VALIDATION OF INTERNAL AND EXTERNAL LOAD METRICS IN NCAA D1 WOMEN'S BEACH VOLLEYBALL

A Thesis for the Degree

Master of Science

by

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ABSTRACT

The purpose of this study was to determine the validity of internal and external load metrics in NCAA D1 women's beach volleyball. Participants included 13 NCAA D1 women's beach volleyball players (age: 20.26 ± 1.41 years). A total of 578 data points were analyzed from 51 team training sessions including practice, games, and conditioning from the pre-season semester from August to Decemember (15 weeks). The participants wore Polar Team Pro heart rate monitors with GPS during each training session to assess internal and external loads. Participants completed a session-rating of perceived exertion (sRPE) questionnaire after every session. Daily environmental condition variables (ECV) were collected during team training sessions to identify potential confounding variables. Statistically significant relationships ($p < 0.01$) were found between TRIMP and sRPE Load (0.81), TRIMP and DC (0.78), and sRPE Load and DC (0.82). A regression model yielded sRPE Load could predict TRIMP with the equation: $TRIMP_{Tometz} = 78.735 + (sRPE\ Load * 0.28)$; this equation predicts 65% of the variance of TRIMP. These findings support sRPE Load as a valid alternative to TRIMP when monitoring internal load in NCAA D1 women's beach volleyball. Additionally, sRPE Load may be more practical and accessible for teams. Distance covered during training should be considered when periodizing and monitoring load because of its relationship with internal loads. ECV should be considered for the safety of the athletes but not for load monitoring. Primary insight into load monitoring provides an opportunity for practitioners to engage in interprofessional education and collaborative practice.

KEY WORDS

sRPE, heart rate, monitoring, TRIMP, GPS, sand

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, 33). 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, post-season). Therefore, regularly monitoring load may aid coaches in effectively implementing and managing appropriate training loads.

Training load is defined as the stimuli imposed on and experienced by an athlete with the intent to increase sport performance. 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). Heart rate is a popular objective measure of monitoring internal training load (17) and is suitable for quantifying training load due to its close relationship with oxygen consumption variables (20). Alternative metrics like Edward's training impulse (TRIMP) (11) can be calculated from heart rate data. Session rating of perceived exertion (sRPE) is another valid and reliable method to monitor internal training load (7). 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 done independent of internal load (35). 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 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.

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, and tennis. There are similar characteristics between beach volleyball and other intermittent team sports, therefore we may reference the knowledge of what is currently known about load monitoring in those sports as a starting point. 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 three studies exist that examine load monitoring in beach volleyball; however, their participants 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 last 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.

Sport science provides an unique opportunity for an integrated high performance staff to further improve their training model. Practitioners including the sport coaches, the strength and conditioning coach, and the athletic trainer can all receive insight from the sport scientist. The data collected from load monitoring has implications that can affect each professional's respective roles. Interprofessional education can be defined as two or more professionals from different fields learning about, from, and with each other (36) and collaborative practice can be defined as practitioners from different fields working together to optimize the collective quality of care given (36). Valid sport science can catalyze collaborative practice by opening discussions and making integrated decisions regarding sports performance.

Evaluating the relationship of internal and external loads may lead to a better understanding of the dose-response relationship (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 can lead to greater affordability and scalability of load monitoring implementation to help progress the sport of beach volleyball. 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 compared to training TRIMP. The second hypothesis was that that all internal and external load metrics would have very strong, positive, significant correlations. The third hypothesis was that sRPE Load and DC could 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 (n = 578) individual training observations from a NCAA D1 women's beach volleyball team were analyzed. Pilot data was collected during the prior in-season semester from January to May. Data collection for this study occurred in the following 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 timepoints of the session within the data were lost. Within the 51 training sessions used for data analysis, 38 were practices (86.63 ± 19.08 min), 11 were games (42.81 ± 8.31 min), and 2 were conditioning (18.74 ± 6.28 min). The games competed in were unofficial matches against other NCAA D1 women's beach volleyball teams. Every session measured TRIMP, sRPE load, DC, and environmental condition variables (ECV).

Subjects

Data from 13 NCAA D1 women's beach volleyball players (age: 20.26 ± 1.41 years, height: 176.24 ± 4.34 cm, body mass: 67.76 ± 5.68 kg) were used for this study. Eligibility criteria included being 18 to 23 years of age and participating in at least 80% of all team training sessions (practice, conditioning, strength and conditioning, and games). Participation credit was not granted for the team training session if the participant started late, ended early, or completed a modified version of the session for whatever reason such as injury. 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 due to injury. The Institutional Review Board granted ethics approval and approved the written informed consent which was given to and signed by the participants 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 participants during practice, conditioning, and games. 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} (200.08 ± 7.45 beats·min^{-1}) was uploaded to their heart rate monitor profile for the subsequent heart rate percentages and zones. Prior to every practice, conditioning session, 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. Participants were instructed to complete the sRPE questionnaires 30 minutes after the end of each session (13).

TRIMP. Edward's TRIMP (11) has been used to validate sRPE Load in previous studies (1, 6, 16, 32). 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). TRIMP was selected because heart rate average alone may not reflect the physiological demands of intermittent team sports (34).

sRPE Load. sRPE 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) (Figure 1) prior to the collection of the pilot data and prior to the beginning of this study. The sRPE questionnaires were administered through the TeamBuildr (TeamBuildr, LLC, Maryland, United States) app individually to each athlete's phone. Due to 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. sRPE 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.

Figure 1 about here.

Distance Covered. DC in meters was measured from the Polar Team Pro heart rate monitors which used 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). DC is the most commonly reported GPS variable in studies investigating GPS in team sport training and competitions (9).

Environmental Conditions. A Kestrel 5400 Heat Stress Tracker (Kestrel Meters, Pennsylvania, United States) was used to monitor the ECV of each analyzed team training session including temperature, wet bulb globe temperature (WBGT), and relative humidity. 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.

Statistical Analyses

The statistical analyses were completed using IBM SPSS Statistics 25 (International Business Machines, New York, United States). Data were analyzed using ANOVA, correlation, and regression models. An ANOVA was completed to determine if a statistically significant difference existed between the three team session types for TRIMP, sRPE Load, and DC. Outliers were evaluated by using the criteria of greater than 3 standard deviations 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 $p < 0.05$.

RESULTS

The means and standard deviations for all analyzed metrics were reported in Table 1. There were no outliers for TRIMP, sRPE Load, and DC. A preliminary independent samples t-test found no significant differences between practice, conditioning, and games. Thus, no data points were removed and all data points were analyzed together regardless of type of training session. Individual correlations for participants of the training load metrics were reported in Table 2.

Table 1 about here.

Table 2 about here.

In order 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 2). In order to test the study's second hypothesis of the relationship between internal and external loads, Pearson product moment correlations were completed sRPE Load and TRIMP to DC (Figure 3; Figure 4). The results indicated a very strong, positive, 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 significantly trivial, weak, or moderate and both positive or negative ($p < 0.05$ and $p < 0.01$).

Figure 2 about here.

Figure 3 about here.

Figure 4 about here.

In order 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. The regression revealed that the two greatest predictors of TRIMP were sRPE Load and DC. The ECV were trivial when predicting TRIMP. However, the contribution of DC was small compared to sRPE Load. The regression model proposed for predicting TRIMP from sRPE Load is as follows: $TRIMP_{Tometz}$ = 78.735 + (sRPE Load * 0.28); this regression explains 65% of the variance of TRIMP. DC 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.

DISCUSSION

The purpose of this study was to validate internal and external load metrics in NCAA D1 women's beach volleyball. This is the 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. This has paramount significance 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 monitors metrics provide a practical tool for impactful insight when training for high performance in sport.

sRPE 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 non-heart rate based metric of monitoring 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 load in that sport (26). In the current study, the second hypothesis of internal and external load metrics having very strong, positive, significant relationships was confirmed. This finding is supported in previous research for TRIMP and sRPE Load to DC in other sports including semiprofessional male soccer (5), professional male soccer (32), and Australian male footballers (15). In this study, the correlation between TRIMP and sRPE Load to 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 requires 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 * 0.28). Although DC was the second best predictor of TRIMP, adding this second variable did not add a meaningful amount of explained variance;

additionally, including DC would require technology to track that variable while the aforementioned regression does not. This proposed regression model using sRPE Load to predict TRIMP, upon future validation, may be used to more effectively monitor training. As internal load drives training adaptation, multiple valid methods for monitoring internal load 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 performance in sport.

Within the unique demands of beach volleyball, ECV may not be a consideration when planning training load. Although certain ECV could lead to complications like heat stress that can negatively impact performance (23, 29), in this study, the ECV were not meaningfully related to any load monitoring metrics. However, the ECV should be considered for the safety and well-being of the athletes.

Some limitations to this study exist. First, individual non-team 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 due to it being completed on a different surface than that used in training; additionally, 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 (36) and collaborative practice (36) among practitioners.

PRACTICAL APPLICATIONS

sRPE Load is a valid alternative for TRIMP when monitoring internal load in NCAA D1 women's beach volleyball. sRPE 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. Due to DC having a very strong, positive, significant correlation with both TRIMP and sRPE Load, the amount of movement or distance covered 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. ECV 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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Table 1. Means and standard deviations for all analyzed metrics and measurements.

Metric or Measurement	**Mean ± SD**	**95% Confidence Interval**
TRIMP (AU)	227.97 ± 80.68	69.84 - 386.10
sRPE Load (AU)	532.49 ± 232.81	76.19 - 988.79
DC (m)	2635.44 ± 884.28	902.25 - 4368.62
sRPE (AU)	7.20 ± 1.64	3.98 - 10.42
Temperature (°F)	76.52 ± 13.71	49.65 - 103.39
Relative Humidity (%)	72.47 ± 13.22	46.56 - 98.37
WBGT (°F)	52.90 ± 19.87	13.96 - 91.84

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 2. Individaul correlations for all participants of load monitoring metrics.*			
Player	**TRIMP x sRPE Load**	**TRIMP x DC**	**sRPE Load x 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**
SD	0.06	0.05	0.04
95% CI	0.73-0.97	0.75-0.95	0.79-0.95
****** p < 0.01			
*Each athlete contributed to an average of 44.46 of the 51 team training sessions used for analysis. 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.			

Figure 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

Figure 2. Scatter Plot and correlation of all data points for Edward's TRIMP and sRPE Load. Pearson product moment correlation was 0.81 at $p < 0.01$. 95% Confidence Interval: 0.78 – 0.84.

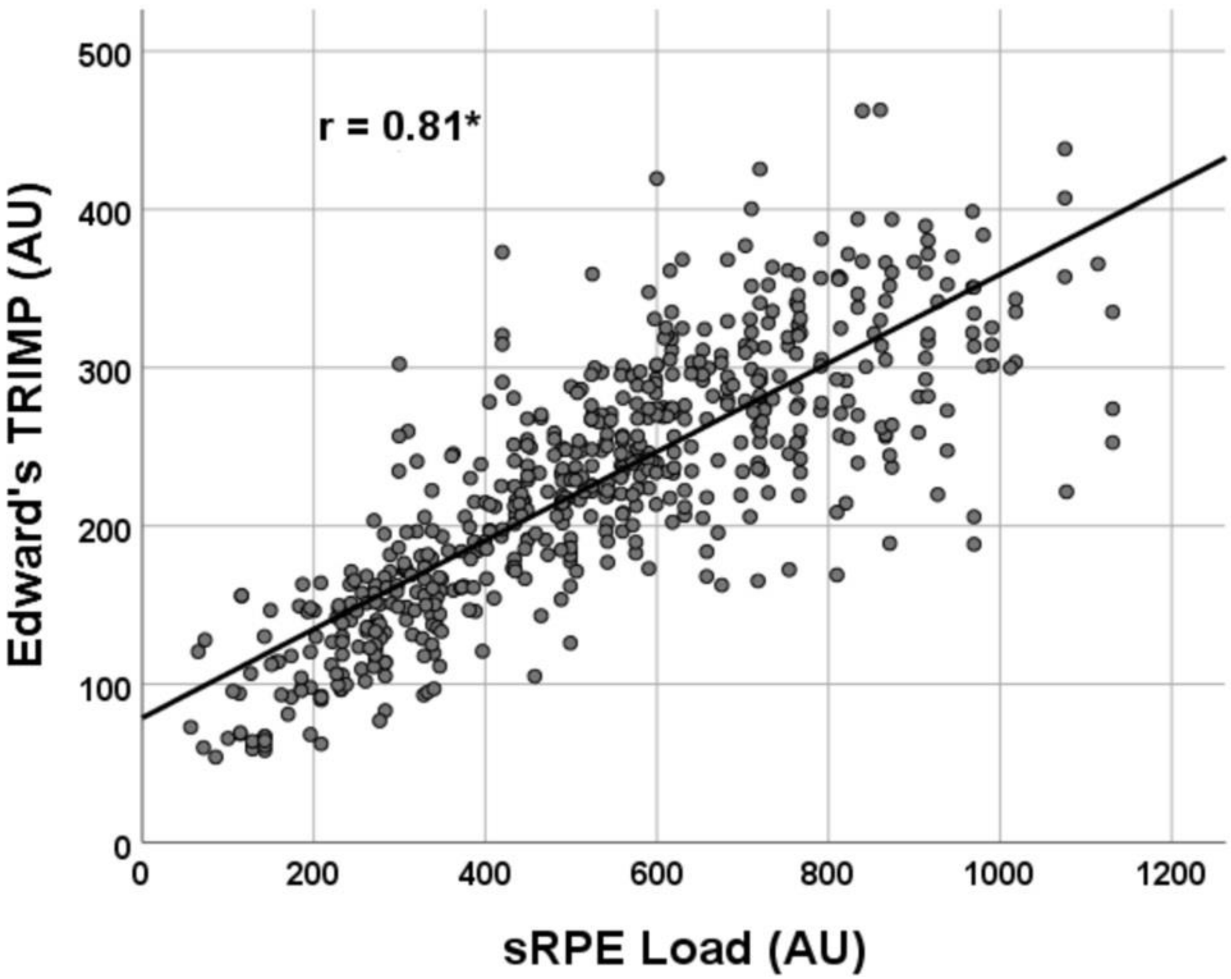

Figure 3. Scatter Plot and correlation of all data points for Edward's TRIMP and Distance Covered. Pearson product moment correlation was 0.78 at $p < 0.01$. 95% Confidence Interval: 0.74 – 0.81.

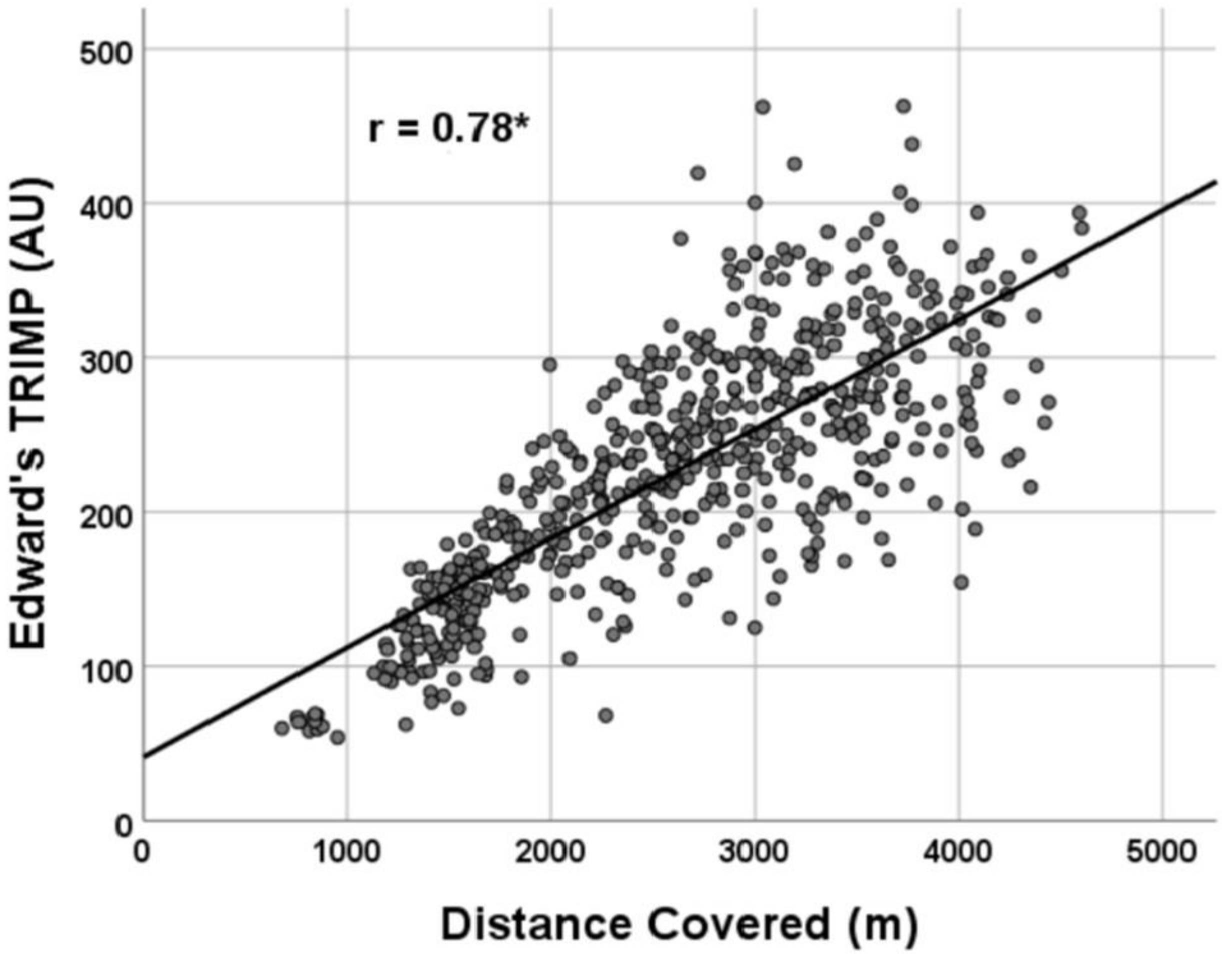

Figure 4. Scatter Plot and correlation of all data points for sRPE Load and Distance Covered. Pearson product moment correlation was 0.82 at $p < 0.01$. 95% Confidence Interval: 0.79 – 0.84.