Spring 2021

The Quantification of Training Load in Professional American Soccer Players

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THE QUANTIFICATION OF TRAINING LOAD IN PROFESSIONAL AMERICAN SOCCER PLAYERS

by

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(Under the Direction of Greg Ryan)

ABSTRACT

Training load (TL) has become a common tool to measure the exertion of athletes over the course of a session or season. However, there is still limited understanding of the load placement throughout training weeks within American professional soccer. The purpose of this study was to quantify potential differences in the external [duration, total distance (D_T), explosive distance (D_E), sprint distance (D_S), maximum speed ($Speed_{Max}$) and number of sprints (#S)] and internal [session rating of perceived exertion load (S-RPE Load), average heart rate (HR_{Avg}), peak heart rate (HR_{Peak}), time spent above 90% heart rate max (time > 90% HR_{Max})] demands of seasonal training on a single Professional American soccer team. A USL 1 soccer team (n=22; 23.3yr, 80.5kg, 181.9cm) was outfitted with GPS bio-harnesses and had all training sessions monitored and recorded. Training sessions were categorized by their distance away from the next competition [match days (MDs) out]. A Kruskal-Wallis analysis of variance (ANOVA) was used to analyze main effect differences. A Fisher's least significant difference post hoc pairwise analysis determined intervariable differences. Alpha was set at 0.05 for all significant main effect findings. Following the analysis of the main effect differences for all variables ($p < 0.01$), various trends in TL were discovered. All external load variables and S-RPE load represented a bell-shaped curve, where TL increased from MD-4 to MD-3, and then decreased toward MD-1. HR_{Avg}, HR_{Peak} and time > 90% HR_{Max} portrayed a linear taper beginning with the highest load on MD-1 and gradually declining toward MD. Interestingly, HR responses did not fall in line with the external load variables, which may indicate athletes were not fully recovered when they resumed training following the previous game. Across all variables analyzed in the present study, MD-1 presented the lowest load across all MDs. Although the data analysis was extensive (10 variables), it is our recommendation to include a regular and concise list of variables when communicating to coaches. Based on these results coaches should be mindful of the recovered state of players returning to training following a game, to not overstress them before they are sufficiently recovered.

INDEX WORDS: Global positioning system, Match day minus, Periodization, Sprinting, Distance, Heart rate

THE QUANTIFICATION OF TRAINING LOAD IN PROFESSIONAL AMERICAN SOCCER PLAYERS

by

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B.S., State University of New York at Cortland, 2018

A Thesis Submitted to the Graduate Faculty of Georgia Southern University

in Partial Fulfillment of the Requirements for the Degree

MASTER OF SCIENCE

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Electronic Version Approved:
May 2021

DEDICATION

- *I would like to dedicate this manuscript to my loving wife, Karissa. Without her love and support, having the ability to devote the time and effort necessary into this project would not have been possible.*
- *Thank you to my family (Susan, Stephen, Abby and Bethany), for their guidance over the past 6 years of my educational journey.*
- *To my many mentors over the years: thank you for your wisdom and knowledge, for it has shaped the way I conduct myself as a human.*

ACKNOWLEDGMENTS

- *I would like to acknowledge the help of my committee members (Greg Ryan, Samuel Wilson, and Stephen Rossi) for their continued help throughout this project.*
- *I would also like to acknowledge the many teachers at Georgia Southern University and SUNY Cortland, who have guided me on my educational path.*

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CHAPTER 1

INTRODUCTION

Training is a pivotal aspect to all athlete's preparation for competition. The carry-over of skill acquisition and heightened performance from proper training demands are the goals of all coaches and players. Within team sports, variations in the daily and weekly training and competition schedule result in variations in the internal and external load placed on athletes (Foster et al., 2001; Impellizzeri et al., 2004; Martín-García et al., 2018; Kelly et al., 2020). Thus, the purposeful monitoring of these loads has grown in popularity over the last decade.

Within training, drills performed by the whole team require similar external load from each player, whereas the internal load response varies by each athlete (Azcárate et al., 2018; Foster, 2001; Impellizzeri et al., 2004). With the use of contemporary tracking technologies, coaches, technical staff, strength and conditioning professionals, and medical personnel have the ability to measure these inter-player differences. The quantification of training load (TL) during the competitive season can help determine player fitness, recovery status, and provide insight into the structure of training schedules. Specifically, the match day (MD) out structure in the volume of training during a session has been proposed because of the insight provided by the sessions' proximity to competition (Anderson et al., 2016; Malone et al., 2015; Stevens et al., 2017).

Session ratings of perceived exertion (S-RPE) provides a subjective measure of TL following team training and competition (Foster et al., 2001). Additionally, S-RPE Load, defined as training time in minutes multiplied by S-RPE value, and expressed in arbitrary units (au), is used to monitor training response and recovery throughout a variety of amateur and professional sports (Clarke et al., 2013; Foster et al., 2001; Malone et al., 2015; Manzi et al., 2010). Within American football and European basketball, the highest training loads were observed during training sessions in the middle of the training week, presenting a bell-shaped curve, where a purposeful build up was followed by a similar reduction in TL in the days preceding the game (Bompa, 1999; Clarke et al., 2013; Manzi et al., 2010). In professional basketball, where training weeks encompassing one and two games were compared, differences in S-RPE Load structure were seen. When solely looking at TL from training sessions, single game weeks (2436 ± 229 au) had significantly more load compared to the two-game week (1722 ± 229 au). Interestingly, when adding in the competition load into the overall weekly load, there was only a 5% difference between the 1 day and 2 day competition week, thus showing purposeful periodization by coaching staff in order to provide proper training stimuli in preparation for the game (Manzi et al., 2010).

Various investigations into S-RPE Load have shed light on the training structure in professional soccer teams. Malone et al. (2015) reported no differences in S-RPE Load throughout the training week, with the exception of MD-1, which was significantly lower ($p < 0.05$, average difference from MD-2,3,4: 158.33 au) than all other days of training. Although there were no significant differences in S-RPE Load from MD-5 to MD-2, a large effect size (d = 1.29) was noted between MD-3 and MD-1, showing the middle of the week training held the highest load. Additionally, Kelly et al. (2020) saw a progressive decline of 70-90 au in S-RPE Load per day leading to MD, in English Premier League players. Lastly, in a study looking at perceived exertion (S-RPE Load) categorized into two sub groups (i.e. the respiratory and muscular portions of the body), they reported the largest loads for both starters (i.e. playing time > 45 minutes) and non-starters (playing time < 45 minutes) in the middle (MD-3) of the week in reserve La Liga players (Los Arcos et al., 2017). Ultimately, there appears to be a consistent finding within elite European soccer teams, that shows MD-1 having the lowest TL, even with differing degrees of tactics.

Similar investigations into the quantification of internal load via heart rate (HR) monitors have been used. In professional Eredivisie soccer, a clear gradual taper from MD-4 (17 ± 10 min) to MD-1 (3 ± 4 min) was seen in time spent > 90% of maximum HR (HR_{max}) across all outfield players (Stevens et al., 2017). Malone et al. (2015) saw contrary results, where MD-5 and MD-1 saw no differences, while MD-3 recorded the highest average overall $\%HR_{max}$ (es = 0.49), in relation to MD-1, going into competition. Thus, potentially showing a purposeful lighter session on MD-5, to continue recovery from a prior game, as a build up to the highest loads on MD-3. This would fall in line with the bell-shaped curve by the aforementioned studies on non-soccer sports (Clarke et al., 2013; Manzi et al., 2010). Additionally, within an American football team (r= 0.69-0.91), and a professional basketball team (r=0.69-0.85), similar relationships with S-RPE Load have been reported between various HR based methods (Clarke et al., 2013; Manzi et al., 2010). Thus, showing a potential benefit of utilizing both objective (HR) and subjective (RPE) measures of internal load to measure TL. While time spent at greater than 90% HR_{max} (time > 90% HR_{max}) and %HR_{max} has been reported by the aforementioned studies, use of mean (HR_{Avg}) and peak HR (HR_{Peak}) has been lacking in the current MD out literature. HR_{max} is defined as maximum HR attainable based on various methods (e.g. age predicted HR_{max}) and HR_{Peak} is defined as the highest measured HR during the training session. The inclusion of the overall HR_{Avg} and its relation to HR_{Peak} and time > 90% HR_{max} may provide a more useful measure when quantifying TL due to the inclusion of various measures of intensity utilizing HR response throughout the session.

While two forms (i.e. S-RPE Load & HR methods) of internal load quantification have been correlated, McLaren et al. (2018) also reported a large positive relationship (r=0.79) between S-RPE and total distance (D_T) traveled. In a study comparing two separate professional second division teams (i.e. Dutch & Portuguese), the Portuguese team covered more D_T (*d* = 1.93; 0.76) and had a higher average maximum speed ($Speed_{Max}$) (*d* = 1.14; 0.62) on MD-3 and MD-2, respectively, while covering less D_T (*d* = 0.84) on MD-1 compared to the Dutch side. The contrast in weekday external load may provide insight into the periodization tactics by the coaching and technical staff across different countries, where the Portuguese team may plan higher loads in the middle of the week (i.e. bell curve) and the Dutch side may implement more evenly distributed sessions (Clemente et al., 2019). Within a La Liga side, high intensity activities [i.e. sprint distance (D_S) and high-speed running distance] followed a trend of a gradual taper as MD approached (Martín-García et al., 2018). Interestingly, Stevens et al. (2017) reported the opposite results, with high speed running showing a bell-shaped curve, while total distance gradually declined toward MD. These results suggest the inclusion of multiple variables across different intensities (e.g. accelerations, sprinting, D_T) may provide a more complete look into teams TL as MD approaches (Stevens et al., 2017).

Across multiple top-flight European leagues (e.g. English Premier League & La Liga), a bell-shaped curve structure in the preceding days prior to MD for D_T have been reported (Anderson et al., 2016; Martín-García et al., 2018). For example, within an English Premier League team, during a one game week, D_T was highest on MD-3, after a slight increase from MD-4 (873 m, ES = 0.3), before tapering gradually to MD-1. Additionally, during a two-game week, D_T increased greatly (4040 m, ES = 1.2) from MD-4 to MD-3 with a similar gradual taper to MD (Anderson et al., 2016). The lower D_T on MD-4 during the two-game week, compared to the one game week shows the potential emphasis placed on recovery from the previous game. Martín-García et al. (2018) reported a ~ 9% increase in D_T from MD-4 to MD-3 before dropping by 37% from MD-2 to MD-1. Due to the variation in leagues and level of skill of the athletes across these studies, it is important to understand these factors when investigating internal and external load.

Even with the vast quantification of internal (S-RPE Load & HR based) and external (GPS metrics) TL previously published across professional European soccer clubs, there is still limited knowledge on the MD out structure in professional American soccer. Within American soccer, it is common to have multiple games within the same training week, similar to the European model, therefore the monitoring of the aforementioned variables may be beneficial throughout the season. Accordingly, the purpose of this study is to quantify potential differences in the external [i.e. duration, D_T, explosive distance (D_E), D_S, $Speed_{Max}$ and number of sprints (#S)] and internal load [i.e. S-RPE Load, HR_{Avg}, HR_{Peak}, time > 90% HR_{Max}] demands of training in professional American Soccer.

CHAPTER 2

METHODOLOGY

SUBJECTS

Twenty-two professional male soccer players (23.35 yrs, 80.45 kg, 181.86 cm) were monitored across a 28-week competitive regular season. These 22 outfield players represent team members who participated in training from the beginning to end of the season. Players who participated in only portions of the season were excluded. This represents the total possible population of athletes within this team. The team competed in two official competitions throughout the season, corresponding to a total of 29 (14 home and 15 away) United Soccer League (USL) League One and United States Open Cup games. The weekly microcycle training structure ranged between 4-6 sessions and 0-2 matches throughout the season.

For the purpose of this study, only outfield players (8 Defenders, 6 Midfielders, 8 Forwards) were included for analysis. All players consented to have their data collected with the prior understanding of the aim of the study, requirements, research procedures, benefits, and risks associated. The Institutional Review Board at Georgia Southern University approved the study.

DESIGN

Data collection took place on home training and game fields. The same natural outdoor grass surface on both the training and game fields were utilized by the team throughout the season. Only field-based sessions involving both starters and non-starters from the first team were included. Each player was fitted with an individualized global positioning system (GPS) (STATSport, Belfast, UK) and HR (Polar Team 2, Bethpage, NY) monitor. Any player that participated in individual, rehabilitation, recovery, or specialized fitness sessions was excluded. Goalkeepers were also excluded from analysis.

Players were provided their monitor approximately 30 minutes before the start of training. All time points included in the analysis comprised whole team warm-ups and drills. The duration of training was marked from the point of organization by the coaching staff to initiate warm-up, concluding with the final drill and players leaving the training facility. All activities outside the starting and ending time points were excluded from the duration of each session. Following training, players returned the monitors and reported their individual RPE number on the intensity of the session. The 6-20 RPE chart (Borg, 1962) was shown to each player, away from teammates and coaches. The data from individual monitors were downloaded, analyzed and uploaded to the master data set.

A typical training schedule consisted of five training days followed by a game. Although, due to the team competing in multiple competitions, training sessions were broken down into their proximity to the following match (i.e. MD -) (Malone et al., 2015; Stevens et al., 2017). Four days or more prior (MD-4+), three days prior (MD-3), two days prior (MD-2), and one day prior (MD-1) to MD were used as the delineation for training day categories. Within microcycles where two matches took place (i.e. Tuesday & Saturday), the Monday sessions were categorized as MD-1, and Wednesday, Thursday and Friday sessions were categorized as MD-3, MD-2 and MD-1, respectively. Thus, a congruent proximation from training is established for all training sessions during the 28-week season.

EXTERNAL TRAINING LOAD

Variables used for analysis were training duration (min), D_T (m), D_E (>25.5 W/kg; m), D_S (> 5.5 m/s; m), $Speed_{Max}$ (m/s) and #S (Stevens et al., 2017 & Malone et al., 2015). The GPS pods were placed inside specially made vests, inside a small pocket, placed on the back between the scapulae. The units record at a sampling rate of 10 hz. Across various metrics no differences in the processing outcomes of the GPS company, compared to the raw data outputs were seen (Thornton et al., 2019).

INTERNAL TRAINING LOAD

The player's internal TL was calculated using S- RPE Load (au). This estimation of internal TL was calculated by multiplying training duration by S-RPE (Foster et al., 2001; Kelly, et al., 2020). All players were familiarized with the RPE scale during the pre-season training phase. The GPS units provide the HR_{Avg}, HR_{Peak}, and time at > 90% HR_{max} (min) through Bluetooth technology between the individualized HR and the GPS units (Stevens et al., 2017). Players 90% of HR_{max} were determined using the age predicted maximum HR method.

STATISTICAL ANALYSES

Data IBM SPSS Version 25.0 (SPSS, Inc., Chicago, IL) was used for all analysis. Shapiro-Wilk test for normality was run on all variables. Parametric continuous variables were analyzed using multivariate analysis of variance (ANOVA), with Bonferroni post hoc analyses conducted on all significant main effect findings. Nonparametric data were analyzed using a Kruskal-Wallis ANOVA. Follow up procedures entailed Fisher's least significant difference post hoc analyses. The data is represented as mean ± SD for continuous data, and median ± IQR for nonparametric data. All variables were categorized and compared between training days in the MD minus structure. Significance is set at $p < 0.05$. Effect size for all significant post hoc relationships were calculated using Cohen's *d*, and assessed using the following delineation: < 0.2 = small; 0.2 to 0.79 = moderate, and ≥ 0.8 = large (Cohen, 1992).

CHAPTER 3

RESULTS

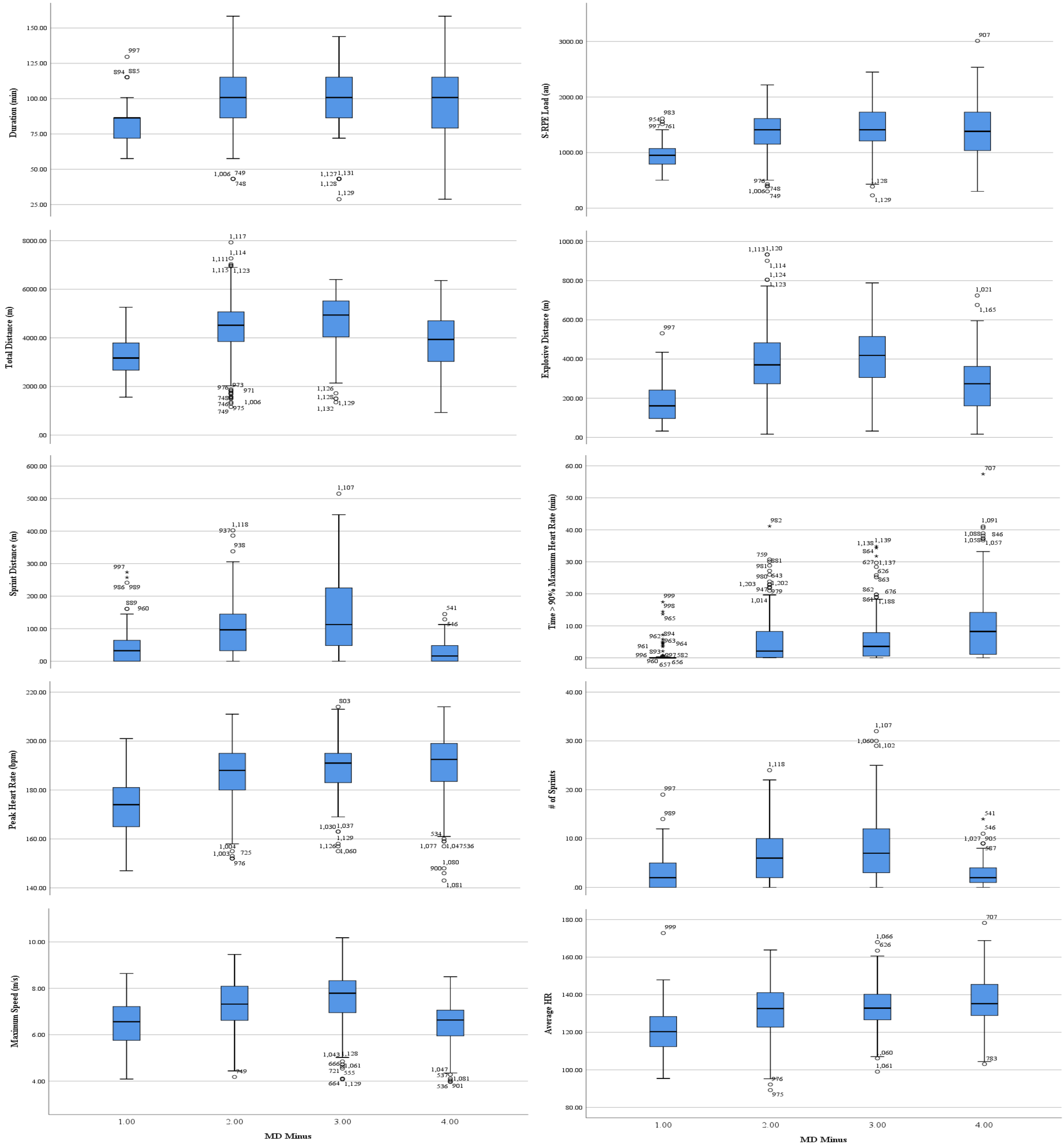
Data was collected on 22 players over 72 practices during the regular competitive season. Following the Shapiro-Wilk test for normality, data was determined to be non-parametric. Descriptive data (median ± IQ) for duration, D_T, D_E, D_S, $Speed_{Max}$, #S, S-RPE Load, HR_{Avg}, HR_{Peak}, and time > 90% HR_{Max} are represented in Table 1.

Table 1. Summary of descriptive data for variables with reference to match days out from competition

Variable	**MD-1 (n=9)**	**MD-2 (n=20)**	**MD-3 (n=18)**	**MD-4 (n=23)**
Duration (min)	86.40 ± 14.40 [! ^]	100.80 ± 28.80 [* ^]	100.80 ± 28.80	100.80 ± 39.60 [* !]
S-RPE-Load (au)	950.40 ± 316.80	1411.20 ± 460.80 [^]	1411.20 ± 518.40	1382.40 ± 691.20 [!]
Total Distance (m)	3170.00 ± 1130.00	4520.00 ± 1245.00 [^]	4940.00 ± 1495.00	3935.00 ± 1682.50 [!]
Explosive Distance (m)	160.93 ± 144.84	370.15 ± 209.21 [#]	418.43 ± 217.27 [!]	273.59 ± 205.20
Sprint Distance (m)	32.19 ± 64.37 [^]	96.56 ± 112.65 [#]	112.65 ± 185.08 [!]	16.09 ± 48.28 [*]
# of Sprints	2.00 ± 5.00 [^]	6.00 ± 8.00 [#]	7.00 ± 9.00 [!]	2.00 ± 3.00 [*]
Maximum Speed (m/s)	6.56 ± 1.52 [^]	7.32 ± 1.50	7.79 ± 1.42	6.64 ± 1.11 [*]
Average HR (bpm)	120.32 ± 16.72	132.64 ± 18.43 [#]	132.84 ± 13.62 [! *]	135.23 ± 16.62 [#]
Peak HR (bpm)	174.00 ± 16.00	188.00 ± 15.00 [# ^]	191.00 ± 12.50 [! ^]	192.50 ± 15.75 [! #]
Time > 90% HR Max (min)	0.00 ± 0.14	2.11 ± 8.32 [#]	3.58 ± 7.41 [!]	8.25 ± 13.22

Descriptive data represented as (median ± IQR). MD-1,2,3,4: days prior to match day (MD), S-RPE Load= session rating of perceived exertion load, HR= heart rate, min= minutes, m= meters, m/s= meters per second, bpm= beats per minute. * denotes no difference with MD-1, ! denotes no difference with MD-2 , # denotes no difference with MD-3, ^ denotes no difference with MD-4.

Figure 1. Training load trends for all variables with reference to MDs out from competition.



Data represented across all variables as median values. MD Minus= training days away from competition, Min= minutes, S-RPE Load= session rating of perceived exertion load, m= meters, m/s= meters per second, HR= heart rate, bpm= beats per minute.

DURATION

Following the independent samples Kruskal-Wallis test, an omnibus significant result was noted for duration between MD out ($\chi^2(3) = 45.201$, $p < 0.01$). The post hoc adjusted pairwise analyses revealed that MD-1 was significantly shorter in duration than MD-3 ($\chi^2(3) = -162.093$, $p < 0.01$, $d = 0.87$), while no different than MD-2 ($\chi^2(3) = 8.905$, p = 1.00, $d = 0.78$), and MD-4 ($\chi^2(3) = -57.401$, $p = 0.42$, $d = 0.58$). MD-2 was significantly shorter than MD-3 ($\chi^2(3) = -170.998$, $p < 0.01$, $d = 0.07$) and no different than MD-4 ($\chi^2(3) = -66.306$, $p = 0.06$, $d = 0.10$). MD-4 was shorter than MD-3 ($\chi^2(3) = 104.692$, $p < 0.01$, $d = 0.16$).

S-RPE LOAD

Following the independent samples Kruskal-Wallis test, an omnibus result found a significant difference for S-RPE Load between MDs out ($\chi^2(3) = 160.956$, $p < 0.01$). The post hoc pairwise analysis revealed that MD-1 was significantly shorter than MD-2 ($\chi^2(3) = -223.742$, $p < 0.01$, $d = 1.31$), MD-3 ($\chi^2(3) = -339.624$, $p < 0.01$, $d = 1.55$), and MD-4 ($\chi^2(3) = -284.995$, $p < 0.01$, $d = 1.08$). MD-2 was significantly less than MD-3 ($\chi^2(3) = -175.882$, $p < 0.01$, $d = 0.21$), and no different than MD-4 ($\chi^2(3) = -61.253$, $p = 0.09$, $d = 0.03$). MD-3 was different than MD-4 ($\chi^2(3) = 114.629$, $p < 0.01$, $d = 0.21$).

TOTAL DISTANCE

Following the independent samples Kruskal-Wallis test, an omnibus result found a significant difference for D_T between MDs out ($\chi^2(3) = 145.522$, $p < 0.01$). The post hoc pairwise analysis revealed that MD-1 was significantly less than MD-2 ($\chi^2(3) = -194.645$, $p < 0.01$, $d = 1.06$), MD-3 ($\chi^2(3) = 113.748$, $p < 0.01$, $d = 1.65$), and MD-4 ($\chi^2(3) = 37.478$, $p < 0.01$, $d = 0.61$). MD-2 was significantly less than MD-3 ($\chi^2(3) = 29.309$, $p < 0.01$, $d = 0.32$), while no different than MD-4 ($\chi^2(3) = 0.670$, $p = 1.00$, $d = 0.42$). MD-3 was significantly greater MD-4 ($\chi^2(3) = 142.845$, $p < 0.01$, $d = 0.81$).

EXPLOSIVE DISTANCE

Following the independent samples Kruskal-Wallis test, an omnibus result found a significant difference for D_E between MDs out ($\chi^2(3) = 142.252$, $p < 0.01$). The post hoc pairwise analysis showed that MD-1 was significantly less than MD-2 ($\chi^2(3) = -215.805$, $p < 0.01$, $d = 1.34$), MD-3 ($\chi^2(3) = -255.106$, $p < 0.01$, $d = 1.61$), and MD-4 ($\chi^2(3) = -111.507$, $p < 0.01$, $d = 0.78$). MD-2 was significantly greater than MD-4 ($\chi^2(3) = 104.298$, $p < 0.01$, $d = 0.61$), while no different than MD-3 ($\chi^2(3) = -39.301$, $p = 0.26$, $d = 0.11$). MD-3 was significantly greater than MD-4 ($\chi^2(3) = 143.599$, $p < 0.01$, $d = 0.78$).

SPRINT DISTANCE

Following the independent samples Kruskal-Wallis test, an omnibus result found a significant difference for D_S between MDs out ($\chi^2(3) = 141.872$, $p < 0.01$). The post hoc pairwise analysis revealed that MD-1 was significantly less than MD-2 ($\chi^2(3) = -147.566$, $p < 0.01$, $d = 0.81$) and MD-3 ($\chi^2(3) = -184.774$, $p < 0.01$, $d = 1.05$), while no different than MD-4 ($\chi^2(3) = 16.755$, $p = 1.00$, $d = 0.31$). MD-2 was significantly greater than MD-4 ($\chi^2(3) = 164.320$, $p < 0.01$, $d = 1.13$), while no difference was seen with MD-3 ($\chi^2(3) = -37.209$, $p = 0.33$, $d = 0.33$). MD-3 was significantly greater than MD-4 ($\chi^2(3) = 201.529$, $p < 0.01$, $d = 1.30$).

NUMBER OF SPRINTS

Following the independent samples Kruskal-Wallis test, an omnibus result found a significant difference for #S between MDs out ($\chi^2(3) = 116.722$, $p < 0.01$). The post hoc pairwise analysis showed that MD-1 had significantly less #S than MD-2 ($\chi^2(3) = -149.906$, $p < 0.01$, $d = 0.83$) and MD-3 ($\chi^2(3) = -173.280$, $p < 0.01$, $d = 0.96$), while there was no difference with MD-4 ($\chi^2(3) = 0.929$, $p = 1.00$, $d = 0.12$). MD-2 had significantly more #S than MD-4 ($\chi^2(3) = 150.835$, $p < 0.01$, $d = 0.98$), while there was no difference with MD-3 ($\chi^2(3) = 0.-23.374$, $p = 1.00$, $d = 0.22$). MD-3 had significantly more #S than MD-4 ($\chi^2(3) = 174.209$, $p < 0.01$, $d = 1.09$).

MAXIMUM SPEED

Following the independent samples Kruskal-Wallis test, an omnibus result found a significant difference for $Speed_{Max}$ between MDs out ($\chi^2(3) = 93.193$, $p < 0.01$). The post hoc pairwise analysis showed that MD-1 was significantly less than MD-2 ($\chi^2(3) = -153.946$, $p < 0.01$, $d = 0.69$) and MD-3 ($\chi^2(3) = -252.049$, $p < 0.01$, $d = 0.94$), while there was no difference with MD-4 ($\chi^2(3) = -44.881$, $p = 0.87$, $d = 0.01$). MD-2 was significantly greater than MD-4 ($\chi^2(3) = 109.065$, $p < 0.01$, $d = 0.69$) and significantly less than MD-3 ($\chi^2(3) = -98.103$, $p < 0.01$, $d = 0.25$). MD-3 was significantly greater than MD-4 ($\chi^2(3) = 207.168$, $p < 0.01$, $d = 0.95$).

AVERAGE SPEED

Following the independent samples Kruskal-Wallis test, an omnibus result found a significant difference for HR_{Avg} between MDs out ($\chi^2(3) = 156.062$, $p < 0.01$). The post hoc pairwise analysis showed that MD-1 had a significantly lower HR_{Avg} than MD-2 ($\chi^2(3) = -318.650$, $p < 0.01$, $d = 0.72$), MD-3 ($\chi^2(3) = -352.645$, $p < 0.01$, $d = 0.99$), and MD-4 ($\chi^2(3) = -359.715$, $p < 0.01$, $d = 1.08$). MD-2 was no different than MD-3 ($\chi^2(3) = -33.995$, $p = 1.00$, $d = 0.18$), and MD-4 ($\chi^2(3) = -41.065$, $p = 0.61$, $d = 0.34$). MD-3 and MD-4 ($\chi^2(3) = -7.070$, $p = 1.00$, $d = 0.19$) saw no difference.

PEAK HEART RATE

Following the independent samples Kruskal-Wallis test, an omnibus result found a significant difference for HR_{Peak} between MDs out ($\chi^2(3) = 192.761$, $p < 0.01$). The post hoc pairwise analysis showed MD-1 had a lower HR_{Peak} than MD-2 ($\chi^2(3) = -334.599$, $p < 0.01$, $d = 01.11$), MD-3 ($\chi^2(3) =- 404.757$, $p < 0.01$, $d = 1.51$), and MD-4 ($\chi^2(3) = -394.286$, $p < 0.01$, $d = 1.36$). MD-2 saw no difference in HR_{Peak} than MD-4 ($\chi^2(3) = -59.687$, $p = 0.10$, $d = 0.30$) and, with MD-3 ($\chi^2(3) = -70.158$, $p = 0.05$, $d = 0.26$). MD-3 was not different from MD-4 ($\chi^2(3) = 10.470$, $p = 1.00$, $d = 0.07$).

TIME > 90% HEART RATE MAXIMUM

Following the independent samples Kruskal-Wallis test, an omnibus result found a significant difference for > 90% HR_{Max} between MDs out ($\chi^2(3) = 187.921$, $p < 0.01$). The post hoc pairwise analysis showed MD-1 had a lower time > 90% HR_{Max} than MD-2 ($\chi^2(3) = -316.959$, $p < 0.01$, $d = 0.79$), MD-3

($\chi^2(3) = -304.705$, $p < 0.01$, $d = 0.89$), and MD-4 ($\chi^2(3) = -413.673$, $p < 0.01$, $d = 1.17$). MD-2 was significantly less than MD-4 ($\chi^2(3) = -96.713$, $p < 0.01$, $d = 0.50$), while no difference was seen from MD-3 ($\chi^2(3) = 12.255$, $p = 1.00$, $d = 0.05$). MD-3 had significantly less time than MD-4 ($\chi^2(3) = -108.968$, $p < 0.01$, $d = 0.48$).

CHAPTER 4

DISCUSSION

In the present study, the quantification and comparison of TL placed on professional American soccer players throughout the competitive season was analyzed through the lens of MDs out from competition. With regard to the general consensus (Anderson et al., 2017; Clemente et al., 2019; Malone et al., 2015; Martín-García et al., 2018; Stevens et al., 2017), training load declined as MD approached. As seen across all variables of interest, MD-1 resulted in the lowest TL. Within each variable, various trends revealed potential purposeful periodization by the technical coaching staff.

Across all the measures of external load (i.e. duration, D_T, D_E, D_S, #S, $Speed_{Max}$) and S-RPE Load, the trend of TL as MD approached showed a bell-shaped curve. More specifically, from MD-4 to MD-3 there was an increase in TL, followed by a taper in load from MD-2 and MD-1. For D_T, the team covered the most distance on MD-3 where a 1005m increase was seen from MD-4, followed by a 420m decrease to MD-2, and then a 1350m drop on MD-1. Similarly, Anderson et al. (2017) and Martín-García et al. (2018) saw a 470.4 (d = 0.44) - 873m (effect size (es) = 0.3) increase in D_T from MD-4 to MD-3. Interestingly, our increase in D_T was higher than both prior studies, although during a two-game week Anderson et al. (2017) saw a 4040m (es = 1.2) increase from MD-4 to MD-3, in an English Premier League club. Unfortunately, we did not investigate 1- vs 2- game week differences. Throughout these results, the studies may shed light on the coaching staff's emphasis on recovery on the first training session following a game, especially when two games are played within one microcycle (i.e. 1 training week).

Following the same trend, Los Arcos et al. (2017) and Martín-García et al. (2017) reported a bell-shaped curve trend for S-RPE Load and duration of training, respectively. Quantifying S-RPE Load into respiratory or muscular separately (i.e. respiratory and muscular perceived exertion), Los Arcos et al. (2017) reported a 9.9% and 19.8% increase from MD-4 to MD-3 in TL for both starters and non-starters of a reserve La Liga team, respectively. Interestingly, the present study's results fell closer in line with the perceived muscular RPE with a 32.7% increase (d = 0.21) across the same MDs. Additionally, Martín-

García et al. (2017) saw a 6.0% increase in duration of training from MD-4 to MD-3 in a La Liga team, whereas the current results show training duration only changed on MD-1 following a 14.3% decrease the from MD-2. The La Liga side shortened training on MD-1 by 23.8%, providing potential insight into the importance placed by the USL staff for on field whole team skill acquisition in a mid-level American soccer team compared to a top-level club in La Liga. Clemente et al. (2019), observed the same trend as the current study (14.8%) in $Speed_{Max}$ following a 7.9% increase in speed from MD-4 to MD-3 and then tapering off into MD-1. Of the other variables in the present study that saw a bell-shaped curve (D_E, D_S & #S) comparable insight with previous literature was not seen.

Prior literature reported a linear taper in TL from the beginning of the week until MD, in various external load variables (Kelly et al., 2020; Martín-García et al., 2017; Stevens et al., 2017). Dissimilar to the current results, Kelly et al. (2019) and Stevens et al. (2017) reported a gradual taper in D_T as MD approached, in English Premier League and Dutch Eredivisie professional soccer, respectively. Whereas the present results showed an increase in D_T (20.3 %, d = 0.81) from MD-4 to MD-3, these prior studies showed a roughly 700-800m and 18% decline in D_T throughout the training week, respectively. Interestingly, where Martín-García et al. (2017) showed similar results with the present study for D_T and duration, their results showed a 38.8% reduction in D_S from MD-4 to MD-3, whereas, the present team showed an 85.7% increase in D_S across the same training days. Additionally, Stevens et al. (2017) saw a linear taper in duration from MD-4 to MD-1, which may add to the theory that individual coaching staffs may hold different internal and external load variables to a higher merit as their basis for periodization tactics when building out training micro- and macrocycles.

Although many results from the current study align with prior documented TL literature, there is still a variety of variations in load response/TL by teams. For example, Malone et al. (2015), only saw a significant difference in TL on MD-1 compared to all other training days for duration, S-RPE Load and D_T ($p < 0.05$). The only variant in those results was for high speed running distance, where MD-1 and MD-2 were not different ($p > 0.05$). This is interesting because in comparison to previous studies and the current results, in this English Premier league side, TL looked fairly similar throughout the training week, and only showed an emphasis on the reduction in load on MD-1. Additionally, similar to Stevens et al. (2017), the present results for time > 90% HR_{Max} shows time in the highest HR zone (i.e. 90-100%) is highest on MD-4 and then tapers off notably as the week of training continues. For example, from MD-4 to MD-3 time in the highest HR zone dropped by 56.6% and 76.3% in the present study and a Dutch Eredivisie team, respectively (Stevens et al., 2017). This provides insight into the potential recovered state of the athletes following the previous competition with their return to the training field.

One of the more interesting results from the present study is connecting the response in internal load (i.e. HR_{Avg}, HR_{Peak}, time > 90% HR_{Max}) to the external load requirements of training. All the external load variables represented a bell-shaped curve structure throughout the training week. Conversely, the three HR variables gradually declined (HR_{Avg}, HR_{Peak}, time > 90% HR_{Max}). In expectation, the HR response of players should follow in the output of the physical exertion (i.e external load) on the field. Although, in the present study HR_{Avg} (135.23 bpm), HR_{Peak} (192.50bpm) and time > 90% HR_{Max} (8.25 min) were the highest in the training week on MD-4 even though the external load variables showed a lower overall load on MD-4 than MD-3. This may be due to the team not fully being recovered following the previous game, where a larger emphasis may need to be placed upon the athletes on their days away from training on proper recovery tactics.

CHAPTER 5

CONCLUSION

In summary, the present study extensively quantified TL throughout a USL League One regular competitive season. Periodization of training was evident across the variables of interest in the study. The training session prior to competition (i.e. MD-1) showed the lowest load placement across all variables. Load placement trends were evident, such as a bell-shaped curve (duration, S-RPE Load, D_T, D_E, D_S, #S & $Speed_{Max}$) and a linear taper into MD (HR_{Avg}, HR_{Peak} & > 90% HR_{Max}). Most interestingly, HR responses did not fall in line with the external load variables, begging the question of the recovered state of the athletes when they resumed training following the previous game. Future research is still needed in order to continue the understanding of TLs experienced by professional soccer players, and differing periodization models and tactics by coaching and technical staff, especially within American professional leagues.

CHAPTER 6

PRACTICAL APPLICATIONS

The data from the present study adds to the limited knowledge on TL in professional American soccer teams. The results of the study provide insight in the variation in load placed on athletes throughout a training week with the hope of understanding what is needed to properly recover and prepare athletes for the next competition. Although the data analysis was extensive (10 variables), it is our recommendation to include a regular and concise list of variables when communicating to coaching staffs. Due to the demands of professional soccer, variables that should be included are a measure of cardiovascular load (e.g. HR), a measure of overall distance (i.e. D_T), and a measure of intensity within the training session (i.e D_E, D_S & #S) (Gaudino et al., 2017; Stevens et al., 2017). Based on these results coaches should be mindful of the recovered state of players returning to training following a game, so as to not over-stress them before they are sufficiently recovered.

CHAPTER 7

LIMITATIONS

Within the current analysis, training weeks were combined, on the basis that the MD-minus structure would adeptly quantify training load. Although, in many professional soccer leagues around the world, teams play in more than one game and competition in a single week on a regular basis. Therefore, the separation of training weeks based on number of matches played (Anderson et al., 2017) may be warranted. Additionally, the number of training sessions recorded on MD-1 (n=9) was much less than the other training days of the week. Unfortunately, the ability to monitor the team was only while they trained at the home practice and game fields. On many occasions, during the 2019 season, the team would depart for away games at least one day in advance. Data was not able to be collected on those occasions. Lastly, within training sessions, comparisons may be formed in relation to the amount of time played in the previous game (e.g. starters vs non-starters) (Los Arcos et al., 201). This may warrant future research to investigate the possible variations in TL between starters and non-starters.

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APPENDIX A

A LITERATURE REVIEW

Over the past two decades, the use of monitoring tactics and devices in team sports has become commonplace. Proper structure of the external and internal load during an individual session and larger training cycles is a continuous goal for coaching staff and sports medicine members, to prepare a team for competition. Quantification of these loads within team sports during a training week has been well studied since the turn of the century (Foster et al., 2001; Impellizzeri et al., 2004; Martín-García et al., 2018; Kelly et al., 2020). The use of subjective measures (RPE), heart rate (HR) monitor technology and metrics provided by global positioning systems (GPS) have all been used. The measurement of various metrics is important, especially at the professional level because of the need to stay contemporary and competitive within the various leagues and tournaments teams play in (e.g. domestic league, league cup, and continental tournaments). Additionally, being able to best understand the load placed on athletes may aid in providing the appropriate training stimulus to prepare for competition. More specifically, recent investigations have focused on match days out (MD-) from competition in an attempt to explore the structure of a training week, with the goal of heightened performance in competition.

Following the fundamental publication by Foster et al. (2001), a multitude of studies in the following years outlined a well-documented look at subjective measures of internal training load within team sports athletes. Foster et al. (2001) proposed the use of session rating of perceived exertion (S-RPE) as a cost-effective method of measuring training load in team sports. Classified as a single global term for quantifying load, S-RPE uses a scale provided to athletes to individually report exertion during training. Additionally, volume (e.g. training duration) and intensity (e.g. S-RPE score) have been used in combination and designated as training load or S-RPE Load (Azcárate et al., 2018; Foster et al., 2001; Gaudino et al., 2015; Impellizzeri et al., 2004; Stevens et al., 2017,). S-RPE Load has shown to be positively correlated with variations of the training impulse (TRIMP) HR method of quantifying training load (Banister et al., 1991; Gaudino et al., 2015). Unfortunately, a direct comparison between TRIMP and

S-RPE Load is difficult because of the 1-5 coefficient scale compared to the CR-10. Additionally, HR is a poor method of evaluating high intense exercise and intermittent activity, such as team sports like soccer. Whereas, the athlete's individual perception of their physiological stress may provide a more valuable measure of internal TL (Foster et al., 2001). Additionally, variations in the RPE scale have been used, including the CR-10 scale (Borg, 1984; Foster et al., 2001; Kelly et al., 2020) and a 6-20 scale (Ryan et al., 2020), making it difficult to compare results of these studies.

S-RPE Load has been studied extensively within soccer in recent years using a variety of different methods. Azcárate et al. (2018) investigated the TL during in-season competition of Second Division professional soccer players. In an attempt to better quantify internal stress, the investigators separated overall TL into perceived respiratory TL and muscular TL (i.e. How hard was your session on your chest? And how hard was the session on your legs?, respectively.) They investigated the effect playing time from the previous match and structure of training week had on the teams TL in following training days. The delineation was broken into three categories of playing time for matches (i.e., ≥45 min; <45 min; 0 min) and training week structure was one game per week. Results showed players who averaged longer than 45 minutes reported higher TL throughout the training week compared to players participating in < 45 min and 0 minutes. It is difficult to compare categories when splitting the match in half, with in-game situations, tactical changes by the coach, red cards, etc. Additionally, there were no meaningful differences between playing time and the type of week structure (e.g. Sat-Sun, 8 days). This result is supported by Malone et al. (2015), that saw no differences in S-RPE load when comparing individual week microcycles during the 6 weeks of preseason in English Premier League players. Splitting weeks based on time between matches also does not provide insight in intraweek variability in training. In most professional leagues, teams play in more than one competition, adding midweek/multiple week games, making it difficult to plan consistent week periodization plans. For example, when solely looking at training days (i.e. excluding matches) a two-match week (1722 ± 229 au) had significantly less TL compared to a one match week (2436 ± 233 au), in elite professional basketball

(Manzi et al., 2010). Although, when including the competitions, the overall internal TL remained constant. Thus, showing that quantifying load based on weekly values may lose the benefit of understanding intraweek and individual session load.

To help mitigate risk to study design, sports scientists and researchers have conceptualized that monitoring the fluctuation in training loads on a day to day basis, may prove valuable. Understanding the potential TL periodization strategies of teams and leagues may give insight into the potential for performance enhancements and decrease injury risk. The theory is the distance a training session is away from the next competition has an impact on the TL of the session (Impellizzeri et al., 2004 and Alexiou & Coutts., 2008). For example, Los Arcos et al. (2017), quantified the TL of professional reserve soccer players in La Liga. Similarly, to Azcárate et al. (2018), this study separated sRPE TL into two subsections (respiratory: sRPEres-TL and muscular: sRPEmus-TL) in starters and non-starters. After investigating the breakdown of these two TL categories, the investigators observed the highest training loads in the middle of the training week. Using Foster's 0-10 scale, SRPE-TL showed a gradual increase from MD-6 to MD-3 having the largest load. From MD-3 to MD-1 a slow taper was seen culminating in MD-1 having the lowest loads of the training week. These results are contrary to the previous results (Azcárate et al, 2018), where there were no differences in the days preceding MD-1. With the discrepancy seen between how load throughout a week is placed, Ryan Et al., 2020 advises to be wary of the sole use of RPE as an estimation of training intensity, due to the inconsistencies of their results.

There is additional evidence of a purposeful periodization regarding S-RPE Load in other team sports and across different professional levels (Clarke et al., 2013; Manzi et al., 2010). In professional American football (Canadian Football League), where teams compete once a week, TL took on a bell-shaped curve structure, representing a purposeful buildup and taper, with the highest TLs noted in the middle of the week and purposeful reductions in TLs the following days as the team prepares for the next competition (Clarke et al., 2013). The reported highest loads in the middle of a training week may provide evidence towards the coach's conscious effort to allow the team to slowly build up to the highest load of the week to recover from the previous competition. Additionally, in professional basketball, a single game week saw clear tapering toward MD. MD-3 (656 ± 88 au) was higher than MD-1 (222 ± 56 au). Interestingly though, the highest load during the single game week was placed farthest from competition (MD-5: 765 ± 89) followed by a lard drop off on MD-4: 309 ± 80) prior to the progressive taper toward MD. During the two-match week, as per expected, the mid-week competition was bordered by two low TL sessions. What is interesting within this two-match week is the internal training load on MD-1 was higher than MD-2. With the added challenge of proper training and player recovery with a multi-game week, when compared to the single match week this study showed that total weekly TL (including matches) were less than 5% different (Manzi et al., 2010). Across different sports other than soccer, comparative and contrasting results have indicated periodization strategies by coaching staffs, with the effort of providing proper training stimuli to players.

Furthermore, within the last decade, a myriad of investigations into the external training load using Global positioning system (GPS) technology have been published. One of the most used GPS systems in collegiate and professional soccer, as well as non-soccer sports, is the STATSports system (Chicago, IL, USA). Utilized by many elite level professional teams (e.g. German Football Association, Manchester United FC, Miami Dolphins, University of North Carolina at Chapel Hill Women's Soccer), STATSport has developed professional relationships all across the globe. This system has evolved from an initial Viper Pod system into a APEX Team Series built for whole sports teams, and most recently (i.e. 2020) into the Sonra 3.0 Apple Watch, Apple iPad compatible system. A reliability study from Bato & Keijzer. (2019) found an excellent inter-class correlation coefficient (ICC) for the STATSport Apex system of 0.99 (0.98, 0.99) for sprints from 5m to 30m. Additionally, they reported a good coefficient of variation (CV) of 1.85% for sprints over the same distance. Concluding that the Apex system is sufficient for measuring peak velocity, but the reliability being higher over 15m traveled. Accordingly, it is important to trust the output of metric measurements a system like the Apex team series gives you. Utilizing a multifaceted design approach, total distance (TD), low, moderate, and high-speed running, and maximum speed showed no difference when comparing processing methods of the manufacturer to the raw data, stipulating minimal filtering by STATSport Apex units (Thornton et al., 2019). Although differences were seen with average accelerations (Acc) and deceleration (Dec) showed a 1.95% ± 0.12 difference between software and raw data. The research team reported an inverse relationship between the magnitude of activity and accuracy of measurements for Acc and Dec. Additionally, the CV for the overall average total Acc and Dec (m/s^2) was 3.6% ± 1.5%. Concluding that as Acc and Dec magnitude increases the reliability decreases slightly while the opposite is true for speed metrics, in that the shorter the sprint (under 15m) the higher the variability, for the Apex system. Additionally, it seems that Acc and Dec (3.6% ± 1.5%) is less reliable compared to unidirectional sprint (1.85%) within the monitoring capability Apex GPS Units (Bato & Keijzer., 2019; Thornton et al., 2019).

A myriad of studies has followed and accompanied the previously mentioned reporting of S-RPE Load across MD out from competition (Anderson et al., 2015; Akenhead et al., 2016; Kelly et al., 2020; Malone et al., 2015 & Stevens et al., 2017). Most recently, Kelly et al. (2020) investigated the training load in accordance to MD from competition in English Premier League players. In the study, the researchers utilized GPSports SPI Pro X (Canberra, Australia) systems. They found a significant main effect across the MD out from competition for all variables ($p < 0.0001$). They broke their training days into 3,2, and 1 days prior to the match, MD and 1- and 2-days following MD. TD was similar on MD- 3, MD+2 and MD+3. On days preceding the match, there was a slow taper toward MD, where the highest load of the training week was seen on MD-3. Additionally, across all field players (starters and non-starters), on a Dutch Eredivisie team, Stevens et al. (2017) also observed a continuous gradual taper from MD-4 to MD-1 across a number of variables. Training time decreased on all consecutive days from MD-4 (*88* ± 11 min) to MD-1 (59 ± 7 min). TD steadily declined from MD-4 (7.3 ± 0.9 km) to MD-1 (3.8 ± 0.5 km). Time spent at greater than 90% of HR_{max} did not follow the same trend as TD and training duration. MD-4 (17 ± 10 min) saw the greatest time spent in the high HR zone, although no meaningful taper was seen during training across MD-3 (4 ± 6), MD-3 (4 ± 5) and MD-1 (3 ± 4). This study did not report peak or average HR, so the comparison between all around internal load between MD-3, 2 and 1 is hard when only using time spent at greater than 90% HR maximum. Malone et al. (2015) also observed similar results for TD and training duration in English Premier League players. Only MD-1 saw significant differences compared to all other MDs out of competition. Across these studies the general finding is that the TL is the lowest on MD-1 with either a slow gradual taper or a constant load placement over the days preceding MD-1. It is clear there is a large emphasis in elite soccer on MD-1 to markedly drop TL to allow for recovery and preparation going into the last 24 hours prior to the match.

There has also been a number of studies observing a different trend in the weekly external training load obtained via GPS units (Anderson et al., 2016, Clemente et al., 2019; Martín-García et al., 2018). In a study combining data from Portuguese Second League and Dutch Second League teams spanning a 7 week in-season period, TD (m) and maximum speed (km/h) showed a peak in training load in the middle of the training week (MD-3) (Clemente et al., 2019). For TD the team covered the most distance on MD-5 (7062.66 ± 1460) and MD-3 (6919.49 ± 1846), with a drop-in distance on MD-4 and a large drop in training load on MD-2 (5701.57 ± 12) and MD-1 (4584.50 ± 1053.1). Mirroring a similar trend in TL as reported loads on professional basketball players in Italy (Manzi et al., 2010). Interestingly, in addition to these combined results from two separate teams, they also compared the separate teams on each training day. For TD the Portuguese team had significantly higher distances on MD-3 and MD-2 followed by a significantly less TD on MD-1, compared to the Dutch team. Even though there was a larger TD for the Portuguese side on MD-3 and MD-2, the switch in a lower load may be attributed to the coaching and technical staff purposefully dropping their external TL in order to allow for proper recovery from the higher distances compared to the Dutch team. In addition, the Portuguese team recorded a higher team average for Maximum speed on MD-3 and MD-2 compared to the Dutch team. This goes in line with the higher TD, which may provide insight into the Portuguese team emphasizing harder training sessions followed by a large drop in load closer to MD, with the Dutch team having a more evenly distributed load on the days preceding the match. Across both teams, there is a clear bell-shaped curve throughout the training week for TD and maximum speed, indicating a potential emphasis on allowing recovery from a prior competition and before reaching the highest load with the focus shifting on recovering for the next match.

Anderson et al. (2016) investigated the external training load of a English Premier League team during the 2013-2014 competitive season. Rather than solely looking at one match week, they investigated the TL implications when one, two or three matches were played in a week. During the one match week, TD was greatest on MD-3 with a slight increase from MD-4 (873 m, ES: 0.3) and then a larger drop off in covered distance from MD-2 (-2126m; ES: 0.8) and MD-1 (-2311 m; ES 0.8). For a two-match week, with competitions at the beginning and end of the week, the main difference seen is a relatively low TD for MD-4 (approx. 1500m) compared to the one game week (approx. 5000m). Martín-García et al. (2018) also saw an increase in TD from MD-4 (5123.2 ± 904.5 m) to MD-3 (5602.8 ± 1205.7) followed by a decline as MD approached (MD-1: 2675.3 ± 601.7). Interestingly, among high intensity activities (i.e. sprint distance and high-speed running distance) TL followed a linear taper toward MD. The similar bell-shaped curve for TD is evident, but the linear drop in measures of intensity (i.e. sprint distance and high-speed running distance) may provide evidence of emphasis of periodization tactics by the technical staff. TD followed the save trend as the average length of training, where the longest session was on MD-3, allowing for a greater volume (e.g. TD) to be acquired, while the high intense activities were placed farthest away from the forthcoming match. In part to the previously discussed methodology by coaches and trainers to allow for recovery from the prior match taking the shape of a bell-shaped curve, when a second game is placed within the same seven-day window, relatively low external training load has been commonplace in elite European soccer when returning to the training field.

In conclusion, a few clear TL periodization tactics have emerged from studies investigating elite level soccer. Utilizing RPE and HR monitors as an internal TL measure both a linear taper and a bell-shaped curve have been reported in both soccer and varying sports (e.g. American football and basketball). Following results utilizing GPS technology, measurements of external load (e.g. distance, speed, Acc & Dec), showed both the linear taper and bell-shaped curve as seen with the internal methods of measuring TL. Additionally, with the use of reliability studies, the use of such technology has been deemed acceptable to aid in coaching and medical staff's goal of creating proper training sessions.

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