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Validation of Internal and External Load Metrics in NCAA D1 Women's Beach Volleyball

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Abstract

Tometz, MJ, Jevas, SA, Esposito, PM, and Annaccone, AR. Validation of internal and external load metrics in NCAA D1 women's beach volleyball. *J Strength Cond Res* XX(X): 000–000, 2020—The purpose of this study was to determine the validity of internal and external load metrics in NCAA D1 women's beach volleyball. Subjects included 13 NCAA D1 women's beach volleyball players (age: 20.3 ± 1.4 years). A total of 578 data points were analyzed from 51 team training sessions, including practice, games, and sport-specific conditioning during the pre-season semester (15 weeks). Data points included Edward's training impulse (TRIMP) (228.0 ± 80.7 arbitrary units [AU]), session rating of perceived exertion (sRPE) Load (532.5 ± 232.8 [AU]), distance covered (DC) in meters (2,635.4 ± 884.3 [m]), and daily environmental condition variables ((temperature (76.5 ± 13.7 [°F]), relative humidity (72.5 ± 13.2 [%]), and wet-bulb globe temperature (52.9 ± 19.9 [°F])). The subjects wore Polar Team Pro heart rate monitors with global positioning system during each session. Subjects completed an sRPE questionnaire after every session. Pearson product moment correlations yielded statistically significant relationships ($p < 0.01$) between TRIMP and sRPE Load ($r = 0.81$), TRIMP and DC ($r = 0.78$), and sRPE Load and DC ($r = 0.82$). A forward selection multiple regression yielded that sRPE Load could predict TRIMP with the equation: $TRIMP_{Tometz} = 78.735 + (sRPE\ Load * 0.28)$ ($p < 0.001$). These findings support sRPE Load as a valid alternative to TRIMP when monitoring internal loads in NCAA D1 women's beach volleyball. Session rating of perceived exertion Load may be more practical and accessible for teams. Distance covered should be considered when periodizing and monitoring training loads because of its relationship with internal loads.

Key Words: sRPE, heart rate, monitoring, TRIMP, GPS, distance covered

Introduction

Training for sport often includes periodization of combining adequately challenging loads and subsequent recovery to increase performance while minimizing the risk of overtraining (7,17,34). Depending on an athlete's training load and recovery status, coaches can modify training loads to help increase or decrease fatigue relative to the training goals (17) at each point of the competitive phase (off-season, pre-season, in-season, and post-season). Therefore, regularly monitoring loads may aid coaches in effectively programming and managing appropriate training loads leading to more optimal performance.

Training load is defined as the stimuli (with characteristics of intensity, volume, and frequency) imposed on and experienced by an athlete with the intent to increase sport performance (34). Internal load is defined as the athlete's physiological and psychological responses to training and has been shown to be the strongest indicator of both training load and physiological adaptation (17,20), specifically, the psychological component addresses the athlete's cognitive perception of training load. Heart rate is a popular objective measure of monitoring internal training loads (17) and is suitable for quantifying training loads because of its close relationship with oxygen consumption variables (20).

Alternative metrics such as Edward's training impulse (TRIMP) (11), a score of internal training load and intensity (36), can be calculated by multiplying the time accumulated in different heart rate percentage zones by a weighted factor (11). Session rating of perceived exertion (sRPE) is another valid and reliable method to monitor internal training loads (7).

However, heart rate monitors and TRIMP do have shortcomings when monitoring an internal load. First, heart rate monitors can only effectively capture a portion of training; they are only suitable for monitoring intensity during aerobic training (34) and are relatively poor for high-intensity exercise including resistance training, plyometric training, and high-intensity interval training (1). Second, the cost of purchasing and maintaining a heart rate monitoring system may be high, as well as the technical expertise required to successfully operate it (1,33). Third, in some sports, heart rate monitors may not be permitted during games that would miss a large and very important amount of data (20). Alternative methods for monitoring internal loads that are low cost and easy to implement may be more effective and appropriate in team sports, including those with larger teams (33). A valid and more universal alternative to measuring an internal load such as sRPE may address these shortcomings. Heart rate and sRPE measures have consistent positive relationships with external loads; however, the relationships may be dependent on training modality or sport (26).

External load is defined as the total work performed independent of internal loads (36). Examples of external loads are total distance covered (DC) in meters, minutes of high-intensity running, or amount of weight lifted. It is important to examine both internal and external training loads to better understand the

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dose-response relationship of each sport (26). However, in relatively understudied sports and populations, the relationships of these loads have not been well established and warrant further investigation to better understand their respective training processes. Both validated external load metrics and a significant understanding of the relationship to internal loads would provide practitioners with more information to both reduce the risk of injury and improve performance of their athletes.

Intermittent team sports are categorized by intermittent bursts of high-intensity play while performing sport-specific skills over a long period of time with scheduled and unscheduled breaks (2), such as basketball, soccer, tennis, and beach volleyball. However, each sport has its own unique demands and consequently should have validated technologies and methodologies specific to that sport. Factors unique to beach volleyball such as court dimensions, sand quality, and temperature may influence responses to training (21). Currently, only 3 studies exist that examine load monitoring in beach volleyball; however, their subjects included international male beach volleyball players and their methods were not validated (21,25,28). NCAA women's beach volleyball has grown 134.5% over the past 6 academic years with almost 70 schools sponsoring a team (22). No study has evaluated NCAA D1 women's beach volleyball and no study has attempted to validate load monitoring metrics in this sport. This leaves a large gap in the literature and an opening to impact this sport beyond just training.

Evaluating the relationship of internal and external loads may lead to a better understanding of how training loads influence adaptation (30) in beach volleyball. With this better understanding, load monitoring can be more effectively implemented to help reduce the risk of injury and increase performance. Establishing ecological validity of load monitoring metrics, the real-world application of this study's findings, can lead to greater affordability and scalability of load monitoring implementation to help progress the sport of beach volleyball; this can yield benefits to both larger teams and teams with smaller budgets. Consequently, valid sport science can catalyze collaborative practice (37) by opening discussions and making integrated decisions regarding sports performance. Therefore, the purpose of this study was to determine the validity of internal and external load metrics in NCAA D1 women's beach volleyball. The first hypothesis was that sRPE Load would be a valid measure of internal load with a very strong, positive, significant ($p < 0.05$) correlation compared with TRIMP as the criterion. The second hypothesis was that all internal and external load metrics would have very strong, positive, significant correlations ($p < 0.05$). The third hypothesis was that the very strong, positive, significant correlations ($p < 0.05$) of sRPE and DC with TRIMP could be used together in a linear regression to best predict TRIMP.

Methods

Experimental Approach to the Problem

Internal and external load metrics have never been validated in NCAA D1 women's beach volleyball. In this study, an observational design was used to validate both sRPE Load and DC to TRIMP. A total of 578 individual training observations from 13 players of a NCAA D1 women's beach volleyball team were analyzed from 51 of the 74 total team training sessions including practice, games, and sport-specific conditioning. An individual training observation included the TRIMP, sRPE Load, DC, and environmental condition variables (ECV) for one athlete during a team training session. Data collection for this study occurred in

the off-season semester from August to December (15 weeks). Of the 74 team training sessions completed during data collection, 23 were excluded from analysis because they were either completed before maximum heart rate (HR_{max}) was determined, the session was completed indoors, or the specific start/end time points of the session within the data were lost. Within the 51 team training sessions used for data analysis, 38 were practices (86.7 ± 19.1 minutes), 11 were games (42.8 ± 8.3 minutes), and 2 were sport-specific conditioning (18.7 ± 6.3 minutes). The games competed in were unofficial matches against other NCAA D1 women's beach volleyball teams. Every session measured TRIMP, sRPE Load, DC, and ECV.

Subjects

Data from 13 NCAA D1 women's beach volleyball players (age: 20.3 ± 1.4 years, range: 18–22 years, height: 176.2 ± 4.3 cm, body mass: 67.8 ± 5.7 kg; $\pm SD$) were used for this study. Eligibility criteria included being aged 18–23 years and participating in at least 80% of all team training sessions (practice, games, sport-specific conditioning, and strength and conditioning). Participation credit was not granted for the team training session if the subject started late, ended early, or completed a modified version of the session for whatever reason, such as injury. Data were used for analysis if participation credit was given and all variables (TRIMP, sRPE Load, and DC) were received for an individual training observation. Of the 17 players on the team, 4 were excluded: 1 failed to meet the age criteria, 1 athlete quit the team, and 2 athletes failed to meet participation in 80% of all team training sessions because of injury. Individual average participation credit for all team training sessions was 90.4%, and each subject contributed data to an average of 44.5 of the 51 team training sessions used for analysis. The institutional review board at Texas Christian University granted ethics approval and approved the written informed consent that was given to and signed by the subjects explaining the purpose, benefits, risks, and requirements of the study.

Procedures

The Polar Team Pro heart rate monitor (Polar Electro Inc., Finland) was used to monitor subjects during practice, games, and sport-specific conditioning. This model of wearable technology has also been used to examine intermittent team sports, such as basketball (3), beach volleyball (21), and soccer (31). At the beginning of the training semester in August, a Yo-Yo Intermittent Recovery Test Level 1 (Yo-Yo IRT) was completed on a turf field to determine the athlete's HR_{max} . This test has been shown to have high reproducibility and validity for testing physical capacities in intermittent team sports (24). Based on the results of that test and HR_{max} achieved from pilot data, each athlete's HR_{max} (200.1 ± 7.5 $b \cdot \text{min}^{-1}$) was uploaded to their heart rate monitor profile for the subsequent heart rate percentages and zones. Before every practice, sport-specific conditioning, and game, the athletes put on a chest heart rate strap with a heart rate monitor. The athletes used the same sensor throughout the duration of the study. Data collection of all variables for every practice and conditioning session started with the initiation of the team stretch or warm-up and ended with the finish of the last drill; games started from the beginning of the first point to the end of the last point. Subjects were instructed to complete the sRPE questionnaires 30 minutes after the end of each session (13).

Edward’s Training Impulse. Edward’s TRIMP (11) has been used to validate sRPE Load in previous studies (1,6,16,32). Edward’s TRIMP is calculated by multiplying the duration in minutes of each session spent in the 50–60% heart rate zone by a factor of 1, 60–70% by a factor of 2, 70–80% by a factor of 3, 80–90% by a factor of 4, and 90–100% by a factor of 5, then summing all the totals together to produce a score in arbitrary units (AU). Edward’s TRIMP was selected because heart rate average alone may not reflect the physiological demands of intermittent team sports (35).

Session Rating of Perceived Exertion Load. Session rating of perceived exertion is the athlete’s subjective rating of the entire training session’s intensity (12). The sRPE scale was explained in accordance to the modified Borg category-ratio 10 scale (13) (Table 1) before the collection of the pilot data and before the beginning of this study. The sRPE questionnaires were administered through the TeamBuildr (TeamBuildr, LLC, MD) app individually to each athlete’s phone. Because of the constraints of the app, on each sRPE questionnaire the athlete was prompted “1 = extremely easy/10 = extremely hard”; however, a PDF version of the modified Borg scale was uploaded to TeamBuildr and was available to the athletes at all times. Session-RPE Load was calculated by multiplying the athlete’s sRPE by the duration of the session in minutes to produce a score in AU. The duration of each session was calculated to the nearest second based on the heart rate monitor start and end timestamps.

Distance Covered. Distance covered in meters was measured from the Polar Team Pro heart rate monitors that used global positioning system (GPS). Although GPS may underestimate DC of court-based movements (10), GPS for team sports has been shown to have acceptable accuracy and reliability for intermittent nonlinear sprinting (8). Distance covered is the most commonly reported GPS variable in studies investigating GPS in team sport training and competitions (9).

Environmental Conditions. A Kestrel 5,400 Heat Stress Tracker (Kestrel Meters, PA) was used to monitor the ECV of each analyzed team training session, including temperature, relative humidity, and wet-bulb globe temperature. Heat stress can decrease performance by inducing sweat loss and affecting the water/electrolyte balance of the athletes (19,23). Consequently, ECV were collected to assess their potential confounding effects on the load monitoring metrics.

Table 1
Modified Borg category-ratio 10 rating of perceived exertion scale (13).

Rating	Descriptor
0	Rest
1	Very, very easy
2	Easy
3	Moderate
4	Somewhat hard
5	Hard
6	—
7	Very hard
8	—
9	—
10	Maximal

Statistical Analyses

The statistical analyses were completed using IBM SPSS Statistics 25 (International Business Machines, NY). Data were analyzed using univariate analysis of variance (ANOVA), Pearson product moment correlation, and forward selection multiple regression models. Univariate ANOVAs were completed to determine if a statistically significant difference ($p < 0.05$) existed between the 3 team training session types (practice, game, and sport-specific conditioning) for TRIMP, sRPE Load, and DC. Both Tukey and Scheffe post hoc tests were completed for statistical significance. To test the study’s first hypothesis that sRPE Load is a valid metric of measuring internal load relative to TRIMP, a Pearson product moment correlation was completed on sRPE Load and TRIMP (Figure 1). To test the study’s second hypothesis of the relationship between internal and external loads, Pearson product moment correlations were completed for sRPE Load with DC (Figure 2) and TRIMP with DC (Figure 3). To test the study’s third hypothesis of sRPE Load and DC being able to predict TRIMP, a forward selection multiple regression was completed with sRPE Load, DC, and the ECV with TRIMP as the dependent variable.

Outliers were evaluated by using the criteria of greater than 3 SDs for TRIMP, sRPE Load, and DC. The magnitude of correlations was classified as <0.1 as trivial, 0.1–0.3 as weak, 0.3–0.5 as moderate, 0.5–0.7 as strong, 0.7–0.9 as very strong, and 0.9–1 as almost perfect (18). For all tests, the level of statistical significance was set at $p < 0.05$. The mean and SDs for all analyzed metrics are reported in Table 2. A posteriori power analysis revealed that an observation number of 578 at $\alpha = 0.05$ yields a power of 1.00 and effect size of ≥ 0.8 .

Results

There were no outliers for TRIMP, sRPE Load, and DC. Univariate ANOVAs found no significant differences ($p < 0.05$) between practice, games, and sport-specific conditioning for TRIMP, sRPE Load, and DC. No data points were removed, and all data points were analyzed together regardless of the type of team training session. Individual correlations for subjects of the training load metrics were reported in Table 3.

The results indicated significant correlations ($p < 0.01$) between TRIMP and sRPE Load, TRIMP and DC, and sRPE Load and DC. The relationships between the ECV and all load monitoring metrics (TRIMP, sRPE Load, and DC) were significant ($p < 0.05$ and $p < 0.01$) but not meaningful with strengths ranging from trivial to moderate.

The regression revealed that the 2 greatest predictors of TRIMP were sRPE Load and DC. The ECV were trivial when predicting TRIMP. However, the contribution of DC was small compared with sRPE Load. The regression model proposed for predicting TRIMP from sRPE Load is as follows: $TRIMP_{Tometz} = 78.735 + (sRPE\ Load \times 0.28)$ ($p < 0.001$); this regression explains 65% of the variance of TRIMP. Distance covered was the second best predictor of TRIMP. However, including DC in the regression only added 11% more explained variance when using sRPE Load to predict TRIMP and is as follow: $TRIMP_{Tometz} = 47.282 + (sRPE\ Load \times 0.182) + (DC \times 0.038)$ ($p < 0.001$).

Discussion

The purpose of this study was to validate internal and external load metrics in NCAA D1 women’s beach volleyball. This is the

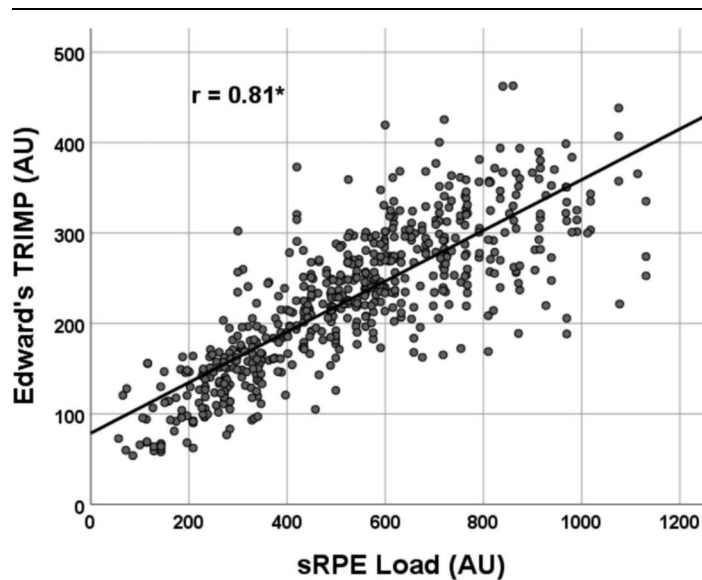


Figure 1. Scatter plot and correlation of all data points for Edward's TRIMP (AU) and sRPE Load (AU). Pearson product moment correlation was 0.81 at $p < 0.01$. 95% confidence interval: 0.78–0.84. AU = arbitrary units.

first study completed on NCAA D1 women's beach volleyball and the first study to validate load monitoring metrics in any population of beach volleyball. Validation was achieved by recording significant ($p < 0.01$) correlations between sRPE Load and DC with TRIMP as the criterion. This has paramount implications because it is important for coaches to consider the unique training characteristics of their sport and their athletes and establish applicable load monitoring standards and guidelines (4). Valid load monitor metrics provide a practical tool for impactful insight when training for high performance in sport.

Session rating of perceived exertion is the most commonly observed internal training load metric in team sports (4). In the current study, the first hypothesis that sRPE Load is a valid alternative for TRIMP was confirmed. This finding is supported in

previous research in other sports including elite women's soccer (1), Canadian male football (6), professional tennis (16), and professional male soccer (32). In this study, the correlation between sRPE Load and TRIMP was 0.81. These findings indicate that sRPE may be a valid nonheart rate-based metric of monitoring an internal load in NCAA D1 women's beach volleyball and may be a practical tool for coaches. In addition, it is a simple and versatile tool because it is scalable and inexpensive (1).

Knowing the relationship between internal and external loads in each sport could lead to a better understanding of the training process and how to most effectively monitor internal loads in that sport (26). In the current study, the second hypothesis of internal and external load metrics having significant relationships ($p < 0.01$) was confirmed. This finding about sRPE Load and TRIMP

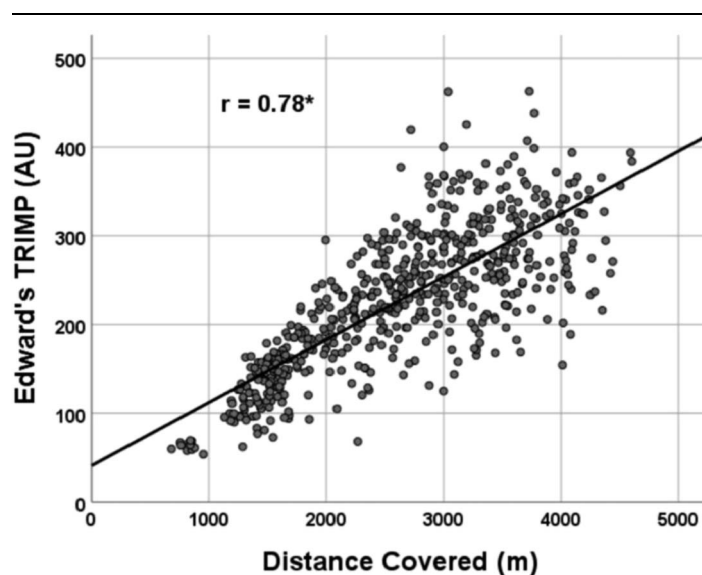


Figure 2. Scatter plot and correlation of all data points for Edward's TRIMP (AU) and distance covered (m). Pearson product moment correlation was 0.78 at $p < 0.01$. 95% confidence interval: 0.74–0.81. AU = arbitrary units.

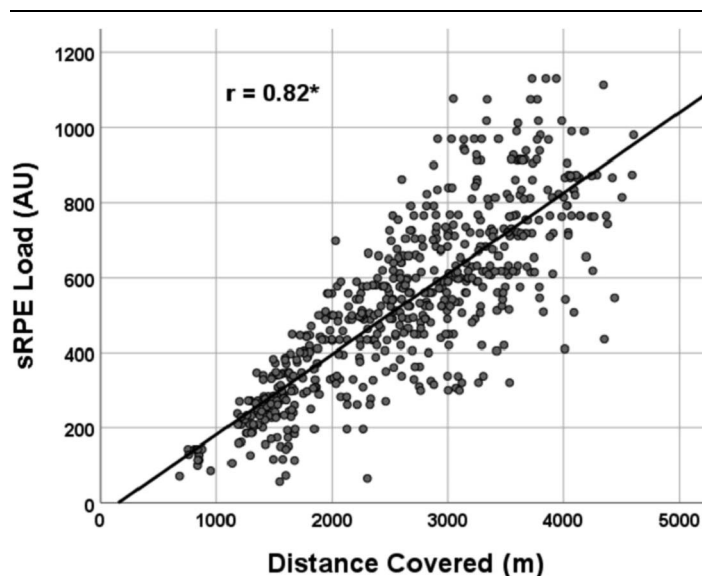


Figure 3. Scatter plot and correlation of all data points for sRPE Load (AU) and distance covered (m). Pearson product moment correlation was 0.82 at $p < 0.01$. 95% confidence interval: 0.79–0.84. AU = arbitrary units.

to DC is supported in previous research including semi-professional male soccer (5), professional male soccer (32), and Australian male footballers (15). In this study, the correlation between TRIMP and sRPE Load with DC was 0.78 and 0.82, respectively. This new understanding of these relationships in this sport between internal and external loads may help plan training to promote positive adaptations and reduce risk of injury. Effective load monitoring and load prescription require a balance of validated internal and external training loads metrics (4,14). With this information, it is now known that external loads are positively associated with internal loads and should be considered when planning training in NCAA D1 women’s beach volleyball.

A combination of valid load monitoring metrics and understanding the relationship between internal and external loads may lead to the creation of other tools to help monitor training. In the current study, the third hypothesis of sRPE Load and DC being able to predict TRIMP was partially confirmed. The regression equation yielded from this study was $TRIMP_{Tometz} = 78.735 + (sRPE\ Load \times 0.28)$. Although DC was the second best predictor of TRIMP, adding this second variable did not add a meaningful amount of explained variance; in addition, including DC would require technology to track that variable, whereas the aforementioned regression does not. Distance covered might have

only accounted for an additional 11% of the variance when predicting TRIMP because sRPE Load and TRIMP are both internal load measures, whereas DC is an external load measure. This proposed regression model using sRPE Load to predict TRIMP, on future validation, may be used to more effectively monitor training. As an internal load drives training adaptation, multiple valid methods for monitoring internal loads may reveal a better understanding of the athletes’ response to training. With ecological validity of load monitoring metrics, coaches can use heart rate data to prescribe the training load of sessions (27); however, this regression model may provide an alternative without requiring a heart rate monitoring system. Being able to use a tool as versatile and practical as sRPE Load to predict TRIMP may provide utility and insight when training for high

Table 2
Mean and SDs for all analyzed metrics and measurements.*

Metric or measurement	Mean ± SD	95% confidence interval
TRIMP (AU)	228.0 ± 80.7	69.8–386.1
sRPE Load (AU)	532.5 ± 232.8	76.2–988.8
DC (m)	2,635.4 ± 884.3	902.3–4,368.6
sRPE (AU)	7.2 ± 1.6	4.0–10.4
Temperature (°F)	76.5 ± 13.7	49.7–103.4
Relative humidity (%)	72.5 ± 13.2	46.6–98.4
WBGT (°F)	52.9 ± 19.9	14.0–91.8

*TRIMP = Edward’s training impulse; sRPE Load = session rating of perceived exertion multiplied by duration in minutes; DC = total distance covered; sRPE = session rating of perceived exertion; WBGT = wet-bulb globe temperature; AU = arbitrary units.

Table 3
Overall and individual correlations for all subjects of load monitoring metrics.*

Player	TRIMP × sRPE Load	TRIMP × DC	sRPE Load × DC
P1	0.80†	0.74†	0.79†
P2	0.83†	0.85†	0.81†
P3	0.92†	0.88†	0.91†
P4	0.91†	0.87†	0.87†
P5	0.84†	0.84†	0.88†
P6	0.82†	0.91†	0.81†
P7	0.91†	0.92†	0.88†
P8	0.74†	0.81†	0.84†
P9	0.76†	0.80†	0.91†
P10	0.83†	0.85†	0.89†
P11	0.91†	0.87†	0.88†
P12	0.87†	0.88†	0.92†
P13	0.89†	0.87†	0.90†
Overall	0.81†	0.78†	0.82†
SD	0.06	0.05	0.04
95% CI	0.73–0.97	0.75–0.95	0.79–0.95

*TRIMP = Edward’s training impulse (AU); sRPE Load = session rating of perceived exertion multiplied by duration in minutes (AU); DC = total distance covered (m). † $p < 0.01$.

performance in sports. For example, sRPE Load could be used to predict TRIMP when a heart rate monitor malfunctions or cannot be worn during competition. Within the unique demands of beach volleyball, ECV may not be a consideration when planning training load. In this study, the ECV were not meaningfully related to any load monitoring metrics. However, because certain ECV could lead to complications such as heat stress that can negatively impact performance (23,29), they should be considered for the safety and well-being of the athletes.

Some limitations to this study exist. First, individual nonteam training sessions completed on the athlete's own time may have influenced their recovery and subsequently their response to training. Second, the warm-up periods of the games were not included in the data collection. Third, the Yo-Yo IRT may not be valid when performed by beach volleyball players because of it being completed on a different surface than that used in training; in addition, performing the exact same protocol on sand may not be valid either. However, a semester of pilot data was useful when determining each athlete's HR_{max} and familiarity with the sRPE questionnaire for the athletes. There may be value in creating a beach volleyball-specific standardized test to determine HR_{max} . Finally, the study was limited by the removal of 23 team training sessions.

Within NCAA D1 women's beach volleyball, these findings provide a valid alternative metric for measuring internal load, a new understanding of the relationship between internal and external loads, and a model using sRPE Load to predict TRIMP. Being the first study in this population and the first to validate load monitoring metrics in this sport, practitioners have additional tools to improve their impact with their athletes. Load monitoring can optimize training for high performance in sport by facilitating interprofessional education (37) and collaborative practice (37) among practitioners.

Practical Applications

Session-RPE Load is a valid alternative for TRIMP when monitoring internal loads in NCAA D1 women's beach volleyball. Session-RPE Load may be the most scalable and cost-efficient option for larger NCAA D1 women's beach volleyball teams and teams who cannot afford a heart rate monitoring system. The utility of sRPE provides coaches, potentially of all populations in beach volleyball, with a versatile tool to monitor training loads for increased performance and reduced risk of injury. Because of DC having a significant correlation ($p < 0.01$) with both TRIMP and sRPE Load, the amount of movement or DC in training should be considered when planning periodization and monitoring training loads. This insight provides a greater understanding of training for high performance in beach volleyball. A proposed regression model can help coaches predict heart rate load with just sRPE and duration. Environmental condition variables should be noted for to the safety of the athletes but not in regard to planning or monitoring training loads. Sport science can allow for collaborative practice by connecting all components of the training model with data.

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