Corporation, Washington, U.S.). All data were analyzed as mean ± standard deviation (SD). The alpha level for significance for all tests was defined as $p \leq 0.05$. Repeated measure correlation analyses with 95% confidence intervals were used to determine if there were any linear relationships between the TL metrics across different smoothing methods, training burdened by injury/illness and coach ratings of performance. Correlations were interpreted as per the recommendations of Hopkins et al.[35] *R-z* transformations were also applied to determine if there were any significant differences between correlations amongst the various smoothing methods. Due to the repeated measure data structure in the TL metrics, linear mixed models with the athlete as the random intercept were then used to assess differences between successful and unsuccessful performances. All models were checked for a) linearity, b) residual independence, and c) residual normality. Again due to the repeated measure data structure, effect sizes of any differences from the models (marginal f^2)[36] were then calculated and interpreted as trivial (<0.02), small (0.02-0.14), moderate (0.15-0.34) and large (>0.35).[37]

RESULTS

A total of 1642 training, 15 games and 167 competition data points across the participants were included in the present analysis. The average sRPE was 5.53 ± 1.67 AU and the average PL/min was 4.62 ± 1.97 AU over all recorded sessions. The average training sRPE was significantly different with small effect size from the average competition sRPE (5.37 ± 1.62 and 7.11 ± 1.22 AU respectively, $p<0.001$, $f^2=0.105$). This was also the case for PL/min in training versus competition with large effect size (4.08 ± 1.02 and 9.72 ± 1.51 AU, $p<0.001$, $f^2=2.344$). The repeated measure correlation between sRPE and PL/min was moderate ($r=0.43$, $p<0.001$). The daily internal TRIMP average was 648 ± 496 AU and the daily external TRIMP average was 398 ± 282 AU. In competition, the average coach rating was 6.40 ± 1.51 and average efficiency score was 6.88 ± 5.55. The repeated measure correlation between coach ratings and efficiency from individual player's box scores was moderate ($r=0.35$, $p=0.02$). The time series of TE_I7 and external/internal TL TSB (calculated using EWMA-W) with coach ratings of performance as z-scores are presented in Figure 1.

FIGURE 1 ABOUT HERE

Repeated measure correlations between coaches' ratings of performance and the different TL metrics are presented in Table 1. There were consistent significant small to moderate correlations with performance across all the external TL metrics when calculated with EWMA-W or EWMA-L with the exception of weekly change and chronic TL EWMA-L. Only external TL TSB VOL21 was correlated with performance when calculated with SMA. There were also consistent small to large significant correlations between all the internal TL metrics and performance calculated with all the smoothing methods. The only exceptions to this were weekly change, acute TL SMA and chronic TL EWMA-W/-L. There were no significant correlations between TE_I5 or TE_I7 and performance. However, there were moderate to large significant correlations between the change in TE_I5 and TE_I7 over the last 21 days preceding competition and performance. There was no significant correlation between training burdened by injury or illness in the last 21 days prior to competition and performance in this investigation ($r= -0.04$, $p=0.60$).

TABLE 1 ABOUT HERE

There were significant differences in a number of the TL metrics between successful and unsuccessful performances in this investigation. For the external TL metrics (presented in

Table 2A), there were consistent significant differences with small effect size between successful and unsuccessful performances in acute TL, TSB, TSB VOL21, and both 7- and 21-day differential load when calculated with EWMA-W and EWMA-L. In contrast, when using SMA, there was only one external TL variable (TSB VOL21) that was significantly different between successful and unsuccessful performances. For the internal TL metrics (presented in Table 2B), there were consistent significant differences across all smoothing methods with small to large effect size between successful and unsuccessful performances in TSB, TSB CH21 and both 7- and 21-day differential load. For the training efficiency index variables (presented in Table 2C), there were significant differences with moderate to large effect sizes between successful and unsuccessful performances in the change in TE_I5 and TE_I7 over the 21 days prior to competition. These differences were significant across all smoothing methods. There was not a significant difference between successful and unsuccessful performance in the training burdened by injury or illness in the last 21 days prior to competition (p=0.79, f^2<0.001).

TABLE 2A-C AROUND HERE

DISCUSSION

To our knowledge, this is the first investigation to detail values of both internal and external TL in an elite international women's basketball team in the qualification stages for the Olympic Games. For external TL, the levels of PL/min were greater than previously reported in amateur and NCAA Division I female basketball athletes.[5,6] Weekly internal TL was also greater than previously published levels in European professional female basketball athletes.[7] The higher playing standard of athletes in this investigation compared to the previous research (i.e. professional international level versus professional national level or collegiate) may explain these differences. It is reasonable that the higher playing standards of international basketball would require more regular training at higher workloads along with players more able to regularly handle these higher workloads. Along with the average daily external TRIMP levels, this information may help coaches and practitioners progress the workloads of athletes to an international level and prescribe workloads at that same level. Of interest was the significant differences between competition and training PL/min levels which were similar to previous research in amateur female basketball athletes.[5] Although training will not always be at competition intensity and skill development (e.g. shooting drills) or periods of coach feedback will reduce the average PL/min of the session, the magnitude of this difference may have represented a situation where competition intensities were not being replicated often enough in training. Practitioners are recommended to monitor differences between training and competition external TL, and in particular the intensities in different components of training (e.g. competition-style scrimmages versus lower intensity skill development) to help ensure athletes are adequately prepared for the intensity demands of competition.

In this investigation, successful performances were characterized by a higher TSB (~10-20 AU external TL, ~50 AU internal TL) and a lower differential load when compared to unsuccessful performances. Further, the TE_I5 and TE_I7 change over the last 21 days before competition had the greatest correlations and largest effect sizes of all the variables when assessed against successful and unsuccessful performances. It is interesting the relationship between changes in TE_I5 and TE_I7 and performance were much stronger than TE_I5 and TE_I7 on the day of competition. This finding indicates relatively higher internal to external TL levels prior to the taper as beneficial in this investigation. This finding may also be related to previous tapering research that suggested an increase in TL ~20% prior to the taper leads to better taper outcomes.[38] As the TE_I quantifies the external-internal TL interaction[10], this finding is novel in that the taper prior to basketball games in this investigation were greater in internal than external TL for successful performances. Related to this finding was the greater internal TSB CH21 of ~140-250 AU for successful compared to unsuccessful performances; which is similar to previous research on elite weightlifting performance.[29] These findings are consistent with the suggestion that internal TL ultimately determines the training outcome (in this case, basketball in-game performance) for athletes.[8] These findings also reinforce the need for practitioners to be cognizant of the potential differences between external and internal TL and to use and compare both to optimize performance in basketball athletes.[8] Based on the results of this study, external TL may not require as much of a taper relative to internal TL as basketball athletes are approaching competition. In practice, this outcome may be achieved "naturally" as athletes become fitter to a consistent external TL and therefore perceive the same workload in training sessions to be easier. We also suggest that a reduction in internal TL relative to external TL could be achieved by coaches reducing the amount of novel cognitive work[39] an athlete needs to complete in training prior to competition or by modifying other coaching behaviours (e.g. more frequent positive reinforcement) that may make athletes subjectively feel "fresher". It is of interest that this may hold true for both subjective (e.g. sRPE) and objective measures (e.g. heart rate) of internal load.[39]

Another item of interest from this investigation was that the significant correlations and differences for external TL and performance were only significant when smoothing the TL variables with EWMA-W or EWMA-L. These findings support previous research on injury risk in Australian Rules football[24] that suggested EWMA smoothing methods may be more appropriate for calculating TL which is potentially due to the increased weighting EWMA gives the more recent TL when compared to SMA. However, given there was no significant difference between correlations for internal TL metrics and performance, this raises the consideration that different smoothing methods may be more appropriate depending on whether the TL is internal or external. It is likely this is again due to the different weightings SMA and EWMA assign earlier or later values in acute and chronic periods. It also raises the consideration that internal TL may be as or more sensitive to performance when calculated using SMA with a greater weighting of TL values in the early stages of acute and chronic periods. There also appeared to be little to no difference between the different change in TL measures used (i.e. TSB, differential load) in correlation magnitude or effect size in this investigation. For practitioners concerned with statistical and methodological issues from previous literature on the ACWR, both the TSB and differential load appear to be non-ratio change in TL measures that have relationships to performance. This recommendation is supported by previous research on both performance in Australian football[13] and injury risk in English cricket.[22]

There are a number of potential limitations with this study. Firstly, having only two coaches assessing basketball performance and both coaches being from the same national team as the players was a potential limitation. Although the coaches were blinded to one another when rating the performances, this situation may have been prone to bias (e.g. coaches generally have preferred players) or similar ratings (e.g. normally an assistant coach will appraise performance relatively similar to the head coach on the same team). Using independent expert raters (e.g. experienced coaches not associated with the team but who would still understand the roles and game plans for individual players) and a greater number of raters would be recommended in the future. Another potential limitation was the timeframes chosen for acute, chronic and taper periods may not be applicable to other basketball teams or to other professional basketball leagues where the game schedule may be both more condensed and over a longer period. There were also only two TL variables measured and other internal (e.g. heart rate measures) and external (e.g. other inertial movement analysis) measures may provide different results. Lastly, as this was only one national team monitored across a single international competitive season, practitioners should interpret this investigation's findings and level of evidence as a case study. More research is warranted in elite basketball populations (both men and women) on the relationship between internal and external TL and performance.

PRACTICAL APPLICATIONS

Coaches and practitioners can use the descriptive values of PL/min and sRPE and the comparison between competition and training intensities (especially with external TL) in this investigation to help prepare athletes for international basketball competition. It also seems that the TSB or differential load is correlated with basketball performance and distinguishes between better and worse performances amongst the same players. The TSB and differential load seem to be suitable alternatives to the ACWR for practitioners wanting to measure change in TL, with the TSB being the most parsimonious. Increasing internal TL TSB in the last 3 weeks prior to competition seems to be worthwhile for basketball athletes and there may also be differences between optimal changes in external TL and internal TL in the taper period. We recommend the internal-external TL interaction should be monitored in some manner (e.g. TE_I7) and potentially manipulated to optimise performance in basketball; ideally at an individual athlete level. It may also be worthwhile for practitioners working in basketball to deliberately plan for these outcomes. Lastly, it may be most appropriate to use an EWMA to calculate TL especially if using external TL measures.

CONCLUSIONS

To the authors' knowledge, this is the first investigation to provide normative values for PL/min and sRPE derived TL metrics in an elite international women's basketball team during the qualifying stages for an Olympic Games. This investigation demonstrated consistent significant small to large correlations between different TL variables and basketball performance and there were also significant differences with small to large effect size between successful and unsuccessful performance groups. Successful basketball performances were characterized by a higher TSB, larger TSB change in the last 21 days before competition and lower differential load compared to non-successful performances in the same basketball players. However, these results seemed to appear to a greater extent in internal TL as evidenced by a greater positive change in the training efficiency index for successful performances. Different smoothing methods did not seem to impact these results for internal TL however external TL variables seemed more sensitive to performance when calculated using an EWMA.

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REFERENCES

1. Stojanovic E, Stojiljkovic N, Scanlan AT, Dalbo VJ, Berkelmans DM, Milanovic Z. The Activity Demands and Physiological Responses Encountered During Basketball Match-Play: A Systematic Review. *Sports Med.* 2018;48(1):111-135.
2. McLean BD, Strack D, Russell J, Coutts AJ. Quantifying Physical Demands in the National Basketball Association-Challenges Around Developing Best-Practice Models for Athlete Care and Performance. *Int J Sports Physiol Perform.* 2019;14(4):414-420.
3. Fox JL, Scanlan AT, Stanton R. A Review of Player Monitoring Approaches in Basketball: Current Trends and Future Directions. *J Strength Cond Res.* 2017;31(7):2021-2029.
4. Fox JL, Stanton R, Sargent C, Wintour SA, Scanlan AT. The Association Between Training Load and Performance in Team Sports: A Systematic Review. *Sports Med.* 2018;48(12):2743-2774.
5. Reina Román M, García-Rubio J, Feu S, Ibáñez SJ. Training and Competition Load Monitoring and Analysis of Women's Amateur Basketball by Playing Position: Approach Study. *Front Psychol.* 2019;9(2689).
6. Ransdell LB, Murray T, Gao Y, Jones P, Bycura D. A 4-Year Profile of Game Demands in Elite Women's Division I College Basketball. *The Journal of Strength & Conditioning Research.* 2020;34(3):632-638.
7. Paulauskas H, Kreivyte R, Scanlan AT, Moreira A, Siupsinskas L, Conte D. Monitoring Workload in Elite Female Basketball Players During the In-Season Phase: Weekly Fluctuations and Effect of Playing Time. *Int J Sports Physiol Perform.* 2019;14(7):941-948.
8. Impellizzeri FM, Marcora SM, Coutts AJ. Internal and external training load: 15 years on. *Int J Sports Physiol Perform.* 2019;14(2):270-273.
9. Coyne JOC, Gregory Haff G, Coutts AJ, Newton RU, Nimphius S. The current state of subjective training load monitoring—a practical perspective and call to action. *Sports Med Open.* 2018;4(1):58.
10. Delaney JA, Duthie GM, Thornton HR, Pyne DB. Quantifying the relationship between internal and external work in team sports: development of a novel training efficiency index. *Science and Medicine in Football.* 2018:1-8.
11. McLaren SJ, Macpherson TW, Coutts AJ, Hurst C, Spears IR, Weston M. The relationships between internal and external measures of training load and intensity in team sports: A meta-analysis. *Sports Med.* 2018;48(3):641-658.
12. Graham SR, Cormack S, Parfitt G, Eston R. Relationships between model predicted and actual match performance in professional Australian Footballers during an in-season training macrocycle. *Int J Sports Physiol Perform.* 2017:1-25.
13. Lazarus BH, Stewart AM, White KM, et al. Proposal of a global training load measure predicting match performance in an elite team sport. *Front Physiol.* 2017;8:930.
14. Staunton C, Wundersitz D, Gordon B, Kingsley M. Construct Validity of Accelerometry-Derived Force to Quantify Basketball Movement Patterns. *Int J Sports Med.* 2017;38(14):1090-1096.
15. Bourdon PC, Cardinale M, Murray A, et al. Monitoring athlete training loads: Consensus statement. *Int J Sports Physiol Perform.* 2017;12(Suppl 2):161-170.
16. Banister EW, Calvert, T.W., Savage, M.V. and Bach, T.M. A Systems Model of Training for Athletic Performance. *Aust J Sci Med.* 1975(7):57-61.

17. Hulin BT, Gabbett TJ, Blanch P, Chapman P, Bailey D, Orchard JW. Spikes in acute workload are associated with increased injury risk in elite cricket fast bowlers. *Br J Sports Med.* 2014;48(8):708-712.
18. Coyne JOC, Nimphius S, Newton RU, Haff GG. Does mathematical coupling matter to the Acute to Chronic Workload Ratio? A case study from elite sport. *Int J Sports Physiol Perform.* 2019:1-8.
19. Lolli L, Batterham AM, Hawkins R, et al. The acute-to-chronic workload ratio: an inaccurate scaling index for an unnecessary normalisation process? *Br J Sports Med.* 2018.
20. Wang C, Vargas JT, Stokes T, Steele R, Shrier I. Analyzing Activity and Injury: Lessons Learned from the Acute:Chronic Workload Ratio. *Sports Med.* 2020.
21. Allen H, Coggan, A. *Training and Racing With A Powermeter.* 2nd ed. Boulder, CO: Velopress; 2010.
22. Tysoe A, Moore IS, Ranson C, McCaig S, Williams S. Bowling loads and injury risk in male first class county cricket: Is differential load an alternative to the acute-to-chronic workload ratio? *Journal of Science and Medicine in Sport.*
23. Williams S, West S, Cross MJ, Stokes KA. Better way to determine the acute:chronic workload ratio? *Br J Sports Med.* 2016;51(3):209.
24. Murray NB, Gabbett TJ, Townshend AD, Blanch P. Calculating acute:chronic workload ratios using exponentially weighted moving averages provides a more sensitive indicator of injury likelihood than rolling averages. *Br J Sports Med.* 2016;51(9):749.
25. Raysmith BP, Drew MK. Performance success or failure is influenced by weeks lost to injury and illness in elite Australian Track and Field athletes: a 5-year prospective study. *J Sci Med Sport.* 2016;19(10):778-783.
26. Foster C, Florhaug JA, Franklin J, et al. A new approach to monitoring exercise training. *J Strength Cond Res.* 2001;15(1):109-115.
27. Delaney JA, McKay, B.A., Thornton, H.R., Murray, A., & Duthie, G.M. Training efficiency and athlete wellness in collegiate female soccer. *Sports Performance & Science Reports.* 2018;1(19):1-3.
28. Buchheit M. Monitoring training status with HR measures: do all roads lead to Rome? *Front Physiol.* 2014;5(73).
29. Coyne JOC, Haff, G.G., Coutts, A.C., Netwon, R.U. & Nimphius, S. The relationship between internal training load variables during a taper and elite weightlifting success. National Strength & Conditioning Association National Conference; 2018; Indianapolis, IN, U.S.
30. Bosquet L, Montpetit J, Arvisais D, Mujika I. Effects of tapering on performance: a meta-analysis. *Med Sci Sports Exerc.* 2007;39(8):1358-1365.
31. Moraes H, Aoki MS, Freitas CG, Arruda A, Drago G, Moreira A. SIgA response and incidence of upper respiratory tract infections during intensified training in youth basketball players. *Biol Sport.* 2017;34(1):49-55.
32. Miloski B, Aoki MS, de Freitas CG, et al. Does Testosterone Modulate Mood States and Physical Performance in Young Basketball Players? *J Strength Cond Res.* 2015;29(9):2474-2481.
33. Mooney M, O'Brien B, Cormack S, Coutts A, Berry J, Young W. The relationship between physical capacity and match performance in elite Australian football: a mediation approach. *J Sci Med Sport.* 2011;14(5):447-452.
34. Efficiency (basketball). Wikipedia. https://en.wikipedia.org/wiki/Efficiency_(basketball). Published 2020. Accessed.

35. Hopkins WG, Marshall SW, Batterham AM, Hanin J. Progressive statistics for studies in sports medicine and exercise science. *Med Sci Sports Exerc.* 2009;41(1):3-12.
36. Aiken LS, & West, S. G. *Multiple regression: Testing and interpreting interactions.* Newbury Park: Sage; 1991.
37. Cohen J. A power primer. *Psychol Bull.* 1992;112(1):155-159.
38. Thomas L, Mujika I, Busso T. A model study of optimal training reduction during pre-event taper in elite swimmers. *J Sports Sci.* 2008;26(6):643-652.
39. Hidalgo-Muñoz AR, Béquet AJ, Astier-Juvenon M, et al. Respiration and Heart Rate Modulation Due to Competing Cognitive Tasks While Driving. *Frontiers in Human Neuroscience.* 2019;12(525).

FIGURE CAPTIONS

Figure 1. A time series of training load variables and performances as z-scores in an elite international female basketball team during the qualifying stages for the 2016 Olympic Games. The training load variables' time series are indicated by the solid line whereas the performances as z-scores are indicated by the circular points. *IL – internal load, EL – external load, TSB – training stress balance, TEI-7 - training efficiency index averaged over 7 days*

Table 1. Correlations between different training load variables with coaches' ratings of competitive performance for an elite international women's basketball team in the qualifying stages for the 2016 Olympic Games.

	SMA		*EWMA-W*			*EWMA-L*			
	r [95% CI]	***p***	***r [95% CI]***	***p***	***SMA r-z p***	***r [95% CI]***	***p***	***SMA r-z p***	***EWMA-W r-z p***
				External Load					
Weekly Change	0.07 [-0.08, 0.23]	0.34	-	-	-	-	-	-	-
Acute TL	-0.14 [-0.29, 0.01]	0.07	-0.38 [-0.51, -0.24]	<0.001***	0.02*	-0.35 [-0.48, -0.20]	<0.001***	0.05*	0.76
Chronic TL	-0.03 [-0.19, 0.13]	0.71	-0.26 [-0.40, -0.11]	<0.001***	0.04*	-0.14 [-0.29, 0.02]	0.09	0.33	0.27
TSB	0.12 [-0.04, 0.27]	0.14	0.39 [0.24, 0.51]	<0.001***	0.01*	0.33 [0.19, 0.47]	<0.001***	0.05*	0.54
TSB VOL21	-0.28 [-0.42, -0.13]	<0.001***	-0.24 [-0.38, -0.09]	<0.01**	0.71	-0.25 [-0.40, -0.10]	<0.01**	0.78	0.93
TSB CH21	0.04 [-0.13, 0.20]	0.66	0.26 [0.11, 0.41]	<0.001***	0.05*	0.21 [0.06, 0.36]	<0.01**	0.13	0.64
DIFF 7-day	-	-	-0.21 [-0.36, -0.06]	<0.01**	-	-0.29 [-0.42, -0.13]	<0.001***	-	0.45
DIFF 21-day	-	-	-0.26 [-0.40, -0.11]	<0.001***	-	-0.19 [-0.34, -0.04]	0.01*	-	0.52
				Internal Load					
Weekly Change	0.06 [-0.09, 0.22]	0.43	-	-	-	-	-	-	-
Acute TL	-0.13 [-0.28, 0.03]	0.11	-0.27 [-0.41, -0.12]	<0.001***	0.20	-0.16 [-0.31, -0.01]	0.04*	0.79	0.31
Chronic TL	0.16 [0.01, 0.31]	0.04*	-0.01 [-0.17, 0.14]	0.82	0.13	0.11 [-0.04, 0.26]	0.16	0.65	0.29
TSB	0.33 [0.19, 0.47]	<0.001***	0.41 [0.26, 0.53]	<0.001***	0.41	0.40 [0.26, 0.52]	<0.001***	0.48	0.92
TSB VOL21	-0.36 [-0.49, -0.21]	<0.001***	-0.23 [-0.38, -0.08]	<0.01**	0.21	-0.11 [-0.26, 0.05]	0.17	0.02*	0.28
TSB CH21	0.64 [0.53, 0.73]	<0.001***	0.53 [0.41, 0.64]	<0.001***	0.14	0.52 [0.40, 0.63]	<0.001***	0.11	0.90
DIFF 7-day	-	-	-0.38 [-0.50, -0.23]	<0.001***	-	-0.45 [-0.56, -0.31]	<0.001***	-	0.45
DIFF 21-day	-	-	-0.44 [-0.56, -0.30]	<0.001***	-	-0.32 [-0.46, -0.17]	<0.001***	-	0.22
				Training Efficiency Index					
TE_I5	0.08 [-0.08, 0.23]	0.31	0.04 [-0.11, 0.20]	0.59	0.72	0.07 [-0.09, 0.22]	0.38	0.93	0.79
TE_I7	0.13 [-0.03, 0.28]	0.11	0.07 [-0.09, 0.22]	0.39	0.59	0.04 [-0.12, 0.20]	0.61	0.42	0.79
TE_I5 CH21	0.56 [0.44, 0.66]	<0.001***	0.51 [0.38, 0.62]	<0.001***	0.54	0.51 [0.38, 0.62]	<0.001***	0.54	1.00
TE_I7 CH21	0.54 [0.41, 0.64]	<0.001***	0.52 [0.39, 0.62]	<0.001***	0.81	0.47 [0.34, 0.58]	<0.001***	0.41	0.56

Note: SMA – simple moving average, EWMA-W – exponentially weighted moving averages as per Williams et al[23], EWMA-L - exponentially weighted moving averages as per Lazarus et al[13], TL – training load, TSB – training stress balance, ACWR – acute to chronic workload ratio, DIFF – differential load, VOL21 - the volatility (standard deviation) of values in the last 21 days prior to competition , CH21 - the value 21 days prior to competition subtracted from the value on the day of the competition, TE_I5 – training efficiency index 5 day average, TE_I7 – training efficiency index 7 day average, TE_I – training efficiency index, r – correlation; CI – confidence interval, * - $p<0.05$, ** - $p<0.01$, *** - $p<0.001$

Table 2A-C. Differences in A) external, B) internal and C) training efficiency index training load variables for successful and non-successful basketball performances by an elite international women's basketball team in the qualifying stages for the 2016 Olympic Games.

A.

		OVERALL	*SUCCESSFUL PERFORMANCES*	*UNSUCCESSFUL PERFORMANCES*	*p*	f^2	*Effect size*
	Week Load	2787 ± 772	2564 ± 492	2619 ± 429	0.64	0.001	Trivial
	Weekly Change	-79.8 ± 706.21	-63.1 ± 544	-252 ± 571	0.38	0.028	Small
SMA	Acute TL	398 ± 110	366 ± 70.3	374 ± 61.2	0.64	0.001	Trivial
	Chronic TL	394 ± 81.8	372 ± 68.3	380 ± 67.1	0.84	0.000	Trivial
	TSB	9.49 ± 67.6	-13.6 ± 50.1	-9.13 ± 48.6	0.68	0.001	Trivial
	TSB VOL21	57.1 ± 22.7	52.3 ± 20.8	60.7 ± 19.2	0.001***	0.046	Small
	TSB CH21	-12.6 ± 92.0	-26.5 ± 85.6	-21.2 ± 79.9	0.61	0.001	Trivial
EWMA-W	Acute TL	401 ± 118	376 ± 72.2	411 ± 76.8	<0.001***	0.042	Small
	Chronic TL	408 ± 95.6	370 ± 63.1	387 ± 65.0	0.01*	0.008	Trivial
	TSB	7.75 ± 53.5	-5.73 ± 29.8	-24.4 ± 38.0	<0.001***	0.081	Small
	TSB VOL21	49.7 ± 12.3	46.6 ± 9.81	50.3 ± 10.3	<0.01**	0.032	Small
	TSB CH21	-0.24 ± 76.5	-14.0 ± 58.7	-29.1 ± 53.9	0.06	0.020	Small
	DIFF 7-day	-71.0 ± 706	-168 ± 291	-86.8 ± 339	0.05*	0.021	Small
	DIFF 21-day	-75.9 ± 231	-89.8 ± 150	-24.2 ± 217	<0.01**	0.037	Small
EWMA-L	Acute TL	404 ± 101	369 ± 64.6	393 ± 67.0	<0.001***	0.020	Small
	Chronic TL	418 ± 93.7	376 ± 64.2	387 ± 70.0	0.25	0.002	Trivial
	TSB	14.2 ± 41.2	7.37 ± 25.4	-6.25 ± 35.7	<0.001***	0.048	Small
	TSB VOL21	32.3 ± 9.73	30.6 ± 8.17	33.3 ± 9.41	0.02*	0.025	Small
	TSB CH21	0.83 ± 57.8	-7.41 ± 52.3	-19.5 ± 49.1	0.07	0.016	Trivial
	DIFF 7-day	-75.9 ± 231	-123 ± 205	-29.2 ± 275	<0.01**	0.045	Small
	DIFF 21-day	-86.7 ± 156	-71.8 ± 92.1	-41.5 ± 150	0.03*	0.020	Small

B.

		OVERALL	*SUCCESSFUL PERFORMANCES*	*UNSUCCESSFUL PERFORMANCES*	*p*	*f²*	*Effect size*
	Week Load	4588 ± 1597	2974 ± 819	3110 ± 793	0.27	0.006	Trivial
	Weekly Change	-171 ± 1642	-1408 ± 826	-1518 ± 991	0.45	0.004	Trivial
SMA	Acute TL	655 ± 228	425 ± 117	444 ± 113	0.27	0.006	Trivial
	Chronic TL	667 ± 152	610 ± 109	576 ± 93.3	0.02	0.028	Small
	TSB	26.0 ± 177	185 ± 81.9	135 ± 92.8	<0.001***	0.089	Small
	TSB VOL21	158 ± 47.1	150 ± 39.3	173 ± 44.0	<0.001***	0.087	Small
	TSB CH21	4.60 ± 286	258 ± 188	8.30 ± 237	<0.001***	0.362	Large
EWMA-W	Acute TL	655 ± 231	427 ± 106	473 ± 118	<0.01**	0.041	Small
	Chronic TL	668 ± 159	550 ± 95.3	546 ± 96.7	0.67	0.001	Trivial
	TSB	13.0 ± 119	123 ± 61.2	72.6 ± 59.6	<0.001***	0.171	Moderate
	TSB VOL21	110 ± 22.8	107 ± 19.5	111 ± 19.5	0.11	0.012	Trivial
	TSB CH21	10.3 ± 181	145 ± 128	4.47 ± 168	<0.001***	0.241	Moderate
	DIFF 7-day	108 ± 1151	-1140 ± 737	-600 ± 805	<0.001***	0.130	Small
	DIFF 21-day	-99.6 ± 634	-640 ± 406	-287 ± 539	<0.001***	0.152	Moderate
EWMA-L	Acute TL	662 ± 187	492 ± 100	515 ± 106	0.14	0.010	Trivial
	Chronic TL	678 ± 134	611 ± 85.4	588 ± 87.8	0.02*	0.021	Small
	TSB	16.0 ± 100	119 ± 55.9	73.3 ± 55.6	<0.001***	0156	Moderate
	TSB VOL21	78.3 ± 21.8	82.0 ± 23.6	81.0 ± 1.0	0.80	0.000	Trivial
	TSB CH21	15.0 ± 152	141 ± 131	-8.84 ± 155	<0.001***	0.280	Moderate
	DIFF 7-day	-92.5 ± 849	-835 ± 597	-301 ± 709	<0.001***	0.176	Moderate
	DIFF 21-day	-65.3 ± 430	-332 ± 288	-161 ± 420	<0.001***	0.066	Small

C.

		OVERALL	*SUCCESSFUL PERFORMANCES*	*NON-SUCCESSFUL PERFORMANCES*	*p*	f^2	*Effect size*
	TE_I	0.89 ± 0.43	1.61 ± 0.44	1.68 ± 0.38	0.22	0.007	Trivial
SMA	TE_I5	0.88 ± 0.27	1.25 ± 0.29	1.20 ± 0.24	0.21	0.008	Trivial
	TE_I7	0.88 ± 0.25	1.21 ± 0.30	1.15 ± 0.21	0.10	0.014	Trivial
	TE_I5 CH21	0.04 ± 0.37	0.54 ± 0.36	0.03 ± 0.42	<0.001***	0.431	Large
	TE_I7 CH21	0.03 ± 0.33	0.48 ± 0.35	0.03 ± 0.32	<0.001***	0.416	Large
EWMA-W	TE_I5	0.88 ± 0.27	1.33 ± 0.27	1.30 ± 0.23	0.34	0.004	Trivial
	TE_I7	0.88 ± 0.24	1.25 ± 0.25	1.22 ± 0.20	0.28	0.005	Trivial
	TE_I5 CH21	0.04 ± 0.36	0.61 ± 0.33	0.23 ± 0.33	<0.001***	0.333	Moderate
	TE_I7 CH21	0.03 ± 0.32	0.52 ± 0.30	0.16 ± 0.29	<0.001***	0.361	Large
EWMA-L	TE_I5	0.88 ± 0.22	1.19 ± 0.23	1.17 ± 0.19	0.33	0.004	Trivial
	TE_I7	0.87 ± 0.20	1.20 ± 0.21	1.10 ± 0.16	0.69	0.001	Trivial
	TE_I5 CH21	0.03 ± 0.29	0.45 ± 0.28	0.13 ± 0.25	<0.001***	0.351	Large
	TE_I7 CH21	0.03 ± 0.25	0.34 ± 0.24	0.10 ± 0.41	<0.001***	0.305	Moderate

Note: SMA – simple moving average, EWMA-W – exponentially weighted moving averages as per Williams et al[23], EWMA-L - exponentially weighted moving averages as per Lazarus et al[13], TL – training load, TSB – training stress balance, ACWR – acute to chronic workload ratio, DIFF – differential load, TE_I – training efficiency index, TE_I5 – training efficiency index averaged over 5 days, TE_I7 – training efficiency index averaged over 7 days, VOL21 - the volatility (standard deviation) of values in the last 21 days prior to competition, CH21 - the value 21 days prior to competition subtracted from the value on the day of the competition, * - $p<0.05$, ** - $p<0.01$, *** - $p<0.001$, f^2 – Cohen's marginal effect size.

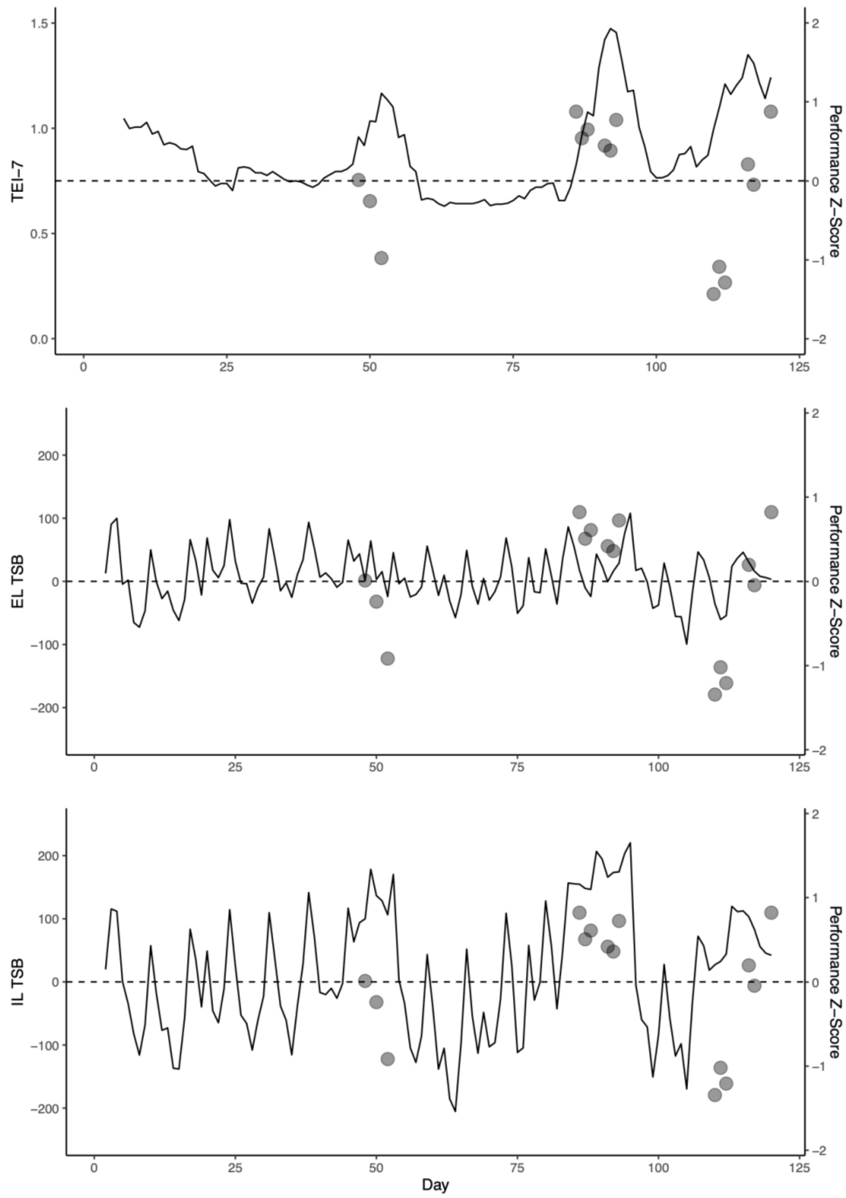

Figure 1. A comparison of training load variables between successful and non-successful performances in an elite international female basketball team during the qualifying stages for the 2016 Olympic Games. IL – internal load, EL – external load, TSB – training stress balance, TEI-7 - training efficiency index averaged over 7 days

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