A descriptive analysis of internal and external loads for elite-level tennis drills.

Abstract

Purpose: Planning tennis sessions accentuating physical development requires an understanding of training load (TL). The aims were to describe the external-internal TL of drills, and analyze relationships between ratings of perceived exertion (RPE), TL and other measures.

Methods: Fourteen elite-level junior tennis athletes completed 259 individual-drills. Six coaches helped devise classifications for all drills: *Recovery/Defensive*, *Open-Pattern, Accuracy*, *2-on-1 Open*, *2-on-1 Net-Play*, *Closed-Technical*, *Point-Play*, and *Match-Play*. Notational analysis on stroke and error-rates was performed post-session. Drill-RPE, and mental-exertion were collected post-drill, while heart-rate (HR) was recorded continuously.

Results: *Recovery/Defensive*, *Open-Pattern* and *Point-Play* were significantly greater than *Closed-Technical* drills ($p<0.05$) for RPE and mental-exertion, as were *Accuracy* drills and *Match-Play* ($p<0.05$). *Recovery/Defensive*, *Open-Pattern*, *Accuracy*, and *2-on-1 Open* drills were of greater stroke-rates than *Match-Play* ($p<0.05$). Error-rates of *Closed-Technical* drills were significantly higher than *Open-Pattern*, *2-on-1* drills, *Point-Play*, and *Match-Play* ($p<0.05$). No HR differences were observed ($p>0.05$) between categories. Substantial correlations existed for drill-RPE and TL with mental-exertion ($r>0.62$) for several categories. TL was substantially correlated with total-strokes ($r>0.65$), whilst HR, stroke and error-rates were in slight-moderate agreement with RPE and TL ($r<0.51$).

Conclusions: *Recovery/Defensive* drills are of highest physiological stress, making them ideal for maximizing physicality. *Recovery/Defensive* drills compromised training quality, eliciting high error-rates. In contrast, *2-on-1 Net Play* drills provided the lowest error-rates, potentially appropriate for error-amelioration practice. *Open-Pattern* drills were characterized by significantly higher stroke-rates, suggesting congruence with high-repetition practice. Finally, with strong relationships between physical and mental-perception, mental-exertion may compliment currently used monitoring strategies (TL and RPE).

Introduction

The extensive competition demands of junior elite-level tennis athletes challenges coaches' abilities to ensure physical, technical and tactical capacities are sufficiently developed.[1,2] Consequently, training time is at a premium within high performance tennis environments. Coaches often prioritize on-court integrated training sessions in order to blend technical and tactical development within match-specific conditioning.[3,4] In order to maximize the efficiency of such integrated sessions, internal and external training load monitoring is necessary to ensure optimal load and recovery needs are met. However, presently there are limited resources available to coaches to describe internal loads in response to external loads prescribed in elite-level training sessions.[3-6]

Numerous studies have reported the external and internal load demands of tennis tournament play.[1,7-12] Previous literature reveals tennis matches (3 sets) are typically comprised of 300-500 high intensity efforts over 1.5-4 h.[1,9] Stroke rates have been reported between 2.5-4.7 shots/rally, dependent on gender and surface.[1,7,8,10,11] During competitive matches, mean heart rate (HR) is between 130-170 bpm with peak HR reaching 190-200 bpm.[1,12,13] RPE has been reported as ranging from 5-7 au (CR-10)[14,15] and 10-16 (Borg 20-point),[8,10,16] with service games of higher intensities.[8,16] Despite such quantification of the psycho-physiological responses to tournament loads, considerably less is known about the response to common on-court tennis training to prepare athletes for such match-based loads.[4-6]

Of the literature to date, Reid et al.[4] quantified the physiological and performance characteristics of four discrete, hand-fed, tennis drills involving movement and stroke patterns of *Star*, *Box*, *Suicide* and *Big X*. Reid et al.[4] reported external loads through stroke count (0.7-2.3strokes.min^{-1}) and velocity (113-123m/s) as well as distance covered (76-114m) through global positioning system measures (GPS). Internal responses were measured via HR (178-182bpm), lactate (6.7-10.6mmol/L) and RPE (5.0-7.6au).[4] Later, Bekraoui et al.[6] compared the energy cost associated with 6 common tennis movements, performed at both low and high speeds, estimated from oxygen consumption (VO_2). Movements included 2-handed backhand, forehand, sidestep without striking the ball, defensive striking of the ball, and attacking striking of the ball, each performed over full- and half-width court distances (7 and 3.5m). It was established that attacking styles of play increase energy cost by 6.5% compared to defensive styles, 2-handed backhand strokes increase energy cost by 7% than forehands, and striking the ball costs between 8-12% more energy than not striking the ball.[6] Regardless, neither of the abovementioned studies directly informs on-going training load monitoring or prescription - particularly given the small sample size of drill and players. Specifically, the discrete number of drills investigated is too constrained to be related to the vast number of drills used in year round periodised training.[3,4] As such, to offer greater information of the external and internal loads associated with currently prescribed drills to coaches, general classifications - encompassing a range of homogenous drills - might help to inform and guide the prescription of session loads.

Currently, there are a range of measures used to monitor training loads (i.e. GPS, lactate, VO_2), however many are either inappropriate or yet to be validated in tennis.[11,13,16,17] Unfortunately, many of these load measures rely heavily on technology and often lack practicality (i.e, portability to competition).[14] As a consequence, load-monitoring tools, like RPE, that are low cost and practical are desirable. Further, RPE has been extensively demonstrated as a valid and reliable load-monitoring tool in the endurance, team sport and resistance exercise literature.[18-20] At present, tennis load monitoring relies on coach intuition of stroke count and intensity during sessions, highlighting the need for an accurate and easily quantifiable measure, such as RPE. As such, the focus of the present study was to describe the internal and external loads of common on-court drills within broader drill classifications. Specifically, we aimed to describe homogenous on-court drills within common categories for external and internal training loads. Furthermore, a secondary aim was to determine the relationship of a common internal load measure in rating of perceived exertion (RPE)[21] and calculated training load (TL) to other load monitoring tools in tennis. It was hypothesized that the physiological and perceptual demands would increase with increased external load, specifically *Recovery/Defensive* drills, due to more intensive running efforts. Secondly, both RPE and TL were hypothesized to be strongly, positively associated with other load measures including mental-exertion, mean-HR, stroke rate, and error rate.

Methods

Subjects

Fourteen elite-level junior tennis athletes (gender: 8 male, 6 female, age: 15±1.2 y, mass: 60±14.2 kg, height: 167±10.8 cm, Australian junior ranking: 7±4, and ITF junior ranking 91±72) as well as their parents/guardians consented to the present study. Athletes routinely trained 2-3 sessions per day, completing 98±20 matches for the year. This study involved intermittent collection of training loads over a 16-week hard court training period. Training weeks were determined by the absence of tournament match play.

Design

All drills were performed on a Plexicushion tennis court, with each athlete appropriately dressed in training gear and using their own racquets. Athletes completed 21±3 sessions, with a mean on-court duration of 71.8±10.9 min. A total of 259 drills were included for analysis, with a mean duration of 24.6±19.0 mins per drill. Six qualified coaches, with whom the athletes worked, devised the eight drill classifications based on open/closed nature, external influences, and number of athletes (Table 1). Coaches reported 10±3 y elite-level experience, and completion of Australia's highest coaching qualification. The classifications included: *Recovery/Defensive, Open-Pattern, Accuracy, 2-on-1 Open, 2-on-1 Net Play, Closed-Technical, Point-Play,* and *Match Play*. Athletes were familiarised with HR, RPE, mental-exertion, and stroke and error rate measures during a 4-week training block prior to the commencement of data collection. Athletes possessed an intimate prior familiarity with each drill during each session. The University Ethics in Human Research Committee approved this investigation.

Methodology

All sessions were filmed using a video camera (DSR-PDX10P, Sony, Japan) positioned 10-m above and 6-m behind one baseline. The footage was later notated to establish stroke-rate, and unforced errors. Strokes were summated throughout the entire drill involving any time in which the ball struck the racquet face. Errors were distinguished inside the coach-prescribed constraints (if any) of the particular drill, which were clearly described by the assigned coach to both the athlete and the research team. These measures are frequently used for coaching purposes to monitor athlete development during tournaments and training, providing athlete feedback, and monitoring external load. [5,22] A trained analyst (Coefficient of Variation <2%) performed notational analysis using customised software (The Tennis Analyst, V4.05.284, Fair Play, Australia).

Athletes wore individual HR monitors, (Suunto Memory Belts, Suunto Oy, Vantaa, Finland) recording at 1s intervals for each session. HR was downloaded post-session to calculate percentage HR maximum (% HRmax), mean and peak HR for each drill (Suunto Training Manager, Suunto Oy, Vantaa, Finland). Peak HR was established from the highest HR reached during the drill, while mean HR was calculated across the entire drill duration. Due to an inability to perform maximal testing on the subject cohort (a noted experimental limitation), estimated %HRmax was compared between drill categories using the formula 211 - 0.64·age (standard error, 10.8 bpm).[23,24] Athletes provided RPE (Borg CR-10)[21] and mental-exertion evaluations (0-10 Likert scale) for each individual drill immediately post-drill.[25] Drill TL was established post-session through multiplication of RPE and duration, similar to that used for session TL.[14,26] Mental-exertion rating (0-10 Likert scale) was used to establish a holistic rating of mental intensity perceived. Athletes rated based on descriptions of mental demand (i.e. “How much mental and perceptual activity was required?” “Was the task easy or demanding, simple or complex, exacting or forgiving?”).[25] All perceptual ratings were provided privately to ensure no predisposition or bias of perceived internal load. Such internal measures are favoured over other markers (i.e. lactate, VO_2) owing to their practicality and utility.[6,13,16]

Statistical Analysis

External and internal load data were reported as mean±SD, unless otherwise specified. Comparison of external and internal load differences between categories was undertaken by repeated measures two-way (category x load measure) ANOVAs with Tukey HSD post-hoc tests to locate differences. Statistical significance was set at $p<0.05$. Within-individual correlations of drill RPE and TL with other variables (mental-exertion, mean-HR, stroke and error-rate) were analysed using Pearson’s correlation coefficients. As gender was mixed, and age varied within the cohort, within-individual statistical procedures were used to alleviate any potential gender or age bias. The following criteria were adopted to interpret the magnitude of the correlations: <0 poor, 0-0.2 slight, 0.21-0.4 fair, 0.41-0.6 moderate, 0.61-0.8 substantial and 0.81-1 almost perfect agreement.[27] All analysis was conducted using PASW statistic software package (PASW, Version 17, Chicago, USA).

Results

Table 2 shows stroke and error rate measures for each drill classification. Stroke-rates of *Recovery/Defensive, Open-Pattern, Accuracy,* and *2-on-1 Open* drills were all significantly greater than during *Match Play* ($p<0.05$). Further, *Open-Pattern* drills had significantly greater stroke-rates than *Point-Play* ($p<0.05$). Error-rates of *Closed-Technical* drills were significantly higher than *Open-Pattern*, *2-on-1 Open*, *2-on-1 Net Play*, *Point-Play,* and *Match Play* ($p<0.05$).

*** Table 2 near here ***

Internal load measures are reported in Table 3. RPE was significantly greater in *Recovery/Defensive*, *Open-Pattern* drills, and *Point-Play* than *Closed-Technical* drills ($p<0.05$). Similarly, mental-exertion was significantly greater in *Recovery/Defensive*, *Open-Pattern* drills and *Point-Play*, as well as *Accuracy* drills and *Match Play* than *Closed-Technical* drills ($p<0.05$). No differences were observed in %HRmax, peak or mean HR between respective categories ($p>0.05$).

*** Table 3 near here ***

Mean±SD of within-individual correlations comparing drill RPE and TL to mental-exertion, mean-HR, stroke and error-rate are presented in Table 4. Analyses revealed substantial relationships (p<0.05) between drill RPE and mental-exertion for *Open-Pattern, 2-on-1 Open, 2-on-1 Net Play, Closed-Technical* drills, and *Match Play* (r>0.61). Substantial correlations were also found with TL and mental-exertion for *Recovery/Defensive* and *2-on-1 Net Play* (r>0.61). A substantial correlation was also displayed between mean HR and RPE in *Open-Pattern* (r=0.62), yet generally in slight to fair agreement with RPE and TL for all other drill categories (r<0.40). Total stroke count was substantially correlated to TL for *Recovery/Defensive, Accuracy, 2-on-1 Open drills,* and *Point-Play* (r>0.65). However, total stroke count and stroke rate for all categories were only slightly to moderately correlated with RPE (r<0.49). Finally, slight to moderate associations were evident between both drill RPE and TL, and error rate (r<0.51).

*** Table 4 near here ***

Discussion

Careful organisation and periodisation of training is an important consideration for coaches, as both physical and technical needs change with athlete development and throughout competitive schedules. Therefore, the aim of the present investigation was to describe the external and internal loads associated with a range of drills that fitted homogeneously within eight, coach deduced, categories deemed common to elite junior tennis environments. Critically, there were apparent trends for open, end range type drills to be characterised by greatest RPE, HR and stroke-rates. Accuracy and defensive drills were otherwise perceived to elicit the greatest mental intensity, whilst technical and defensive drills induced the greatest error-rates and open, 2-on-1 and pattern drills were ideal for error-amelioration practice. Specifically, established from mean drill rankings, *Recovery/Defensive* drills were punctuated by the highest internal load (RPE, mental-exertion and HR), *Open-Pattern* drills recorded elevated RPE, *and Accuracy* drills demanded the greatest mental-exertion. Physiologically, *Recovery/Defensive* and *Open-Pattern* drills induced the greatest %HRmax, while *Point-Play* and *2-on-1 Open* drills showed the uppermost peak and mean-HR respectively. Analysis of stroke-rate revealed *Open-Pattern* and *Recovery/Defensive* drills to elicit the largest number of strokes. Technical outcomes (error-rate) were poorest in *Closed-Technical* and *Recovery/Defensive* drills and best throughout *2-on-1 Net-Play* and *Match Play*. A secondary aim was to determine the relationship of drill RPE and TL with other training load monitoring variables. Correlations across each drill category revealed strong relationships between drill RPE and mental-exertion. Furthermore, drill TL was positively correlated with total strokes, but negatively correlated with stroke-rate. Finally, mean HR and error-rate were only characterised by slight-moderate associations with both drill RPE and TL.

Open-Pattern drills were punctuated by significantly higher stroke-rates (1.2 ± 0.8strokes·6sec^{-1}) than *Closed-Technical* drills, *Point-Play*, and *Match Play* (0.4 ± 0.2strokes·6sec^{-1}). Further, *Recovery/Defensive, 2-on-1 Open,* and *Accuracy* drills were significantly greater than *Match Play* (p<0.05). Previously, Reid et al.[4] described the stroke-count of 4 hand-fed drills over 30 and 60 s. After adjusting the 60 s stroke-counts to reflect our data (6 s periods as per mean point duration in matches), two of the drills (*Star* and *Box*) presented much higher stroke rates than any drill categories in this study. *Star* (2.0strokes·6sec^{-1}) and *Box* (2.3strokes·6sec^{-1}) drills were characterised by considerably higher stroke-rates than any current category.[4] The discrete, hand-fed, nature of these drills (1 set/6 repetitions) combined with high metabolic demand, suggest *Star* and *Box* drills may not be sustainable if comprising the bulk of a 90-120 min session.[4] However, *Suicide* (0.7strokes·6sec^{-1}) and *Big X* (0.8strokes·6sec^{-1}) drills were comparable to *2-on-1 Open, Closed-Technical* drills and *Point-Play*. Moreover, it appears that drill stroke-rates during *Point-Play* and *Match Play* are generally below that of stroke-rates reported from tournament data. Previous tournament play stroke-rates have been reported as 2.7 strokes/rally (7.5 sec),[10] through to 4.7 strokes/rally (6.7 sec).[11] Therefore, stroke frequency during drills aimed at skill development is below that considered optimal to simulate tournament intensity. Although, it should be acknowledged that drills designed to achieve technical outcomes are usually not completed at tournament intensity. In any case, the current data show that whilst below tournament intensity, stroke-rate was greatest within *Open-Pattern* drills, making these drills ideal for instilling "match-like" stroke frequencies into training.

Currently there is limited literature reporting the error-rates associated with tennis tournaments and training. Pieper et al.[2] analysed seven hard-court men's singles matches of ATP players ranked 1-63. Percentile error ratios described low, medium and high time pressure situations on hard-courts with respective error-rates of 13.7, 21.0 and 26.4% on the forehand with 13.5, 16.8 and 25.6% on the backhand.[2] Reid et al.[5] reported the error-rates of four 2-on-1 tennis drills on both hard and clay-courts. The error-rates reportedly increased through drills one to four from 10.6 ± 6.1% (hard-court) for basic 2-on-1 rally patterns, through to 23.9±11.8% (hard-court) as movement intensity and drill difficulty increased.[5] In contrast, our data suggests *Closed-Technical* drills (19.2±11.1%), which were the least physically demanding (low stroke-rates), produced the greatest error-rates. This is likely due to technical adjustments and changes in stroke mechanics during these drills, whereby errors are tolerated in the optimisation of technical outcomes. However, the higher intensity *Recovery/Defensive* drills (17.3±6.5%) also comprised of high error-rates, likely due to the heightened physical load. Coaches should take caution in prescribing drills of increased physical intensity when the session focus is to alter stroke mechanics or specific movement patterns, as excessive loads may affect stoke performance. Further, during rally-based drills, where the intensity is high, increased error-rates may alter the duration of continued exertion of effort, resulting in reductions to the physical demands of sessions. Contrastingly, *2-on-1 Net Play* drills (11.8±3.4%) provided the lowest error-rates making them ideal for error-amelioration practice.

Internal load measures determined from drill RPE were highest for *Recovery/Defensive* drills (6.5±1.8au), followed by *Open-Pattern* drills and *Point-Play*. *Recovery/Defensive, Open-Pattern* drills and *Point-Play* were each perceived to be significantly harder than *Closed-Technical* drills (4.6±1.9au). Similar to external load measures related to stroke-rate, there is limited literature describing the internal loads associated with tennis training.[4,6] As aforementioned, Reid et al.[4], post-drill RPE (6 reps/60 sec) of the *Star* drill (5.8±1.2au) were of similar intensity to *Accuracy, 2-on-1 Net Play* drills, *Point-Play* and *Match Play*. Furthermore, Reid et al.[4] report the *Box* drill (5.0±1.5au) to be of lower intensity, resembling *Closed-Technical* drills. Meanwhile, *Suicide* (7.6±1.1au) and *Big X* (7.6±1.0au) drills were of intensities higher than any category documented currently. Case studies have previously reported Tournament RPE's of 5–8au for elite athletes (ranking<120 ATP).[14,15] As such, these data suggest that the intensity of the present training categories, including *Match Play*, may not compare favorably to the intensity of tough matches for aspiring professional athletes, despite obvious age and expertise differences. The current relationships between external load and RPE are not as strong as previous literature in other sports, most likely due to the maturity of the present cohort, and a lack of understanding or ability to associate drill intensity with external stimuli despite persistent familiarization.[28,29] Conversely, it could be argued that the current internal and external load markers differ from that of previous studies and are of different sporting cohorts. Nevertheless, there is a need to monitor loads in such immature subject cohorts in tennis due to early specialization, but how valid these measures are is unknown.

As tennis involves precise movements, with multiple short bursts over long periods, the mental skills required from athletes (i.e. concentration, anxiety and arousal management) should not be overlooked. Currently, no quantitative literature exists on the mental-exertion perceived by tennis athletes during training or tournaments. However, somewhat predictably, *Accuracy* (6.6±1.1au) drills recorded the greatest mental-exertion followed by high-pressure drills (i.e, *Recovery/Defensive* drills, 6.5±1.2au) and open, match-like situations (i.e., *Match Play*, 6.4±1.5au; *Open-Pattern* drills, 6.3±1.6au; and *Point-Play*, 6.0±1.3au). Each of the abovementioned drills was of significantly greater mental demand than *Closed-Technical* drills (4.8±1.8au), which involved closed-skill focus. Seemingly, when considering load for session design, *Recovery/Defensive* drills appear to most closely reproduce physical and mental intensities typical of tournaments.[14,15] Similarly, *Open-Pattern* drills can induce sizeable physical exertion, whilst a by-product of *Accuracy* drills might be mental skill development.

Despite significant perceptual differences between drill categories, there were no significant differences in any heart rate measure (%HRmax, peak or mean HR) between any of the categories. Categories inducing the greatest absolute peak-HR and relative (%HRmax) were *Point-Play* (181±11bpm; 87±9%), *Recovery/Defensive* drills (181±13bpm; 90±9%), and *Open-Pattern* (176 ± 21bpm; 89±6%), with *Closed-Technical* drills (171±13bpm; 86±8%) producing the lowest peak-HR – consistent with the trends observed for RPE and mental-exertion. Mean-HR however, were greatest in *2-on-1 Open* (154±16bpm) and *Recovery/Defensive* drills (154±18bpm), whilst lowest during *Match Play* (143±16bpm). Previously, Reid et al.[4] report similar HR's (160-180bpm) to the present study. Bekraoui et al.[6] report HR following 4 min of activity to be of a much larger range (150-182bpm). However, each of the present drill categories is comparable to the peak-HR reported during drills conducted at high speeds.[6] Meanwhile, mean HR's during tournaments reportedly range from 140-160bpm.[13] The present data represent physiological demands comparable to these tournament ranges; albeit towards the lower end. Surprisingly, *Match Play* in training induced the lowest %HRmax and mean-HR, again indicating that the physiological demands of training-based tournament preparation is insufficient. However, *Point-Play, 2-on-1 Open* and *Recovery/Defensive* drills elicited the greatest absolute peak and mean-HR values that are comparable to tournament-like demands. This is most likely due to the increased intensity and pressure associated with the open-play nature of these drills. Conversely, drills that could be prescribed for reduced physiological load are closed, technical and target-hitting drills. Prescription of these drills could be used during de-loading cycles, tapers, or within sessions designed to reduce cardiovascular strain.

A unique finding from this study is the substantial within-individual correlations between both drill RPE and TL with other measures of internal and external load in tennis (i.e., mental-exertion and stroke rates). Previously, Lovell et al.[30] used within-individual correlations to demonstrate strong relationships between session RPE and TL respectively, with speed, body load, and HR, ultimately suggesting a multifactorial approach to load monitoring. Previously, no literature has compared the RPE (intensity) or TL (volume) of tennis drills to load variables. Current data suggests that mental-exertion is related closely to the perceived intensity of drills (i.e., substantial correlations with RPE). Interestingly however, the two categories of greatest mental-exertion (*Accuracy* and *Recovery/Defensive* drills) were only slightly-moderately correlated with RPE. While, *Recovery/Defensive* drills were substantially correlated with drill-TL. Therefore, it can be inferred that athlete perception of mental exertion in affected by drill duration. Meanwhile, both stroke-count and rate were only slightly-moderately correlated with RPE. However, analysis revealed that drill duration (i.e., as a basis of TL) interacts substantially and positively with total stroke volume, yet negatively with stroke rate. Consequently, drill duration plays a larger role in stroke-specific external load than intensity (i.e., stroke rate); though and as would be expected, stroke rate is negatively affected as drill duration increases. Therefore, such data suggests that for tennis drills strong interactions exist between drill duration and load.

Error-rates were slightly-moderately correlated to RPE and TL for all categories. Intriguingly, one of the largest correlations for error-rate with RPE and TL was *Closed-Technical* drills, suggesting that in “closed” drills, stroke production and execution likely contribute to the perception of intensity. Finally, in contrast to previous studies, only slight-moderate correlations were observed for RPE and TL with mean-HR.[18,30] The slight-moderate associations were evident for all drill categories except for *Open-Pattern* drills - a category of high RPE. Collectively, these observations - similar to Lovell et al.,[30] - indicate that poor relationships of RPE and TL with HR, stroke and error rate in the current study, reaffirming that a multitude of variables contribute to variation in perceived load in tennis training.

Practical Applications

Due to the limited training time in elite junior tennis development, appropriately integrated training session design is vital. As such, informed drill and session prescription of internal and external loads are critical. Whilst previous tennis studies have provided selected quantitative data on the internal and external loads of discrete drills,[4,6] a larger, catalogued description of drills provides greater applicability to session design and implementation across all tennis environments. A ranking summary of categories (highest-lowest) for each load variable is reported (Table 5) to assist in the prescription of external and internal load for tennis training. Results highlight open, recovery drills as being greatest for RPE, HR and stroke-rates, whilst target-hitting, defensive drills place athletes under highest mental pressure. Technical and high time-pressure (defensive) drills induced the greatest error-rates. Open, 2-on-1 and pattern drills tended to encourage lower error-rates, making them ideal for high-repetition practice. Furthermore, we have provided a holistic ranking of drill categories for physiological intensity based on internal load and stroke rates, and technical development ranking based on drill stroke rate and error rates. As the use of load monitoring is becoming more common within elite tennis environments, the present descriptive analysis can be used as a tool for prescribing load-appropriate training drills within a periodised development plan.

*** Table 5 near here ***

Conclusions

The current tennis investigation has developed a hierarchy of drill categories considering RPE, mental-exertion, %HRmax, peak and mean-HR, stroke and error-rate. Results indicate that categories were of insufficient load to replicate those previously reported during mean or maximal components of tournaments. Regardless, stroke-rate analysis revealed *Open-Pattern* and *Recovery/Defensive* drills to be of greatest external load, while *Point-Play* and *Match Play* recorded the lowest. Technical performance (error-rate) was poorest in *Closed-Technical* and *Recovery/Defensive* drills and best throughout *2-on-1 Net-Play* and *Match Play*. Furthermore, *Recovery/Defensive* drills were characterized by high internal load (RPE, mental-exertion and HR), while *Open-Pattern* drills recorded high RPE. Whereas, *2-on-1 Open* and *Closed-Technical* drills were perceived contrarily. *2-on-1 Open* and *Closed-Technical* drills elicited the lowest mental-exertion, while *Accuracy* drills required the greatest. Physiologically, *Recovery/Defensive* and *Open-Pattern* drills were of highest %HRmax, while *Point-Play* and *2-on-1 Open* drills presented greatest peak and mean-HR respectively. Contrastingly, *Closed-Technical* and *Match Play* presented with the poorest %HRmax, peak and mean-HR. Substantial correlations were observed for drill RPE and TL with mental-exertion. Further substantial relationships were found between TL and total-strokes. Such information enables trainers and coaches to develop evidence-based training sessions using quantifiable insights into the most commonly used drill categories. Drill prescription can therefore be tailored to target on-court preparation specific to the physiological, psychological and technical needs of elite tennis athletes.

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