Quantification of the physiological and performance characteristics of on-court tennis drills

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ABSTRACT

Objective: To determine the physiological responses and stroke characteristics of common on-court tennis training drills.

Methods: Six high-performance players performed 1×6 repetitions of four common on-court training drills on two separate occasions; once with 30:30 seconds work:rest, and once with 60:30 seconds work:rest. Heart rate (HR), blood lactate [La−], distance covered by the player (GPS) and rate of perceived exertion (RPE) were measured before the start of each drill and after the first and last repetition. Measures of shot count and accuracy and post-impact ball velocity per drill were also recorded.

Results: Significant differences were observed between drills in measures of [La−] and RPE both during ([La−] 2.1–4.4 mmol/l; RPE 2.6–5.1) and after ([La−] 4.4–10.6 mmol/l; RPE 4.3–7.6) drills, yet individual HR responses (160–182 beats/minute) were similar. Increased work times (60 *v* 30 seconds) also produced consistently raised [La−] and RPE responses, yet players' average movement velocities and forehand ball speed and accuracy remained consistent. Significant decreases in forehand ball speed and accuracy were observed during higher-intensity training drills, whereas significantly lower mean movement velocities underpinned performance of less intensive drills.

Conclusions: The four drills produced physiological responses that reflect previously reported normal or maximal matchplay demands. These results point to the adaptations possible with adjustment of training drill type and load specific to matchplay demands or training phase.

Sports involving short, intensive work periods interspersed with recoveries of variable length are usually classified as multiple-sprint sports.[1] From a metabolic standpoint, they typically require the aerobic energy system to meet the energetic demands of lower-intensity locomotion, while using anaerobic energy production for higher-intensity efforts. With training time at a premium, coaches are increasingly relying on an integrated approach to conditioning and skill-based work, often resulting in the programming of game-specific, on-court exercises that include both technical and tactical assignments as part of sport-specific conditioning. Prescribing game-specific training is believed to provide a stimulus that develops not only sport-specific fitness but also tangible game skills and knowledge.[2]

In tennis, an intermittent-sprint sport involving similar physiological demands to many team sports, this type of game-specific conditioning is regularly programmed. Where particular intermittent drills may be an inevitable consequence of group training, their individual physiological and performance (eg number of balls hit) loads are often determined by chance. Indeed, Ferrauti *et al*[3] have reported that such drills comprise 56% of all drills used in performance training, so the burden on the coach's "feel" for the training is sizeable. That is, for coaches using these drills to develop tennis-specific fitness, the lack of quantitative information describing expected physiological responses results in limited recommendations for exercise duration (number of strokes per work period), intensity (length of rest periods) or volume (total number of strokes per exercise drill). Consequently, this ensures that any prescription is intuitive, rather than based on scientific data, which in turn, may result in drills that fail to train satisfactorily the required metabolic pathways used in tennis.[4]

Some consensus exists to suggest that elite tennis players need highly trained aerobic and anaerobic energy systems. Indeed, after speed and agility, aerobic and anaerobic endurance are considered by coaches to be the most important fitness components for tennis.[5] If game-specific training drills are used, it is important that they provide sufficient physiological overload to improve these capacities. Although players may be ill-advised to rely solely on on-court training as a means of energy-system development, there are indications that such sessions can provide a suitable and game-specific alternative to more traditional conditioning protocols.[6] Thus, the aim of this study was to quantify the physiological and performance responses of four on-court drills commonly used in the training of professional players ranked in the top 10.[7]

METHODOLOGY

Participants

The study was approved by the institutional ethics in human research committee, and six high-performance male players (mean age 22 (6) years, height 1.80 (0.03) m, weight 72.0(4.0) kg), and predicted VO_{2max} of 58.5 ml/kg/min (20 m shuttle run) consented to participate in the study. Participants were required to attend each testing session in a rested state, refraining from the ingestion of food, caffeine or alcohol in the 3 h before testing. All participants completed a food diary before the first testing session and then maintained this standardised diet and fluid consumption for all subsequent testing sessions.

Protocol

Data collection was performed on a Rebound Ace tennis court, with participants wearing appropriate match-play attire and using their own racquets, while participating in four drills: the Star, Suicide, Box and Big X (fig 1), on two occasions over 4 days. These drills were chosen as they are known to feature in the training programmes of top professional players,[7] and are likely to be commensurate with those intuitively prescribed in other performance training.[3] The drills also selectively emphasise the different footwork and movement patterns used across various game situations, but most specifically during baseline play.

Participants were familiarised with all drills and testing procedures before the commencement of testing. A standardised 15-minute warm-up consisting of dynamic movement/flexibility exercises and stroke play was performed before each testing session. Participants completed 1 set of 6 repetitions of all four drills; once with 30 seconds of work and 30 seconds of rest, and once with 60 seconds of work and 30 seconds of rest. Two drills were performed daily, separated by 3 h of rest. Drill and participant orders were controlled, but protocols were randomised so that participants were only informed of the drill's work:rest ratio immediately before commencement. The work and rest intervals were prescribed in accordance with those commonly undertaken in practice.[7]

An experienced professional coach hand-fed new tennis balls to the participant at a speed determined by the completion of the previous shot and movement of the participant to the next shot (that is, self-selected). Irrespective of the drill, all players were instructed to move and hit with maximum effort, directing all shots to the target areas down the line (fig 1). The number of shots played (both forehands and backhands) was counted as an indicator of work completed during each repetition. The post-impact ball speeds of only forehand shots were measured with a Stalker ATS radar gun (Applied Concepts, Texas, USA), and the number of forehand shots landing in the target area (expressed as a percentage of total forehand shots played) per repetition was also noted as measure of accuracy. Mean scores and percentage decrements[8] for both forehand stroke accuracy and speed and mean shot (forehand and backhand) count were then calculated for each drill. Shot accuracy, speed and count were all emphasised as being equally important during pre-testing instructions to participants.

Heart rate (HR) was measured throughout the drills (Polar Electo Oy, Kempele, Finland), and blood lactate level [La$^-$] (Lactate Pro, Arkray, Kyoto, Japan) and C-10 rate of perceived

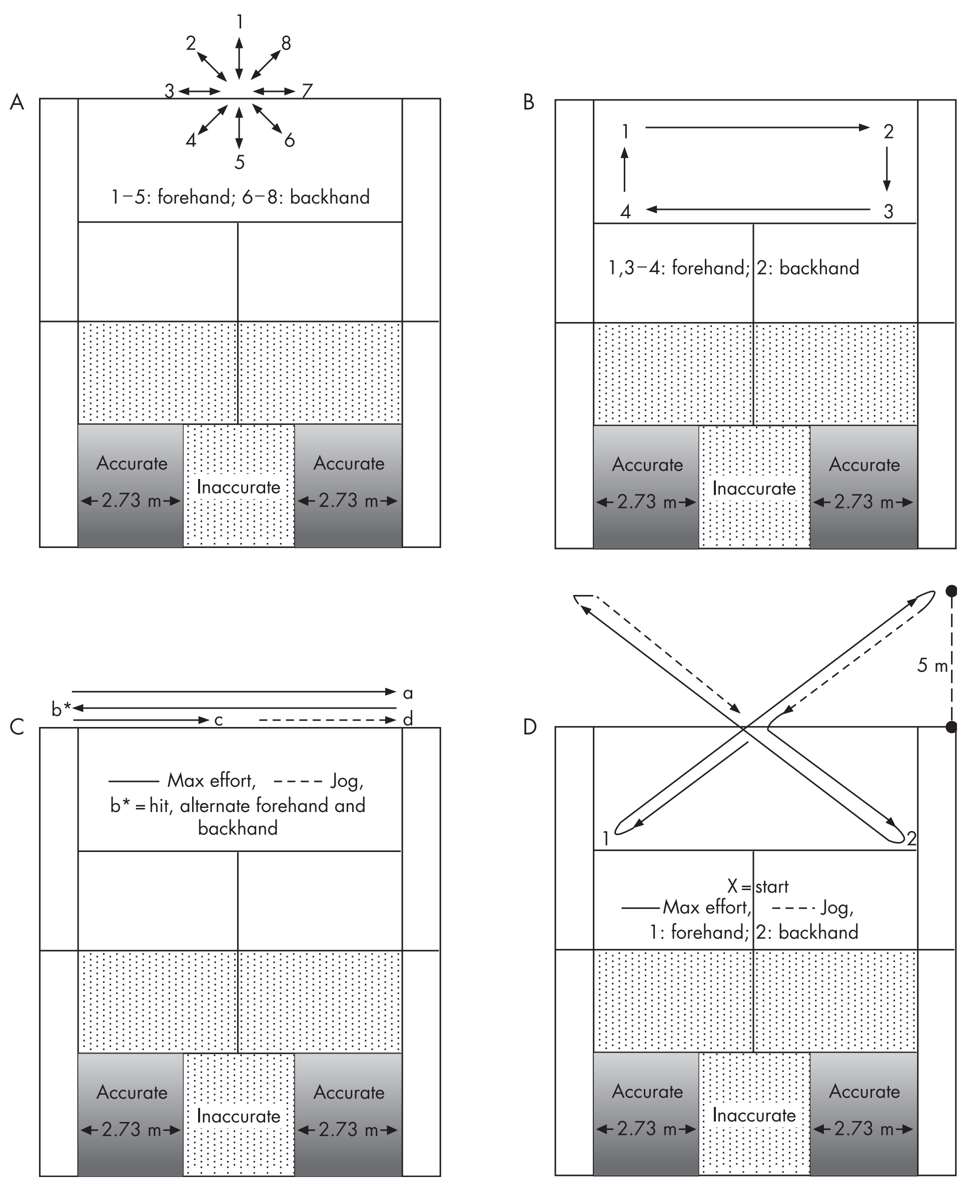

Figure 1 Movement and stroke patterns of (A) Star, (B) Box, (C) Suicide and (D) Big X.

exertion (RPE) were measured before the drill and immediately (within 10 seconds) after the first and sixth efforts. Ten minutes after the completion of the set, RPE was recorded as a global measure of the perceived exertion of the set.[9] Distance covered per drill (metres) was also recorded using a Minimaxx global positioning system (GPS) unit (Australian Institute of Sport, Canberra, Australia), similar to the GPSports unit (with a systematic overestimation error of 4.8 (7.2)%), as endorsed by Edgecomb and Norton[10], but sampling at 5 Hz; this was affixed to the participants with a custom-fit harness.

Statistical analysis

Comparison of differences within each drill and between drills was achieved through repeated measures two-way (drill × time) analyses of variance (ANOVAs). To further investigate main or interaction effects, one way ANOVAs were undertaken, with post-hoc Tukey analyses. Statistical significance was set a priori at $p<0.05$.

RESULTS

Physiology of on-court training drills comprising repetitions of 30 and 60 seconds

No differences were observed in HR before exercise or after the completion of one repetition. However, after repetition 6, HRs were shown to approximate 170 to 190 beats/min, increasing with drill duration ($p<0.05$) but not drill type (table 1).

Pre-drill [La⁻] levels were consistent across all drills. Main effects for drill type and duration ($p<0.05$) were noted after repetition 1, with raised [La⁻] responses characterising the 60 s drills and the 30 s Suicide drill ($p<0.05$) compared with all other 30 s drills. In undertaking the 60 s drills, players produced significantly lower [La⁻] after one repetition of the Box drill ($p<0.05$). Performance of the longer duration drills produced significantly higher post-exercise [La⁻], and post hoc analyses also showed that the 30 s Suicide drill resulted in higher post-exercise [La⁻] than the 30 s Box drill ($p<0.05$).

As with pre-drill HR and [La⁻], RPEs of ≈0.5 were recorded independent of drill duration and type. Following the completion of repetition 1, only a main effect for drill type was evident ($p<0.05$), with the 30 s and 60 s Box considered less physically demanding by the players than the 30 s Suicide and all other 60 s drills ($p<0.05$) respectively. Ten minutes after completing all drills, players rated longer drills and the performance of the Suicide and Big X (as compared with the Box) as significantly more difficult ($p<0.05$).

Distance covered and peak velocity in drills, with repetitions lasting 30 and 60 seconds

Distance covered increased with drill duration ($p<0.05$), as players were able to maintain the same average movement speed (table 2). Main effects were observed for drill, but not in combination with time, for distance covered and movement speed ($p>0.05$). Post hoc analyses revealed that players moved shorter distances and at lower average speeds in the 30 s Star (34.0 (4.3) m; 1.08 (0.16) m/s) than in the 30 s Suicide (67.5 (12.3) m; 2.21 (0.39) m/s) ($p<0.05$) and Big X (57.6 (13.7);

Table 1 Results for all drills performed for 30 and 60 seconds

Parameter and duration	Drill	Pre	Post-rep 1	Post-rep 6
Heart rate				
30 s*	Star	91.8 (14.9)	174.3 (7.3)	174.4 (8.3)
	Suicide	98.2 (13.8)	164.8 (9.2)	177.6 (3.8)
	Box	99.2 (19.5)	174.2 (10.4)	172.2 (8.3)
	Big X	97.4 (18.9)	159.4 (13.7)	173.6 (6.5)
60 s	Star	80.8 (14.9)	170.4 (8.1)	180.6 (5.2)
	Suicide	84.0 (16.5)	165.6 (12.3)	182.2 (8.5)
	Box	86.4 (10.8)	172.6 (7.0)	178.7 (8.3)
	Big X	92.8 (22.9)	163.4 (7.7)	180.7 (6.4)
Lactate				
30 s*	Star	1.9 (0.2)	2.4 (0.3)	5.6 (1.8)
	Suicide	1.5 (0.3)	2.7 (0.5)	8.8 (2.0)†
	Box	1.9 (0.5)	2.1 (0.4)	4.4 (0.6)
	Big X	1.5 (0.5)	2.3 (0.4)	7.0 (2.7)
60 s	Star	1.6 (0.4)	3.6 (1.0)	7.6 (1.4)
	Suicide	1.7 (0.3)	4.2 (1.5)	10.6 (2.7)†
	Box	1.4 (0.3)	2.6 (0.4)	6.7 (2.0)
	Big X	1.4 (0.3)	3.4 (0.4)	8.7 (2.7)
RPE				
30 s*	Star	0.5 (0.3)	2.6 (0.9)	4.3 (1.6)
	Suicide	0.4 (0.4)	3.7 (1.0)‡	5.8 (1.8)†
	Box	0.3 (0.3)	2.6 (0.4)	3.1 (0.9)
	Big X	0.3 (0.4)	2.9 (1.2)	5.2 (0.9)†
60 s	Star	0.6 (0.5)	3.3 (1.1)‡	5.8 (1.2)
	Suicide	0.7 (0.6)	5.0 (1.9)‡	7.6 (1.1)†
	Box	0.2 (0.3)	2.9 (0.7)	5.0 (1.5)
	Big X	0.2 (0.1)	5.1 (1.0)‡	7.6 (1.0)†

Data are mean (SD).
Rep, repetition number; RPE, rate of perceived exertion.
*Significant difference ($p<0.05$) for drill duration in all Rep 6 measures and for Rep 1 lactate.
†Significantly different ($p<0.05$) from Box drill for Rep 6 within drill duration.
‡Significantly different ($p<0.05$) from Box drill for Rep 1 within drill duration.

1.89 (0.45) m/s) ($p<0.05$) drills. A similar pattern emerged in the 60 s drills, with players covering less court distance and travelling at slower average speeds in the Star (76.8 (4.9) m; 1.26 (0.08) m/s) compared with the other three drills (Suicide 113.6 (14.0) m, 1.87 (0.24) m/s; Box 102.1 (7.1) m, 1.67 (0.12) m/s; Big X 107.4 (20.5) m, 1.78 (0.34) m/s) ($p<0.05$). The decline in average distance covered per repetition was significantly more pronounced in the 30 s drills (8.6 (3.3)% than in the 60 s drills (5.8 (2.1)%; $p<0.05$), yet no interaction or drill effect was observed. An analogous main effect for time was observed in average movement speed decrement per repetition (30 s 10.2 (5.2)%; 60 s 6.4 (3.0)%, $p<0.05$), and the Star was also characterised by variously greater decrements with different drill durations.

Shot performance in 30 s and 60 s drills

Players were able to generate comparable average ball speeds using their forehands in all drills, regardless of time ($p>0.05$, table 3). Drill type ($p<0.05$) but not duration affected players' capacities to maintain consistent forehand ball speeds, with significant declines observed in the ball speeds generated during the Suicide compared with the Star and Box drills ($p<0.05$). Similar to ball speed, average forehand shot accuracy was produced independent of drill time. However, drill type was shown to influence average accuracy ($p<0.05$), with post hoc tests revealing players to be less precise with their forehand shots in the 60 s Suicide (58.1 (6.5)%) than in the corresponding Star (72.5 (6.3)%, $p<0.05$), Box (75.7 (6.0)%, $p<0.05$), and Big X (81.3 (7.5)%, $p<0.05$) drills. Interestingly, augmentation in forehand shot accuracy decrement was observed with increased drill duration (30 s: 20.6 (8.9)%; 60 s: 28.4 (8.1)%, $p<0.05$). A drill effect on the same variable was evident with the 60 s Suicide drill, again resulting in a greater decrement in forehand shot accuracy than in the other three 60 s drills ($p<0.05$), over its duration.

DISCUSSION

Drill physiology compared with matchplay

Specificity is an important training principle, implying that training should be both mechanically and metabolically specific to the demands of the particular sport. From a metabolic perspective, most contemporary research points to tennis being characterised by predominantly anaerobic energy production during rallies, followed by aerobic oxidation of carbohydrates during rest periods.[11–13] Mean heart rates of 140–160 beats/min are reported to remain relatively stable throughout game-play,[14–17] but increase to >180 beats/min with more defensive gamestyles and longer or higher intensity rallies.[17] Similarly, whereas [La$^-$] values have been shown to rise only marginally above resting levels during normal play (1.8–2.8 mmol/l[18 19]), lengthier or more intense rallies, and serving rather than returning, require greater anaerobic energy supply.[12 16] Indeed, professional players competing in tournament conditions have recorded maximum [La$^-$] values >8 mmol/l.[16]

The drills performed in this study generally resulted in physiological responses, such as heart rates (160–180 beats/min) and [La$^-$] (4.4–10.6 mmol/l) that mirrored aspects of both normal and maximum matchplay. Mean HRs following the first repetition of all drills were similar, but upon completion of the final effort did increase with drill duration. As anticipated because of the larger volume of work, a similar relationship was observed between [La$^-$] and drill duration. The 30 s Suicide drill produced higher [La$^-$] than other 30 s drills, whereas acute [La$^-$] responses of the Box drill were the lowest of all 60 s drills, indicating the lower loading on glycolysis present in this drill. The small sample and the well-documented variable nature of individual [La$^-$] responses may have precluded further statistical differences.[12] Whereas the 30 s Box (4.4 (0.6) mmol/l) and Star (5.6 (1.8) mmol/l) drills produced [La$^-$] responses commensurate with those observed in the service games of professional players (4.6 (2.5) mmol/l;[16]), the 60 s drills (in particular the Suicide and Big X drill) were characterised by [La$^-$] responses similar to maximum in-game values. From a physiological perspective, it would therefore appear that the Star and Box drills (30 s) most closely resembled the previously reported mean demands of matchplay. Although the drill durations (30 s and 60 s) exceeded typical rally durations (that is 4–8 s,[20]), training specificity guards against prescribing all work:rest intervals to reflect those observed in matchplay, rather advocating average work:rest times to closely resemble those of competition, with the prescription of both longer and shorter exercise intervals as most appropriate.[21] Further, in order to impose physiological loads resulting in sufficient stress to cause adaptation for capacities such as VO_{2max}, durations longer than typical 5 s rallies or even the investigated 30 s drills are required, hence the potential value of 60 s drill lengths.

As the stimulus for training-induced adaptation results from the physiological stress imposed on athletes (and not necessarily the external training load), valid measures of internal training load are important.[22] Despite growing support for various RPE measures in the quantification of internal load in other intermittent sports,[23 24] their use in tennis is much less common. Nevertheless, Novas *et al*[25] reported that RPE can be used to estimate the energy cost of tennis play, with indications that

Table 2 Distance covered and mean movement speed for the four drills performed with repetitions lasting 30 and 60 s

Work time (s)	Drill	Distance covered: Mean (m)	Distance covered: Decrement (%)	Movement speed: Mean (m/s)	Movement speed: Decrement (%)
30	Star	34.0 (4.3)	12.6 (2.5)	1.08 (0.16)	18.7 (2.6)
	Suicide	67.5 (12.3)*	6.4 (3.0)	2.21 (0.39)†	8.1 (3.3)‡
	Box	51.8 (6.0)*	9.0 (1.1)	1.70 (0.21)†	8.4 (2.0)‡
	Big X	57.6 (13.7)*	7.5 (2.6)	1.89 (0.45)†	7.5 (3.0)‡
60	Star	76.8 (4.9)	7.1 (1.9)	1.26 (0.08)	9.3 (4.9)
	Suicide	113.6 (14.0)*	5.3 (0.7)	1.87 (0.24)†	5.3 (1.6)‡
	Box	102.1 (7.1)*	6.1 (3.6)	1.67 (0.12)†	6.8 (2.1)‡
	Big X	107.4 (20.5)*	4.9 (1.7)	1.78 (0.34)†	4.6 (1.2)‡

*Significantly different ($p<0.05$) from Star drill within drill duration for distance covered.
†Significantly different ($p<0.05$) from Star drill within drill duration for mean speed.
‡Significantly different ($p<0.05$) from Star drill within drill duration for speed percentage decrement.

Table 3 Forehand ball speed and accuracy and shot count for the four drills performed with repetitions lasting 30 and 60 s

Work time (s)	Drill	Forehand ball speed		Forehand accuracy		Shot count	
		Mean (m/s)	Decrement (%)	Mean (%)	Decrement (%)	Mean	Decrement (%)
30	Star	124.3 (10.5)	4.6 (2.8)	75.0 (7.1)	25.3 (7.6)	10.4 (0.7)	2.9 (2.3)
	Suicide	120.7 (6.3)	6.8 (3.3)*	65.0 (7.0)†	24.0 (6.1)†	4.0 (0.1)	0.9 (1.9)
	Box	113.7 (11.2)	3.5 (2.3)	81.2 (5.5)	20.3 (6.7)	11.9 (0.8)	4.7 (3.9)
	Big X	119.5 (5.3)	6.5 (2.7)	77.2 (15.6)	12.1 (10.3)	4.3 (0.3)	6.7 (6.8)
60‡	Star	123.5 (10.8)	3.4 (1.9)	72.5 (6.3)	29.9 (7.0)	19.9 (1.1)	4.7 (2.5)
	Suicide	115.8 (5.9)	6.3 (1.2)*	58.1 (6.5)†	35.4 (3.2)†	6.9 (0.4)	4.4 (5.1)
	Box	113.6 (13.7)	4.0 (0.7)	75.7 (6.0)	28.4 (6.7)	22.8 (1.1)	3.4 (0.8)
	Big X	118.6 (8.4)	5.9 (2.5)	81.3 (7.5)	19.6 (7.3)	7.9 (0.4)	6.4 (5.9)

Data are mean (SD).
*Significantly different ($p<0.05$) to the Star and Box drills within drill duration for decrement in forehand ball speed.
†Significantly different ($p<0.05$) to the Star, Box and Big X drills within drill duration for both forehand accuracy measures.
‡Significant difference ($p<0.05$) for drill duration in mean forehand accuracy.

competitive matchplay is typically perceived as "somewhat hard" by elite players.[16 25 26] Global session RPEs, recorded 10 min after the completion of the final effort,[24] for all 30 s drills (3.1–5.8), and to a lesser extent the 60 s Star drill (5.6 (1.2) and Box (5.0 (1.5)), were generally within a similar range. Consistent with the more elevated [La^-] responses described above, the 60 s drills were rated as more physically demanding than the 30 s drills, and the 60 s Suicide (7.6 (1.1)) and Big X (7.6 (1.0)) drill were perceived as being "hard".

Court coverage during individual drills

Interestingly, the performance of both the 30 s and 60 s Star drill, as variously compared with the other drills, was characterised by players covering less distance and at lower average speeds. This may be explained by the Star drill being considered to challenge the quality of players' close-range positioning skills and the related technical assignment.[27] That is, all feeding of the ball is arranged so that players are typically able to "set up" for their stroke, and with shorter distances covered, there is less time to accelerate, resulting in slower overall speeds; a point of importance, albeit rudimentary, for coaches looking to develop court-based speed. It could be argued that the ball feeding of the other three drills places players under greater time pressure, a hypothesis that receives indirect support through mean forehand shot speed being slightly, but not significantly, higher in the Star drills. If interpreted as an indicator of potential fatigue, the more pronounced declines in average distance covered and average movement velocity per repetition in the 30 s drills is surprising and not easily explained. It is possible however, that players better acquire the drill's movement rhythm, especially for the Star and Box, as drills progress, resulting in less variability in the movement velocity and distance covered during the 60 s drills. Further, the concept of self-pacing in repeated high-intensity drills of longer duration to maintain performance and "survive" may also explain the lower decrement in 60 s drills.

Shot performance

Mean forehand shot speed was developed independent of drill type and duration, providing some contrast to previous research that has shown that decreased recovery (10 s vs 15 s between repetitions) negatively affects mean stroke velocity during a 6×5 passing shot drill.[4] The varied methods of ball feeding and more particularly the divergent work:rest times of the two protocols, and by extension, the relatively greater role of anaerobic metabolism in the passing shot drill, possibly accounts for some of this dichotomy. This latter hypothesis is offered further support by the significant decrement in forehand ball speed observed during the Suicide compared with the Star and Box drills. That is, the aforementioned raised [La^-] response of the Suicide drill points to it being more "anaerobic" than either the Star or Box drill, resulting in players possibly experiencing greater difficulty in maintaining the same average ball speeds, or in other words, producing more variable stroke velocities.

Although average forehand shot accuracy, like shot speed, was not influenced by drill duration, the amplified accuracy decrement in the 60 s drills compared with the 30 s drills indicated that ball placement became more variable as drill time increased. Furthermore, when players performed the 60 s Suicide drill, their forehand shot precision and consistency (accuracy across repetitions) was worse than when performing the other drills for 60 s. In addition, the higher intensity (as inferred by [La^-] response and average distance covered) of the Suicide drill may have contributed to these relative declines in shot performance. Certainly, the Suicide drill appears to fit the profile of a high-intensity on-court drill, as described in the training literature.[3] Thus, coaches may be wary of prescribing particular drills (such as the Suicide drill) when attempting to implement sessions designed to focus on technique or specific skill learning.

What is already known on this topic

- More than half of all drills used in performance training for tennis are intermittent in nature.
- The stroke quality and running speed of players throughout these drills is largely dependent on the amount of recovery time provided.

What this study adds

- The physiological responses to four on-court drills, commonly used in elite tennis player training, were comparable to normal or maximum tennis matchplay demands.
- Aspects of shot performance and court movement differed between drills, helping to underline each drill's potential application in achieving specific training goals.

CONCLUSIONS

In traditional tennis coaching, the training loads of intermittent on-court drills have for the most part, been determined intuitively. This study represents the first effort, to our knowledge, to simultaneously quantify and compare the physiology, movement and shot characteristics of four common on-court training drills. Results indicate that the drills are characterised by physiology similar to previously reported mean or maximal aspects of matchplay, with drills such as the Star and Box more akin to typical game physiology. Players' average movement velocities and forehand ball speed and accuracy were relatively consistent, yet significant performance declines in aspects of shot performance were observed in the drill (Suicide) considered most intensive and most representative of near maximum matchplay demands. This information should provide trainers and coaches a descriptive and quantitative basis upon which to develop on-court training drills that better target selected fitness training goals of high-performance tennis players.

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Commentary

This publication discusses the study of training loads during on-court drills. It makes clear that it is possible to evaluate a training programme in an appropriate manner. Approaches like the one described in this paper should be used more often.

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