Full Title: Differentiating stroke and movement accelerometery profiles to improve prescription of tennis training drills

Abstract

This study compared the movement- and stroke-related accelerometer profiles and stroke counts between common on-court tennis training drills. Ten junior-elite male tennis players wore a cervical-mounted GPS, with in-built accelerometer, gyroscope and magnetometer during hard court training sessions (n=189). Individual training drills were classified into eight categories based on previous research descriptions. Manufacturer software calculated total Player Load (tPL), whilst a prototype algorithm detected forehand (FH), backhands (BH) and serves, and then calculated a stroke player load (sPL) from individual strokes. Movement player load (mPL) was calculated as the difference between tPL and sPL. Drill categories were compared for relative ($\cdot min^{-1}$) tPL, sPL, mPL and stroke counts via a one-way ANOVA with effect sizes (Cohen's *d*) and 95% confidence intervals. Highest tPL$\cdot$min^{-1} existed in Accuracy and Recovery/Defensive drills ($p<0.05$), with lowest tPL$\cdot$min^{-1} values observed in Match-Play simulation ($p<0.05$). For sPL$\cdot$min^{-1}, Accuracy drills elicited greater values compared to all other drill types ($p<0.05$), partly via greater FH-sPL$\cdot$min^{-1} ($p<0.05$), with lowest sPL$\cdot$min^{-1} existing for Match-Play ($p<0.05$). Accuracy, Open and Recovery/Defensive drills result in greater BH-sPL$\cdot$min^{-1} and BH$\cdot$min^{-1} ($p<0.05$). Serve-sPL$\cdot$min^{-1} is highest in Technical and Match-Play drills ($p<0.05$). Higher mPL$\cdot$min^{-1} existed in Accuracy, Recovery/Defensive, 2v1 Net, Open, and 2v1 Baseline ($p<0.05$). Further, mPL$\cdot$min^{-1} in Points drills were greater than Technical and Match-Play simulation drills ($p<0.05$). Higher hitting-based accelerometer loads (sPL$\cdot$min^{-1}) exist in Accuracy drills, whilst Technical and Match-Play drills show the lowest movement demands (mPL$\cdot$min^{-1}). These findings can aid individual drill prescription for targeting movement or hitting load.

Key Words: athlete monitoring, wearable technology, physical demands

INTRODUCTION

Preparation for tennis competition often occurs during interspersed training blocks, whereby players develop their collective physical, technical and tactical skills through coach-prescribed on-court tennis drills (32). Appropriate drill prescription during training is critical for tennis players given the dominance of tournament match-play within the annual calendar (34). Current evidence to guide training prescription describe the physiological and perceptual demands of different on-court drills, with higher perceptual (exertion) and physiological (blood lactate, heart rate) responses in drills with greater movement requirements (i.e., distance covered, movement speed) (3, 26, 32). However, such research fails to provide insights on the accompanying stroke demands for technical and point-play development, which make up the dominant training focus prescribed by coaches (25). For example, Murphy, Duffield, Kellett and Reid (26) highlight that closed-technical drills are popular for skill development, though the stroke counts used to quantify training load did not differentiate hitting demands between drills with greater physical exertion. Accordingly, further insights are required from concurrent hitting and movement activities during on-court drills to better guide training prescription and training load monitoring.

As an example of the limited insights available on tennis drill demands, Reid et al. (32) reported the movement demands of four typical tennis drills via global positioning systems (GPS). "Suicide" drills that required players to alternate movements to the forehand and backhand corners elicited greater distance covered and movement speed compared to drills focusing on more central court positions (32). Whilst hitting volumes did not differ between drill type, reductions in ball speed and stroke accuracy were observed in drills with greater movement loads (i.e., "Suicide" drills) (32). However, this study required laborious manual coding from video footage to determine hitting demands, which is impractical to rely upon in tennis's daily training environment. The later work of Murphy et al. (26) expanded on reports of specific drill types by identifying that stroke rates (per 6 s) were higher during "Open-pattern" drills compared to drills focused on technique development or point-play. Further, drills requiring pre-determined tactical patterns show similar stroke rates to drills with repeated hitting at on-court targets and drills with altered defensive court positions (26). Hence, current measures of absolute and relative hitting volumes do not distinguish the demands between common on-court drills used for discrete training practices, warranting further investigations of concurrent moving and hitting.

Commercially available GPS units, consisting of in-built accelerometer, gyroscope and magnetometer devices are used in court-based sports to profile acceleration demands as well as sport-specific event detection (7). However, current reporting of whole-body acceleration metrics are unsuitable to capture the high-acceleration trunk rotations separate to running actions that contribute to hitting loads (31). Emerging research in other racket sports (i.e., badminton) have demonstrated a multi-sensor approach to distinguish upper and lower limb actions during technical drills (22). Specifically, drills focused on serving actions resulted in highest acceleration loads at the racket arm, with greater acceleration magnitudes at the lower leg during net-play drills (22). However, the requirement of multiple sensors to ascertain these loads is impractical for tennis. Given the lack of wearable technology in tennis, establishing the stroke and movement loads from a single device would allow more detailed reporting and prescription of training drills for physical and technical development. Recently, developments in stroke detection algorithms for forehands, backhands and serves have been developed from cervical-mounted wearable units (White Paper, Catapult Sports), which suggests potential for a segregated approach to quantify concurrent hitting and movement acceleration loads from a single sensor. Thus, the aim of this study was to describe and compare the movement- and stroke-related accelerometer profiles and stroke count metrics between typical tennis training drills.

METHODS

Experimental Approach to the Problem

An observational study design captured respective movement and hitting accelerometer loads measured from a commercial wearable sensor during hard court tennis trainings in a group of junior-elite male tennis players. A prototype algorithm, developed from the wearable sensor's accelerometer, gyroscope and magnetometer outputs, was used to classify tennis stroke events with accuracies from 84-99% and consequently determined stroke-specific player load (i.e., sPL). Movement demands (i.e., mPL) were inferred from the difference between traditional player load and the sPL metric. Training drills were classified from tennis coaches using previously published methods (26), and analysed for their influence on respective sPL, mPL and stroke count metrics.

Subjects

Ten junior-elite male tennis players (age 15.4 ±1.3 y) were recruited for this study and were part of Tennis Australia's National Academy program. All training and competition activities complied with Tennis Australia guidelines, including; 1) ≈20 h of on-court training per week, 2) ≈6 h off-court training per week and 3) competing in regular International Tennis Federation (ITF) sanctioned junior tournaments. All players were right-handed and utilised and a double-handed backhand. Nine athletes were aged under the age of 18 and required parental consent to participate in the present study, with one athlete aged 18 able to provide their own consent. The university Human Research Ethics Committee (HREC) gave ethical approval for the methods used in this study (ETH19-4062).

Procedures

Data was collected across designated training periods spanning from late 2019 to early 2020. All group and individual training sessions that were delivered by the high-performance coaches within the National Academy program were monitored. The coaches in this study held high-performance coaching certificates from Tennis Australia and had combined playing and coaching careers spanning >10 years. Training drills within each session were devised by the coaches without influence from the researchers, though the training sessions were clearly explained to the investigator. Individual drills were categorised into broader categories adapted from those reported by Murphy, Duffield, Kellett and Reid (26) (Table 1). All training sessions were conducted on outdoor hard courts (or indoor hard courts if raining). A total of 189 observations were obtained, resulting in at least two observations per drill per player.

*****TABLE 1 NEAR HERE*****

All players wore a global positioning system (GPS) unit (Catapult OptimEye S5, Catapult Sports, Melbourne) and were housed in the manufacturer-designed harnesses. The GPS unit sampled at 10 Hz with an in-built triaxial accelerometer sampling at 100 Hz, though in this study only the accelerometer data, by way of Player load (PL), were analysed. PL is defined as the square root of the sum of instantaneous accelerations in the medio-lateral (x), vertical (z) and antero-posterior (y) planes and is presented in arbitrary units (AU). Reliability of the PL metric has previously been established at 1.9% coefficient of variation (CV) from observations in team sport athletes (4). Specifically for tennis, measured PL·min^{-1} may vary by 0.35 AU·min^{-1} between devices during simulated tennis match-play, with random error determined by limits of agreement (LOA) ranging between 2.12 and -1.42 AU·min^{-1} (14). To identify the start and end times for all drills, training sessions were video recorded using Sony video cameras (HDR-CX700VE, Sony, Japan) and positioned 10 m and 6 m behind the baseline in accordance with previous training protocols (26, 29).

Raw accelerometer data was downloaded to calculate PL via the manufacturer's software (OpenField 2.3.4, Catapult Sports, Melbourne), though, it is noted that varied methods of the PL calculation have been previously reported (5). This process enabled the calculation of a traditional generic PL, as has previously been described (2), herein defined as total PL (tPL). In addition to this metric, the raw accelerometer data was exported and stored as a comma-separated values (.csv) file to be further analysed to discern the PL specific to stroke actions. Investigations from Catapult Sports (Catapult Sports, Melbourne) on a prototype algorithm documented in an internal "white paper" describes the machine learning models implemented to detect 'forehand' (FH), 'backhand' (BH), 'serve' and 'other stroke' events based on absolute rotation yaw values and showed respective accuracies of 94%, 96.5%, 99.9% and 83.5% (Personal Communication, Catapult Sports). We have previously tested these findings, revealing respective accuracies of 89%, 94% and 98% for 'forehand', 'backhand' and 'serve' swings. This validation work was performed via manual coding of individual stroke events during tennis match-play and comparing to the output of the manufacturer's prototype algorithm. Following stroke detection and ensuing count, the manufacturer's prototype algorithm is trained over a one-second window (i.e., 0.5 s before and after event detection) to quantify the sum of accelerations (i.e., PL) and is classified in the present study as stroke PL (sPL). Hence, determination of sPL allowed for separation of movement-based PL (mPL) by subtracting sPL from tPL determined from the manufacturer software.

The processed file from Catapult Sports contained the coordinated universal time (UTC) of each stroke event, which was used in combination with the video footage to time align the start and end times of each drill on the manufacturer software. This ensured data captured are reflective of those experienced within a given drill inclusive of within-drill rest time (but not between-drill recovery). Accordingly, all movement and stroke activities captured during specified drill-times were included for analysis. Using this dataset, stroke counts and respective PL metrics across the four categories (forehand, backhand, serve and other) were quantified for each drill. All metrics were reported in relative (per minute [$AU·min^{-1}$, $n·min^{-1}$]) terms across drills to account for different drill durations. Additionally, the sPL associated with respective strokes was classified in relative terms as described above for each stroke type (i.e., FH, BH, serve). The “other stroke” category was not reported for sPL measures or count data given its lack of specificity to stroke type, and therefore limited application to drill prescription.

Statistical Analyses

All statistical analysis was performed in the R language (RStudio, 1.1.463, RStudio, Inc.). Descriptive statistics of the mean and standard deviation were used for PL and stroke count variables in all drill types. Normality of data was first assessed via Shapiro-Wilk’s test and due to non-uniformity of independent variables (i.e., PL and stroke count), data were log-transformed. To compare drills for accelerometer load metrics and stroke counts, a one-way analysis of variance (ANOVA) was used, with follow-up Tukey’s post-hoc tests. Significance level was set at 0.05, with Bonferroni’s correction used to minimise effect of Type II errors. Effect size (ES) was calculated using Cohen’s d statistic with $d < 0.2$ classified as trivial, d = 0.2-0.5 small, d = 0.5-0.8 medium, and $d > 0.8$ large, with 95% confidence intervals (CI).

RESULTS

Table 2 shows the relative (·min^{-1}) tPL, mPL and sPL metrics ranked by largest to smallest values for each drill category. Accuracy and Recovery/Defensive drills show significantly higher tPL·min^{-1} compared to 2v1 Net, 2v1 Baseline, Points, Technical and Match-Play drills (p<0.05, d=0.55-2.78[0.11-3.49]). Further, tPL·min^{-1} in Open, 2v1 Net and 2v1 Baseline drills were significantly higher than Points, Technical and Match-Play drills (p<0.05, d=0.83-2.12[0.50-2.69). Points drills showed significantly greater tPL·min^{-1} compared to Match-Play simulation (p=0.01, d=0.73[0.37-1.08]). The highest sPL·min^{-1} values are observed in Accuracy drills compared to all other drill types (p<0.05, d=0.67[0.24-3.04]; Table 2). Recovery/Defensive and Open drills showed significantly greater sPL·min^{-1} compared to 2v1 Net, Points, Technical and Match-Play drills (p<0.05, d=0.51-1.50[0.20-2.00]), with 2v1 Baseline drills significantly greater than 2v1 Net, Points and Match-Play drills (p<0.05). Lastly, sPL·min^{-1} in Technical was significantly lower than observations during Match-Play drills (p<0.01, d=0.95[0.49-1.40]). Table 2 further shows significantly higher mPL·min^{-1} values in Accuracy, Recovery/Defensive, 2v1 Net, Open and 2v1 Baseline compared to Points, Technical and Match-Play drills (p<0.05, d=0.93-2.77[0.59-3.48]). Points drills revealed significantly greater mPL·min^{-1} compared to Technical and Match-Play drills (p<0.05, d=0.43-0.53[0.15-0.87]).

*****TABLE 2 NEAR HERE*****

Table 3 shows the relative (·min^{-1}) sPL and count data for respective stroke categories (forehand, backhand and serve) ranked by highest to lowest values for drill type. Forehand data revealed Accuracy drills produce the significantly highest FH-sPL·min^{-1} values compared to all other drill types (p<0.05, d=0.43[0.02-1.93]). Recovery/Defensive, 2v1 Baseline and Open drills demonstrated the next largest FH-sPL$\cdot$min^{-1} values and were significant compared to 2v1 Net, Points, Technical and Match-Play drills (p<0.05, d=0.66-1.50[0.38-1.99]). In turn, 2v1 Net drills were only significant to Match-Play, with greater FH-sPL$\cdot$min^{-1} (p=0.01, d=0.73[0.33-1.11]). Relative forehand count (i.e., FH$\cdot$min^{-1}) were significantly higher in Accuracy and Recovery/Defensive drills compared to Open, 2v1 Net, Points, Technical and Match-Play drills (p<0.05, d=0.33-1.66[0.05-2.24). Further, FH$\cdot$min^{-1} in 2v1 Baseline and Open drills were significantly greater than 2v1 Net, Technical, Points and Match-Play drills (p<0.05, d=0.44-3.27[0.16-4.02]). Additionally, 2v1 Net and Points drills showed significantly greater FH$\cdot$min^{-1} compared to Match-Play (and p<0.01 d=0.91[0.51-1.31] and p=0.04, d=0.1.06[0.66-1.45], respectively). Accuracy drills involved greater BH-sPL$\cdot$min^{-1} compared with 2v1 Baseline, 2v1 Net, Points, Technical and Match-Play drills (p<0.05, d=0.49-0.98[0.06-1.48]). Open and Recovery/Defensive drills were also significantly greater for BH-sPL$\cdot$min^{-1} compared to 2v1 Net, Points, Technical and Match-Play drills (p<0.05, d=0.44-1.06[0.12-1.45]). Additionally, for BH-sPL$\cdot$min^{-1}, 2v1 Baseline and Points were significantly greater than Technical drills (p=0.01, d=0.68[0.27-1.08] and p=0.03, d=0.50[0.22-0.78], respectively). Accuracy, Open and Recovery/Defensive drills produced significantly larger BH$\cdot$min^{-1} values compared to 2v1 Net, Points, Technical and Match-Play drills (p<0.05, d=0.39-1.06[0.07-1.56]), with 2v1 Baseline drills showing significantly greater values to Points, Technical and Match-Play (p<0.05, d=0.59-1.22[0.28-1.69]). Further, BH$\cdot$min^{-1} during Points drills were significantly higher than observations in Technical drills (p=0.02, d=0.52[0.24-0.80]). Serve s-PL$\cdot$min^{-1} values were significantly higher in Technical and Match-Play drills compared to all other drill categories (p<0.05, d=0.77-4.29[0.31-5.21]), with Accuracy and Points drills producing significantly larger Serve-sPL$\cdot$min^{-1} compared to Recovery/Defensive, 2v1 Baseline, Open and 2v1 Net drills (p<0.05, d=0.53-0.83[0.13-1.16]). Finally, Technical drills produce significantly larger Serve$\cdot$min^{-1} compared with all other drill categories ($p<0.05$, $d=0.71[0.27\text{-}1,76]$), with 2v1 Net, Recovery/Defensive, Open and 2v1 Baseline drills showing significantly lower Serve·min^{-1} compared to all other drill types.

*****TABLE 3 NEAR HERE*****

DISCUSSION

This study compared the hitting and movement accelerometery from a single wearable sensor between common on-court training drills. The findings show greater hitting demands (i.e., sPL·min^{-1}) during highly situational or rally-based drills (Open, 2v1 Baseline and Recovery/Defensive) compared with those focused on technical outcomes or point-play. The novel sPL metrics in the present study also revealed that Accuracy drills had the highest hitting loads across all drill types. These insights from the use of a single wearable microsensor offer tennis coaching staff a more specific understanding of the game's movement and hitting demands to better plan on-court training.

Accelerometery measures have enabled court-based sports to quantify movement demands in arguably more suitable ways than previous attempts with GPS technology (9, 36). Our observations of tPL·min^{-1} show overall accelerometer responses to be highest during Accuracy and Recovery/Defensive drills. As this is the first study to report such measures in these drills, direct comparisons to other research are difficult. However, drills that involve greater court coverage culminating with high-speed stroke actions (i.e., "Recovery/Defensive") have shown higher levels of physiological stress (i.e., blood lactate) (32), and are consistent with the high demands inferred from tPL·min^{-1} in this study. Conversely, drills that emphasised technical refinement or point-play had less intensive activity profiles as characterised by lower measures of tPL·min^{-1}. This is likely attributable to more stationary stroke actions occurring during technical drills (30), which may also feature extensive coaching feedback and discussion time. Further, the time taken for players to collect their own balls and the changing of ends could explain these findings for match-play simulations. Alternatively, it is also possible that the duration of individual points during match-play drills are longer than official matches.

A novel aspect of the current study was the application of a prototype algorithm to quantify stroke-specific player load (i.e., sPL) and stroke counts. This represents an important step for tennis in capturing hitting loads, which have historically existed as either simple stroke counts or complex biomechanical analysis of the upper limb and trunk (10, 35). The present approach to quantifying tennis hitting load revealed an unexpected finding, where highest sPL·min^{-1} was observed in Accuracy drills. This contrasts with previous literature that has outlined stroke rates within Accuracy drills were similar to all drills, other than match-play simulations (26). These findings may infer that the repeated hitting actions that feature in Accuracy drills result in higher sPL·min^{-1}, and pose greater mechanical stress to the upper limb and trunk than previously reported via interpretation of hitting volume (26). Interestingly, the higher sPL·min^{-1} during Accuracy drills may relate to the increased FH-sPL·min^{-1} and stroke counts (i.e., FH·min^{-1}), highlighting forehand-dominant patterns of play. Indeed, drills involving forehand play-patterns (i.e., “inside-out” drills) have been previously characterised by increased physiological loads and blood lactate levels (3). Practically speaking, this could represent a specific training focus for aspiring players to build a physical tolerance towards forehand-specific hitting loads (i.e., FH-sPL) given they contribute the most strokes (≈44%) in typical junior-elite tennis rallies (18).

As expected, increased hitting demands (i.e., sPL·min^{-1}) featured in the Recovery/Defensive drills compared to Technical drills. This is likely reflective of the high lateral and vertical ground reaction forces and hip joint loading when executing “defensive” shots (23), like those in Recovery/Defensive drills. Interestingly, previous research has revealed comparable stroke rates (i.e., shot frequency) in Recovery/Defensive and Technical drills (26), though our findings suggest differences in stroke intensity (i.e., sPL·min^{-1}). As such, on-court drill prescription by tennis coaches may have been limited given stroke count metrics lack information on the intensity of upper extremity and trunk actions during stroke execution. For example, while prescribing drills of ≥7 strokes/rally elicits higher perceived effort than hitting volumes of ≤4 strokes/rally (17), this may reflect the influence of locomotor (lower-body) rather than hitting (upper-body) demands (3). Hence, the use of PL measures may assist in clarifying the assessment of intensity and imposed mechanical stresses on the upper limb and trunk such that practitioners can better monitor athlete health (1).

Given the importance but also injurious profile of the serve, monitoring serve actions is useful for ensuring appropriate training exposures (27). These exposures are elevated in Technical drills, as characterised by higher Serve-sPL·min^{-1} and Serve·min^{-1}, where the serve’s closed nature and coordinative complexity are catered for (19). The observation from previous work that these drills are often performed in ‘blocked’ fashion, and for concentrated periods of time (6, 11), likely explains the increased Serve-sPL·min^{-1} and Serve·min^{-1} that characterised the Technical drills. The is likely the result of coaches attempting to achieve high volumes of serves to mimic the demands of match-play, which for junior-elite players have been reported at 120 serves/match (27). Indeed, with serve practice in mind, Points drills feature lower Serve-sPL·min^{-1} and Serve·min^{-1} than Match-Play and could become more representative with the inclusion of additional serving (21).

Suggestions that upper and lower body load may be broadly inferred through the sPL and mPL metrics appear to be supported by the finding that mPL·min^{-1} was consistently higher in drills focused on pre-defined patterns of stroke-play. Reid, Duffield, Dawson, Baker and Crespo (32) reported that drills challenging court position (i.e., Recovery/Defensive drill category) require players to traverse greater distance at higher speeds, though our study did not dissect movement demands in more detail. Interestingly, we observed similar mPL·min^{-1} for Recovery/Defensive, Open and 2v1 Baseline drills, which likely points to comparable acceleration/deceleration and changes of direction demands. Where previous technologies may not have adequately captured the relatively low-speed but high-acceleration movements of tennis (33), the use of accelerometers to derive mPL offers coaches with the potential to explore concepts like movement efficiency. Indeed, team-sport researchers have postulated that reduced accelerometer load measures for similar activity profiles could indicate improved movement efficiency (24, 28). However, the more refined reporting of mPL in the present study may better detect the cumulative demands of deceleration strategies prior to stroke execution, which influences joint position and resultant mechanical stress imposed on lower limb structures (13, 16). Accordingly, strength and conditioning professionals working in tennis could use mPL to determine player-specific lower limb acceleration and deceleration profiles, leading to more informed on- and off-court training drill prescription (15, 20).

This study is limited by a relatively small and male only sample size however it represents the population of players that was accessible in the country's high-performance academies. Given the likelihood of sex differences across accelerometer-derived metrics (8), sex comparisons represent a probable avenue of future research. Further, tennis is contested on hard, grass and clay court surfaces, which have known alterations to hitting and movement activity profiles as well as tactical demands (12) and thus, future investigations may wish to explore the interaction of surface on drill activities. Further tennis-specific influences on PL measures may include the individual player’s game-style and represents another avenue for future research. The prototype algorithm used in the present study is limited in its generic description of stroke types and accordingly, lacks detail to describe strokes such as volleys, slices or end-range. Future developments of this technology would provide coaches with greater insights on specific strokes. Lastly, this study was limited to a cross-section of tennis training sessions and further investigations into the longitudinal hitting and movement loads could provide external training loads for periodised training plans.

This study analysed respective stroke and movement accelerometery demands across typical training drills prescribed in an elite junior tennis environment. Novel reporting of sPL revealed the increased demands of hitting in Accuracy drills, though still highlighting the heightened overall movement demands of Recovery/Defensive and Open drills. Technical development and point-play refinement suitably exist in specialised drills that involve lower relative hitting and movement demands. Serving events occurred most frequently in Technical drills followed by Match-Play, which points to a gap in the way that serves are incorporated into representative training design that also involves groundstrokes. Consequently, these insights can guide drill prescription throughout dedicated training blocks and provides a starting point for future investigations describing the external training loads throughout the tennis ‘season’.

PRACTICAL APPLICATIONS

Tennis coaches and sport science staff can improve their prescription of training drills to explicitly target movement or hitting demands through measures of sPL and mPL. This improved monitoring of external load specific to tennis training drills can be integrated with previous reports of physiological drill demands (26, 32) for more comprehensive load monitoring strategies in the sport. Sport science practitioners implementing load surveillance systems should be aware of the potential increases in mechanical stress at the upper limb and trunk from Accuracy drills and thus, may require careful prescription during training microcycles. Additionally, simple accelerometery-based load and volume measures can assist the distribution of serve loading during trainings and could suggest to coaches that involving the serve more numerously in Points drills can improve match preparation strategies.

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Table 1. Drill classifications and descriptions, as adapted from Murphy, Duffield, Kellett and Reid (26)

Drill Category and (n)	Drill Description
Accuracy (n = 37)	Open play from the baseline requiring accuracy hitting to obtain points.
Recovery/Defensive (n = 73)	Open play from baseline involving repeated strokes under time, fatigue, court position pressures.
2v1 Baseline (n = 52)	Baseline drill with two players on one end and one player at the opposite end.
Open (n = 153)	Open play from the baseline using a pre-determined tactical pattern.
2v1 Net (n = 82)	Open play drill with two players on one side of the court and one player on the opposite side. One player minimum is at the net.
Technical (n = 55)	Deliberate closed drills targeted at a specific technical component of a given stroke.
Points (n = 491)	Open play with a multitude of possible scoring systems as deemed necessary by the coach. Serves are involved at the coach's discretion.
Match-Play (n = 41)	Simulated match-play in training with full serving.

Table 2. Mean and standard deviation of player load metrics ranked across training drill type

Drill Ranking	**Total Player Load (AU/min)**	**Drill Ranking**	**Movement Player Load (AU/min)**	**Drill Ranking**	**Stroke Player Load (AU/min)**
Accuracy	9.21 ± 3.03[d,e,f,g,h]	Accuracy	6.68 ± 2.15[f,g,h]	Accuracy	2.53 ± 1.00[*]
Recovery/Defensive	8.48 ± 1.70[d,e,f,g,h]	Recovery/Defensive	6.62 ± 1.07[f,g,h]	Recovery/Defensive	1.85 ± 0.94[d,f,g,h]
Open	7.80 ± 1.61[f,g,h]	2v1 Net	6.23 ± 1.17[f,g,h]	Open	1.73 ± 0.71[d,f,g,h]
2v1 Net	7.41 ± 1.64[f,g,h]	Open	6.07 ± 1.15[f,g,h]	2v1 Baseline	1.61 ± 0.61[d,f,h]
2v1 Baseline	7.40 ± 1.64[f,g,h]	2v1 Baseline	5.80 ± 1.21[f,g,h]	Technical	1.36 ± 0.59[h]
Points	6.17 ± 1.35[h]	Points	5.07 ± 1.06[g,h]	2v1 Net	1.17 ± 0.82
Technical	5.84 ± 2.12	Technical	4.48 ± 1.86	Points	1.10 ± 0.41
Match-Play	5.29 ± 0.76	Match-Play	4.41 ± 0.59	Match-Play	0.88 ± 0.31

[*]significantly different to all other drill types ($p<0.05$)
[d]significantly different to 2v1 Net ($p<0.05$)
[e]significantly different to 2v1 Baseline ($p<0.05$)
[f]significantly different to Points ($p<0.05$)
[g]significantly different to Technical ($p<0.05$)
[h]significantly different to Match-Play ($p<0.05$)

Table 3. Mean and standard deviation of relative stroke player load (sPL) and stroke counts ranked across training drill type

Drill Ranking	Forehand Stroke Player Load (AU/min)	Drill Ranking	Backhand Stroke Player Load (AU/min)	Drill Ranking	Serve Stroke Player Load (AU/min)
Accuracy	1.55 ± 1.33[*]	Accuracy	0.68 ± 0.68[c,e,f,g,h]	Technical	0.58 ± 0.64[*]
Recovery/Defensive	1.07 ± 0.78[e,f,g,h]	Open	0.57 ± 0.48[e,f,g,h]	Match-Play	0.32 ± 0.10[*]
2v1 Baseline	0.99 ± 0.39[e,f,g,h]	Recovery/Defensive	0.50 ± 0.63[e,f,g,h]	Accuracy	0.16 ± 0.41[b,c,d,e]
Open	0.91 ± 0.57[e,f,g,h]	2v1 Baseline	0.43 ± 0.31[g]	Points	0.11 ± 0.18[b,c,d,e]
2v1 Net	0.53 ± 0.56[h]	Points	0.34 ± 0.23[g]	2v1 Net	0.01 ± 0.03
Technical	0.50 ± 0.69	2v1 Net	0.27 ± 0.35	Recovery/Defensive	0.01 ± 0.02
Points	0.50 ± 0.34	Match-Play	0.21 ± 0.12	Open	0.00 ± 0.02
Match-Play	0.24 ± 0.13	Technical	0.17 ± 0.43	2v1 Baseline	0.00 ± 0.01
Drill Ranking	**Forehand Count (n/min)**	**Drill Ranking**	**Backhand Count (n/min)**	**Drill Ranking**	**Serve Count (n/min)**
Accuracy	6.57 ± 4.64[d,e,f,g,h]	Accuracy	2.76 ± 2.61[e,f,g,h]	Technical	2.24 ± 2.40[*]
Recovery/Defensive	5.50 ± 3.94[d,e,f,g,h]	Open	2.57 ± 2.01[e,f,g,h]	Match-Play	1.03 ± 0.29[b,c,d,e,f]
2v1 Baseline	5.05 ± 1.62[e,f,g,h]	Recovery/Defensive	2.18 ± 2.31[e,f,g,h]	Accuracy	0.52 ± 1.30[b,c,d,e]
Open	4.40 ± 2.54	2v1 Baseline	2.03 ± 1.38[f,g,h]	Points	0.37 ± 0.59[b,c,d,e]
2v1 Net	3.15 ± 3.14[h]	2v1 Net	1.40 ± 1.59	2v1 Net	0.05 ± 0.15
Points	2.30 ± 1.53[h]	Points	1.35 ± 0.87[g]	Open	0.02 ± 0.09
Technical	2.30 ± 3.17	Match-Play	0.79 ± 0.41	Recovery/Defensive	0.02 ± 0.09
Match-Play	1.09 ± 0.56	Technical	0.67 ± 1.64	2v1 Baseline	0.01 ± 0.06

[*]significantly different to all other drill types ($p<0.05$)
[b]significantly different to Recovery/Defensive ($p<0.05$)
[c]significantly different to 2v1 Baseline ($p<0.05$)
[d]significantly different to Open ($p<0.05$)
[e]significantly different to 2v1 Net ($p<0.05$)
[h]significantly different to Match-Play ($p<0.05$)
[g]significantly different to Technical ($p<0.05$)
[f]significantly different to Points ($p<0.05$)