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Application of representative learning design for assessment of common practice tasks in tennis

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ABSTRACT

Objectives: This study assessed the representativeness of four common tennis practice tasks.
Design: Cross-sectional.
Method: In pairs, ten elite junior male and female tennis players (12.8 ± 1.05 yrs old) performed four, 4-min practice tasks and a 2-set tennis match. The previously validated representative practice assessment tool (RPAT – see Krause et al., 2018) was used to gain subjective assessments of each practice tasks representative design. Additionally, three-dimensional ball and player movement data was collected using an 8-camera HawkEye system. Mixed models were conducted to compare each practice task to matchplay revealing significant differences across a range of shot and movement characteristics.
Results: While players hit the ball faster and with more spin they consistently made contact with the ball further behind the baseline and generated fewer winners in most practice tasks compared to matchplay.
Conclusion: Common practice tasks are not representative of the shot and movement characteristics typical of matchplay. More careful design of practice appears to be needed.

1. Introduction

The main goal of practice is to acquire skills that translate directly to improved competition performance (Davids, Araújo, Vilar, Renshaw, & Pinder, 2013). Attempts to enhance skill acquisition and/or skill transfer have traditionally centered around tasks that (a) prioritize movement consistency over adaptability (Farrow, Baker, & MacMahon, 2013), (b) consist of massed repetition of the same skill (Barreiros, Figueiredo, & Godinho, 2007; Brady, 2008; Farrow & Maschette, 1997), and (c) possess low levels of uncertainty (Renshaw, Chow, Davids, & Hammond, 2010).

For example, hitting balls projected from a machine when there are no opponents available is common practice in cricket and tennis. Despite providing a simple means to increase practice volume, the machine removes important perceptual information (i.e., the opponent) critical to supporting decision-making behaviours. The result being significantly different ball strike kinematics and movement timing (Carboch, Süss, & Kocib, 2014; Pinder, Renshaw, Davids, & Kerhervé, 2011; Shim, Carlton, Chow, & Chae, 2005). Examples in other sports also reinforce short (Barris, Davids, & Farrow, 2013; Maloney, Renshaw, Headrick, Martin, & Farrow, 2018; Travassos, Duarte, Vilar, Davids, & Araújo, 2012) and longer-term (Oppici, Panchuk, Serpiello, & Farrow, 2017) implications for skill and movement transfer related to practicing in tasks devoid of competition specific information. The efficacy of traditional practice will therefore continue to be challenged until key movement (e.g., spatiotemporal kinematics) and performance characteristics (e.g., ball speeds) expected in domain-specific competition contexts are more effectively represented (Davids, Araújo, Vilar, et al., 2013; Pinder et al., 2011; Reid, Crespo, Lay, & Berry, 2007).

Representative learning design (RLD) is a framework that assesses the degree to which information sampled in experimental and practice tasks is representative of the specific performance contexts that the tasks are attempting to simulate. RLD proposes that simulating the necessary sources of contextual information (i.e., making a task more representative) will allow athletes to use this information to develop adaptive movement solutions that are more likely to transfer to competition performances (Pinder, Davids, Renshaw, & Araújo, 2011; Renshaw et al., 2010). To maximise representativeness, coaches need to design tasks that (a) ensure the functional coupling between perception and action processes, (b) adequately sample informational

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characteristics from within competition (e.g., incoming ball flight information; speed, spin) and (c) consider the interrelating constraints on movement characteristics (Pinder et al., 2011; Pinder, Headrick, & Oudejans, 2015). As a starting point coaches should consider designing tasks which more closely simulate the information sources from competition to provide similar decision making demands (Araujo, Davids, & Hristovski, 2006) and/or challenges to the emotional state of the learner (Headrick, Renshaw, Davids, Pinder, & Araújo, 2015; Maloney et al., 2018). For example, in tennis, ball flight information (Loffing, Sölter, Hagemann, & Strauss, 2016) and the opponents' on-court position (Loffing & Hagemann, 2014) are cited as key affordances (opportunities) for performers to act on. As such, a representative task would require that both the ball flight and opponents court positioning is simulated closely to provide the appropriate affordances that athletes require to contextualize likely solutions to benefit them during a rally. Additionally, in certain sports gender-specific differences may also need to be considered; for example in grand slam tennis males have been noted to hit the ball and move significantly faster compared with females (Reid, Morgan, & Whiteside, 2016).

To assist coaches and practitioners in evaluating practice and ensuring that tasks replicate key aspects from competition, RLD proposes two key terms; functionality and action fidelity (Pinder et al., 2011). Functionality provides a measure of the degree to which an athlete can use the same information sources (e.g., range of ball flights, speeds and spin rates in tennis) present during competition to contextualize their decisions and movement to achieve a similar level of success in practice (Pinder et al., 2011). Action fidelity, on the other hand, refers to the degree to which an athlete's movement characteristics during practice replicate those of competition (Pinder et al., 2011; Stoffregen, Bardy, Smart, & Pagulayan, 2003). For example returning serve against a ball machine demands significantly different movement coordination's (i.e., movement initiation and backswing durations) than returning against an opponent (Carboch et al., 2014).

Despite research identifying cross-sectional benefits of practicing in more versus less representative conditions (Barris et al., 2013; Maloney et al., 2018; Pinder et al., 2011; Travassos et al., 2012), the effectiveness of representative practice to enhance skill learning and transfer lacks empirical support in the form of learning interventions. A common reason is that assessments of functionality and action fidelity are often difficult, time consuming and/or invasive outside of controlled research settings (for example, assessing approximate entropy in soccer (Travassos et al., 2012) biomechanical analysis of batting in cricket (Pinder et al., 2011). In tennis, recent innovations including HawkEye (Hawk-Eye Innovations, 2015a) provides accurate 3-dimension ball and player tracking of performances in-situ (Loffing, Hagemann, & Strauss, 2009; Reid et al., 2016). Additionally, the validated Representative Practice Assessment Tool (RPAT) also presents as secondary option for subjectively assessing the design of tennis practice tasks (Krause, Farrow, Reid, Buszard, & Pinder, 2018). As such, these tools provide a significant opportunity to review current practice task designs in tennis.

This study aimed to compare the representativeness of four tennis tasks commonly delivered in high performance tennis settings, all with the primary goal of enhancing ground stroke performance (National Academy Victoria, 2008). Subjective measures of task representativeness were obtained via the RPAT while objective movement and hitting data was obtained via Hawkeye. Based on previous examples comparing common practice tasks to competition-like simulations (Barris et al., 2013; Pinder et al., 2011), it was hypothesized that shot (e.g., ball speed, spin and placement) and movement characteristics (e.g., average distances covered and ball contact locations) would differ between the simulated match play and practice tasks. We also anticipated gender to influence ball speed and distances covered per shot, with males being higher than females (Reid et al., 2016).

2. Method

2.1. Participants

Twenty elite junior right-handed tennis athletes (males; n = 10, age: M = 13.5 years, SD = 1.08 years, females; n = 10, age: M = 12.3 years, SD = 0.71 years) participated in the study. All participants were currently ranked within Australia's top 20 age-based rankings.

2.2. Protocol

Each participant was paired with a player of the same gender and similar ability according to their age-based Australian ranking. Each pair then undertook a one-off testing session consisting of four, 4-min practice tasks performed in a randomised order, followed by a two-set tennis match (M = 73 min, SD = 8 min, per match). Both the practice and matchplay tasks were filmed using HawkEye (HawkEye innovations, 2015) on an indoor Plexicusion court. Two new Australian Open Wilson tennis balls were provided for use in each of the four practice tasks and two for each set of matchplay.

2.3. Experimental tasks

Each of the four practice tasks (see Fig. 1) were restricted to 4 min. Pilot testing, including observation/discussions with coaches of elite junior tennis players were used to decide on the length of the practice tasks. The final time limits were based on (a) coaches often providing short breaks or progressing between practice tasks every 4–5 min and (b) players potentially losing interest if the task duration was too long. Prior to commencing data collection, the participants completed a 10-min self-directed warm-up. Additionally, task-specific familiarization consisted of a researcher reciting the task descriptions in Fig. 1 before participants undertook two run-throughs. The participant with the highest score after 4 min (using a tiebreak format) was deemed the winner of the task. To ensure each participant was provided equal hitting opportunity, 'feeding' (the method of commencing the point) and returning was alternated between participants after every point.

The two-set simulated matchplay required players to adjudicate their own line calls while conforming to international competition guidelines (International Tennis Federation, 2016). The winner was the first participant to reach two sets, or in the case whereby the players were tied at one-set each the winner was decided by an 11-point tiebreak.

2.4. Data collection and analysis

HawkEye consists of eight permanently fixed 60 Hz cameras that track the four-dimensional coordinates of the ball and both players during a rally. Each unique ball trajectory was then subjected to model fitting through propriety algorithms that provided the descriptive ball and player movement characteristics presented in this study. Importantly, independent testing has confirmed HawkEye as a reliable measure for ball tracking (± 2.6 mm mean error) compared to gold standard high speed footage (Hawk-Eye Innovations, 2015b).

HawkEye characteristics are presented in Table 1. Notably, to enable a more direct comparison between the practice and matchplay tasks only rally groundstrokes (i.e., all shots excluding the serve and return) commencing on the deuce side of the court were analyzed. Confining the data set to groundstrokes and rallies commencing from the deuce court ensured a more direct comparison between the shots played in the practice tasks and matchplay. Mixed models with a fixed effect for gender were used to assess the influence of fatigue between the first 4 games of set one and last 4 games of set two. No significant differences ($p > .1$) were found between any of the performance data. For example mean differences of < 1 kph in ball speed, < 20 rpm in ball spin and < 20 cm in contact depth between the first 4 games in set

Task 1: Cross Court Plus

Coaching objective:
Establish forehand rhythm and groundstroke consistency while performing at high intensity.

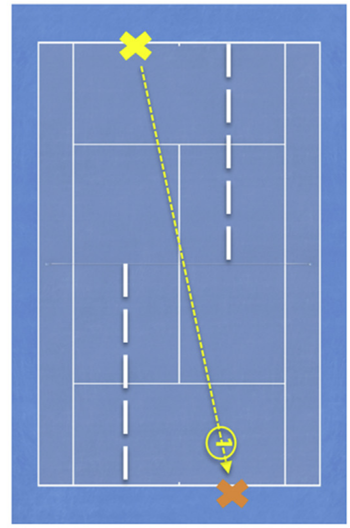
Tactical focus:
(i) Limit direction change.
(ii) Play consistent percentages.
(iii) Changing gears (changing tactics & rhythm during a rally).

Player objective:
Win the rally.

Playing area:
Singles deuce court plus two-racket lengths left of centre line (see adjacent image).

Rules:
(i) Players allowed to hit cross court only, using only forehands.
(ii) Volleys are allowed but players must use a forehand grip.
(iii) Ball must be fed by a player underhand and deep to the deuce side of the court. Players alternate feed after each rally.
(iv) Players to call their own lines.

Scoring:
Player with the most points after 4 minutes is the winner. Players can win a point in three ways.
(i) Player hits a winner.
(ii) Opponent hits the ball outside the playing area or into the net.
(ii) Opponent plays a backhand



Task 2: Cross, Cross, Line

Coaching objective:
Establish a tactical pattern of play that requires players to change the direction of the incoming ball.

Tactical focus:
(i) Improve understanding of the court and target zones.
(ii) Play consistent percentages.
(iii) Changing gears (changing tactics & rhythm during a rally).

Player objective:
Win the rally.

Playing area:
Full court - singles lines (see adjacent image)

Rules:
(i) Feeding player is restricted to the same hitting pattern: cross court, cross court, line. The other player hits cross court only. The roles are reversed after each rally.
(ii) Players can use both forehands and backhands as long as the desired pattern is performed.
(iii) Ball must be fed underhand and deep to the deuce side of the court. Players alternate feed after each rally.
(iv) Players to call their own lines.

Scoring:
Player with the most points after 4 minutes is the winner. Players can win a point in three ways.
(i) Player hits a winner.
(ii) Opponent hits the ball outside the playing area or into the net.
(iii) Opponent does not follow the prescribed pattern.

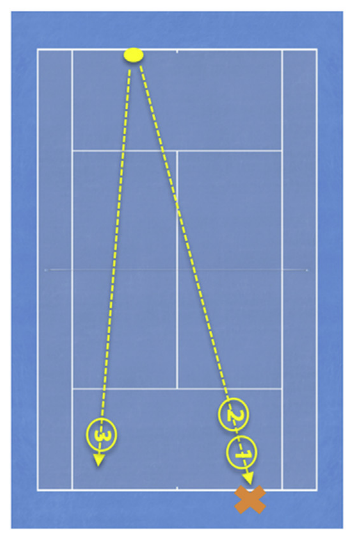


Fig. 1. Detailed overview of the practice tasks.

1 and last 4 games set in 2. The entire two-set match data for each participant was therefore used. Resultantly, 1152 shots (525 points) and 1384 shots (1018 points) were analyzed for the practice tasks and matchplay respectively.

Additional to HawkEye, three high performance tennis coaches unaware of the study's aims rated each task using the RPAT (Krause et al., 2018). The final scores are indicative of assessments of one randomly selected video recorded session. The entire playing field was captured using a hand held digital video camera mounted on top of the tennis fencing, parallel and centre to the court baseline. Between rater consistency within each task (i.e., Task 1 ICC = 0.74, task 2 = 0.50, task 3 = 0.70 and task 4 = 0.75) and across all 14 RPAT questions between raters for each question (ICC range = 0.51 to 0.92) and was good to excellent (Cicchetti, 1994). The most frequent (i.e., mode) RPAT scores provide by the raters are presented in Table 2. Note, at least two of three raters agreed on every question.

All analyses were performed using R Studio (R Core Team, 2017). To estimate differences in the dependent characteristics (Table 1) for each of the practice tasks compared to matchplay, mixed modeling was undertaken using the *lme4* package (Bates, Mächler, Bolker, & Walker, 2014). A random effect for participant was added to each model to account for the irregular number of trials across practice tasks. Practice

Task 3: Cross Court Animal

Coaching objective:
Establish cross court patterns and develop ability to defend and attack.

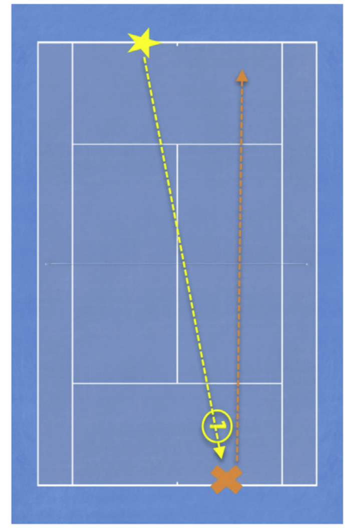
Tactical focus:
(i) Adjust to changes in defensive, neutral and/or offensive positioning within a rally.
(ii) Play consistent percentages.
(iii) Changing gears (changing tactics & rhythm during a rally).

Player objective:
Win the rally.

Playing area:
Full court - singles lines. (Figure 3)

Rules:
(i) 'Returner' is restricted to hitting only cross court on all shots, the 'server' can play unrestricted.
(ii) Players can use either forehands or backhands (including volleys).
(iii) Ball must always be fed by the 'unrestricted' player underhand and deep to the forehand side of the court.
(iv) Players swap roles (restricted or unrestricted) after every rally.
(iv) Players to call their own lines.

Scoring:
Player with the most points after 4 minutes is the winner. Players can win a point in three ways.
(i) Player hits a winner.
(ii) Opponent hits the ball outside the playing area or into the net.
(ii) If 'cross court constrained player' does not hit cross court their opponent wins the point.



Task 4: Point Play

Coaching objective:
Create a winning point from a neutral rally position.

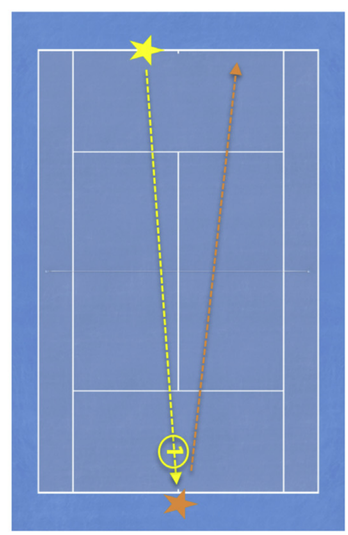
Tactical focus:
(i) Adjust to changes in defensive, neutral and/or offensive positioning within a rally.
(ii) Changing gears (changing tactics & rhythm during a match).
(iii) Play consistent percentages.

Player objective:
Win the rally.

Playing area:
Full court - singles lines.

Rules:
(i) Both players can play unrestricted.
(ii) Ball must be feed by a player underhand and deep toward the centre of the court. Players alternate feed after each rally.
(iii) Returner must play first shot towards feeding players backhand.
(iii) Players to call their own lines.

Scoring:
Player with the most points after 4 minutes is the winner. Players can win a point in two ways.
(i) Player hits a winner.
(ii) Opponent hits the ball outside the playing area.



Legend:

Color codes:
Yellow = Feeding play
Orange = 'Live' opponent play

Symbols:
Player who can only direct shots crosscourt
Shots hereafter, can be played by this player in any direction
Direction of constrained feed/shot
Feeding players shot number

7

Fig. 1. (*continued*)

task, gender and their interaction were included as fixed effects. Gender interactions were tested for based on previous research identifying distinct playing differences in male and female tennis (Fernandez-Fernandez, Sanz-Rivas, & Mendez-Villanueva, 2009; Reid et al., 2016). When the outcome measure was continuous (e.g., contact width) absolute measurements were used. For the binary outcomes of stroke type, shot outcome, spin type and winners, a generalized linear mixed model was used with a logistic link function. Assessments of the magnitude of

Table 1
Dependent variables.

	Description
Descriptive shot performance	
Total shots (n)	Count of total groundstrokes hit
Forehand (%)	Percentage of groundstrokes classified as being hit with players forehand
Backhand (%)	Percentage of groundstrokes classified as being hit with players backhand
In (%)	Percentage of groundstrokes classified as landing inside the singles playing lines
Error (%)	Percentage of groundstrokes classified as landing outside the singles playing lines or not travelling over the net
Topspin (%)	Percentage of groundstrokes classified as having over-spin
Slice (%)	Percentage of groundstrokes classified as having under-spin
Winner (%)	Percentage of groundstrokes resulting in the player directly winning a rally without their opponent making any contact with the ball
Continuous shot performance	
Mean speed (kph)	Average groundstroke speed (measured as speed off the racket)
Mean spin (rpm)	Average ball revolutions per minute
Mean net clearance (m)	Average height of the ball as it traveled over the net
Mean contact depth (m)	Average distance from the net at which the ball was contacted
Mean contact width (m)	Average distance from the centre of the court at which the ball was contacted
Mean bounce depth (m)	Average distance from the net at which the ball landed
Mean bounce width (m)	Average distance (expressed in absolute terms) from the centre of the court at which the ball landed
Mean shots per rally (n)	Average number of rally groundstrokes hit per rally
Movement performance	
Mean distance per rally (m)	Average distance covered by an individual player per rally

Table 2
Mode RPAT ratings for each practice task, from 3 coaches independent to the studies aims.

	Task 1	Task 2	Task 3	Task 4
	Cross Court Plus	Cross, Cross, Line	Cross Court Animal	Point Play
Task initiation	Racket-Fed	Racket-Fed	Racket-Fed	Racket-Fed
Activity type	Constrained point	Constrained point	Constrained point	Constrained point
Q1 – Is the task goal:				
(i) Specific enough for its intended outcome to be measured?	4	4	5	5
(ii) Similar to the type of goal required to be executed by players in competition?	3	4	4	5
Q2 – Do the task constraints (i.e., task design and equipment) placed on the task assist in:				
(i) Achieving the task goal?	4	3	5	5
(ii) Transferring skills to competition?	4	3	5	4
Q3 – Does the task encourage variation between shots (e.g., FH, BH, Volley, Serve)?				
(i) Appropriate to the task goal?	3	4	4	5
(ii) Transferring skills to competition?	2	4	3	5
Q4 – Does the task encourage variation within the same shots (e.g., FH topspin, FH flat, FH slice)?				
(i) Appropriate to the task goal?	4	4	4	5
(ii) Similar to what is expected during competition?	3	4	4	5
Q5 – Is the ball being fed (first ball & subsequent shots) in a manner:				
(i) Appropriate to the task goal?	4	4	4	5
(ii) Similar to what is expected during competition?	3	2	3	2
Q6 – Is the athlete striking the ball and moving with intent?				
(i) Appropriate to the task goal?	4	4	5	5
(ii) Similar to what is expected during competition?	3	4	3	5
Q7 – Does the task encourage decision making?				
(i) Appropriate to the task goal?	4	3	4	5
(ii) Similar to what is expected during competition?	2	1	4	4
Task goal score (sum of i scores)/35:	**27**	**26**	**31**	**35**
Matchplay score (sum of ii scores)/35:	**21**	**22**	**26**	**30**
Total score/70	**48**	**48**	**57**	**65**

Note. For full definition see Krause et al., 2018. Scores are provided on a scale of 1 (not at all) to 5 (certainly).

effects between practice tasks and matchplay were based on linear contrasts from mixed effect modeling and their 95% confidence intervals. Cohen's *d* effect sizes were also calculated from the model estimates whereby small ≤0.20, medium = 0.20 to 0.50 and large ≥0.80 (Sawilowsky, 2009). Statistical significance was set at $p < .05$ with Holm-Bonferroni adjustments made for multiple comparisons.

A measure of practice variability was included based on recommendations provided by Buszard, Reid, Krause, Kovalchik, and Farrow (2017). Specifically, a two-category indicator called 'between skill variability' described the sequencing between forehands and backhands. Subtle switches within skills was then defined by a six-category indicator including three shot and two spin types (i.e., shot type = crosscourt, middle, line and spin type = topspin or slice). This 6-category indicator was defined as 'within skill variability'.

3. Results

3.1. RPAT ratings (Table 2)

RPAT ratings for each task (Table 2) suggest that they could be considered from least to most representative in the following order; task 1 (RPAT score = 48), task 2, (RPAT score = 48), task 3 (RPAT

Table 3
Shot characteristics (descriptive).

Task	Total shots	Shot outcome (%)		Shot type (%)		Spin type (%)		Winner (%)		Practice Variability[a]	
	(n)	In	Error	Forehand	Backhand	Topspin	Slice	Yes	No	Between	Within
Males											
1. Cross Court Plus	320	89.69*	10.31	98.44**	1.56	94.38**	5.63	1.88**	98.13	–	0.83
2. Cross, Cross, Line	200	91.50**	8.50	72.00**	28.00	95.50**	4.50	1.50*	98.50	0.90	0.85
3. Cross Court Animal	340	89.41	10.59	67.35**	32.65	91.18	8.82	2.06**	97.94	0.91	0.91
4. Point Play	278	85.97	14.03	44.24	55.76	90.29	9.71	6.12	93.88	0.94	0.95
Matchplay	748	85.83	14.17	52.54	47.46	87.03	12.97	6.42	93.58	0.99	0.93
Females											
1. Cross Court Plus	238	87.82*	12.18	99.58**	0.42	97.90*	2.10	1.26*	98.74	–	0.87
2. Cross, Cross, Line	233	87.55**	12.45	77.68**	22.32	96.14	3.86	1.72*	98.28	0.94	0.81
3. Cross Court Animal	131	82.44	17.56	84.73**	15.27	93.89	6.11	5.34	94.66	0.99	0.89
4. Point Play	224	83.04	16.96	50.45*	49.55	93.75	6.25	4.02	95.98	0.93	0.82
Matchplay	558	81.54	18.46	56.27	43.73	93.01	6.99	6.09	93.91	0.97	0.93

Note. Data are presented as estimated mean and standard deviations.
$^{*}p < .05$, $^{**}p < .01$ between observed task and matchplay, within gender.
[a] Between skill variability; 2 category indicator of the sequencing between forehands and backhands. Within skill variability, 6 category indicator of switches in skill type (shot direction [i.e., crosscourt, middle, line] X spin type [i.e., topspin or slice]), see Buszard et al. (2017).

score = 57) and task 4 (RPAT score = 65). While all tasks scored high in relation to their task goal (i.e., score range for part (a) of each question = 3-5), assessments of how representative each task was of competition was more variable (i.e., score range for part (b) of each question = 1-5).

3.2. Objective HawkEye data (Tables 3–6)

Independent of gender, the measured characteristics that did not vary between any of the practice tasks and matchplay were average, net clearance, and bounce depth. Between and within skill variability differences were also limited to ≤10% across each practice task and matchplay for both males and females. Conversely, players hit the ball significantly faster ($p < .01$) but from deeper in the court (i.e., contact depth $p < .03$) in all practice tasks compared with matchplay. Additionally, compared to matchplay players hit more forehands ($p < .01$), contacted the ball from locations significantly further from the centre of the court (i.e., contact width; $p < .01$) and hit with more spin ($p < .01$) in tasks 1–3. Bounce width only differed in task 1 where players hit the ball to more central court location than in matchplay ($p < .01$). Lastly, both males and females made fewer errors in tasks 1 and 2 ($p < .02$) compared to matchplay.

A few notable differences remained specific to males and females. Specifically, compared to matchplay, females only covered greater distances in task 3 ($p < .04$), hit more shots with topspin in task 1 ($p < .04$) while males hit more topspin in both tasks 1 and 2 ($p < .01$). Significantly more winners were hit during matchplay compared to tasks 1 (p < .01), 2 ($p < .02$) and 3 ($p < .01$) for males and only task 1 ($p < .04$) and 2 ($p < .04$) for females. Analysis also revealed some between gender differences. Specifically, males covered greater distances ($p < .01$), hit more shots per rally ($p < .01$) and contacted the ball further from the centre of the court ($p < .02$). Comparatively, females hit the ball with more depth ($p < .01$) while making ball contact deeper in the court ($p = .02$).

4. Discussion

The primary aim of this study was to assess how well tennis practice, as portrayed by four common practice tasks, replicated tennis matchplay. The analysis was comprised of both qualitative (RPAT – Krause et al., 2018) and quantitative measures (HawkEye ball and player movement data). Qualitatively, the RPAT highlighted that the RLD of the observed practice tasks could be improved. In support, HawkEye data revealed that the four tennis practice tasks generally failed to replicate ball and movement dynamics of matchplay. Specifically, important changes in ball speed, spin and trajectory (i.e., functionality) as well as player court positioning (i.e,. action fidelity) were identified between all practice tasks and matchplay.

Table 4
Shot characteristics (continuous).

Task	Speed (kph)				Spin (rpm)				Net Clearance (m)			
	M	SD	*d*	95% CI	M	SD	*d*	95% CI	M	SD	*d*	95% CI
Males												
1. Cross Court Plus	101.21**	17.75	0.39	[96.76, 105.66]	1873**	503	0.30	[1690, 2004]	0.93	0.63	0.06	[0.81, 1.05]
2. Cross, Cross, Line	101.38**	12.10	0.40	[96.75, 106.02]	1752*	498	0.30	[1619, 1941]	0.95	0.52	0.03	[0.82, 1.08]
3. Cross Court Animal	98.27**	13.46	0.21	[93.83, 102.69]	1820**	484	0.18	[1637, 1949]	1.03	0.62	0.09	[0.91, 1.14]
4. Point Play	98.47**	15.92	0.22	[93.98, 102.98]	1688	499	0.11	[1559, 1874]	0.94	0.58	0.05	[0.82, 1.06]
Matchplay	94.99	17.93	–	[90.72, 99.27]	1738	545	–	[1543, 1849]	0.97	0.65	–	[0.87, 1.08]
Females												
1. Cross Court Plus	105.25**	13.62	0.52	[100.70, 109.80]	1865**	476	0.52	[1712, 2030]	0.99	0.66	0.02	[0.87, 1.12]
2. Cross, Cross, Line	101.49**	13.98	0.28	[96.93, 106.05]	1757*	471	0.29	[1607, 1925]	0.93	0.59	0.08	[0.80, 1.06]
3. Cross Court Animal	103.23**	14.92	0.39	[98.33, 108.12]	1863**	531	0.52	[1697, 2031]	1.01	0.66	0.05	[0.86, 1.16]
4. Point Play	102.14**	12.37	0.32	[97.56, 106.71]	1748*	468	0.27	[1603, 1922]	0.92	0.63	0.09	[0.79, 1.05]
Matchplay	97.03	17.17	–	[92.71, 101.35]	1626	481	–	[1516, 1823]	0.98	0.78	–	[0.87, 1.09]

Note. Data are presented as estimated mean, standard deviations; d = Cohen's d effect size (small < 0.20, medium = 0.20 to 0.50, large > 0.80); CI = confidence interval.
$^{*}p < .05$, $^{**}p < .01$ between observed task and matchplay, within gender.

Table 5
Per rally shot characteristics (continuous).

Task	Distance per rally (m)†				Shots per rally (n)†			
	M	SD	*d*	95% CI	M	SD	*d*	95% CI
Males								
1. Cross Court Plus	4.93	3.59	0.10	[4.17, 5.68]	3.19*	1.86	0.30	[2.84, 3.54]
2. Cross, Cross, Line	4.75	3.36	0.20	[3.87, 5.61]	2.95	1.83	0.16	[2.55, 3.56]
3. Cross Court Animal	5.42	3.95	0.18	[4.68, 6.17]	3.18*	1.96	0.29	[2.84, 3.52]
4. Point Play	4.74	3.40	0.20	[3.96, 5.51]	2.87	1.79	0.12	[2.51, 3.23]
Matchplay	5.10	4.16	–	[4.70, 5.50]	2.66	2.05	–	[2.49, 2.82]
Females								
1. Cross Court Plus	4.25	3.72	0.03	[3.47, 5.04]	2.45	1.83	0.16	[2.08, 2.81]
2. Cross, Cross, Line	4.64	3.53	0.25	[3.83, 5.46]	2.56	1.44	0.22	[2.18, 2.93]
3. Cross Court Animal	3.04*	1.96	0.65	[2.14, 3.94]	1.76	0.91	0.23	[1.34, 2.18]
4. Point Play	3.80	2.91	0.22	[3.01, 4.59]	2.26	1.31	0.05	[1.90, 2.63]
Matchplay	4.19	3.31	–	[3.76, 4.16]	2.17	1.44	–	[1.99, 2.35]

Note. Data are presented as estimated mean, standard deviations; d = Cohen's d effect size (small < 0.20, medium = 0.20 to 0.50, large > 0.80); CI = confidence interval.
*$p < .05$, **$p < .01$ between observed task and matchplay, within gender; †Significant 'gender' interaction ($p < .05$).

4.1. RPAT ratings

Using the previously validated RPAT (Krause et al., 2018), the design of each practice task was assessed relative to the task goal, and to performance demands in competition. RPAT assessments suggested that each task successfully achieved the task goal (i.e., majority of RPAT ratings > 4 for all questions). In relation to competition, ratings reflect the constraints imposed on performers in each task. For example, task 4 was ranked the highest overall with only ball feed (i.e., underhand down the centre of the court) considered a limitation (RPAT score = 2). Similarly in task 1, between skill variability was rated poorly (RPAT score = 2) due to the requirement for players to only hit forehand shots. Importantly, these examples highlight that while the tasks are rated as successful in achieving their desired goal maintaining key information sources and opportunities for decision-making could further enhance their design and ability to replicate matchplay demands (Davids, Araújo, Correia, & Vilar, 2013; Davids, Araújo, Hristovski, Passos, & Chow, 2012; Davids, Araújo, Vilar, et al., 2013; Pinder et al., 2011).

4.2. Quantitative HawkEye findings

While the RPAT provides a quick and effective assessment of tasks in on-court situations, further information is required to quantify changes to ball and athlete movement characteristics. Accordingly, HawkEye was used to collect data to capture key ball and player movement characteristics. While this study used inferential p value statistics obtained from group level mean comparisons to differentiate significant performance differences in practice and matchplay it is imperative that any assessments are considered relative to the specific constraints and goals of each task. For example, it is only intuitive that players hit significantly more forehands in task 1 given this was an important design factor of the task itself (i.e., players were constrained to hitting only forehands). Inferences of task representativeness in such instances need to be cautioned.

In all tasks, compared to matchplay both males and females hit the ball faster (males: M = 4.8 kph, SD = 1.7 kph, females: M = 6.0 kph, SD = 1.6 kph) and with more spin (male: M = 77 rpm, SD = 61 rpm, females: M = 183 rpm, SD = 65 rpm). While it would appear that the players are hitting more aggressively (i.e., hitting with more speed and spin), arguably playing with more risk, further analysis revealed that players hit a higher (tasks 1 and 2) or similar (tasks 3 and 4) percentage of shots landing 'in' compared to matchplay. Given hitting with more speed and/or spin was neither an explicit instruction or included in the tasks goal, one explanation is the tasks failed to successfully represent the psychological constraints of matchplay. That is players were less

Table 6
Ball contact and bounce characteristics.

Task	Contact Depth (m) † [a]				Contact Width (m) † [b]				Bounce Depth (m) † [a]				Bounce Width (m)			
	M	SD	*d*	95% CI	M	SD	*d*	95% CI	M	SD	*d*	95% CI	M	SD	*d*	95% CI
Males																
1. Cross Court Plus	−0.53**	1.75	0.60	[-0.21, −0.85]	2.59**	1.53	0.20	[2.43, 2.75]	4.15	2.17	0.14	[3.85, 4.44]	1.81**	1.43	0.43	[1.66, 1.96]
2. Cross, Cross, Line	−0.60**	1.27	0.71	[-0.25, −0.95]	2.89**	2.89	0.41	[2.70, 3.08]	3.81	2.03	0.01	[3.45, 4.15]	2.10	2.38	0.07	[1.92, 2.28]
3. Cross Court Animal	−0.69**	1.42	0.85	[-0.37, −1.01]	2.77**	2.96	0.33	[2.62, 2.92]	3.64	2.19	0.09	[3.55, 4.12]	2.13	2.41	0.04	[1.98, 2.27]
4. Point Play	−0.39*	1.74	0.38	[-0.06, −0.72]	2.23	2.25	0.07	[2.06, 2.40]	3.52	2.22	0.14	[3.11, 3.38]	2.08	2.19	0.10	[1.92, 2.24]
Matchplay	−0.14	1.95	–	[0.16, −0.44]	2.33	2.67	–	[2.22, 2.44]	3.84	2.15	–	[3.61, 4.07]	2.16	2.37	–	[2.06, 2.27]
Females																
1. Cross Court Plus	−1.14**	1.32	0.89	[-0.80, 1.47]	2.48**	1.36	0.27	[2.30, 2.66]	3.34	2.23	0.12	[3.02, 3.67]	1.81**	1.18	0.34	[1.64, 1.97]
2. Cross, Cross, Line	−0.95**	1.44	0.60	[-0.60, −1.29]	2.84**	2.66	0.54	[2.66, 3.02]	3.67	2.26	0.03	[3.34, 4.00]	2.10	1.20	0.01	[1.93, 2.27]
3. Cross Court Animal	−1.19**	1.02	0.97	[-0.80, −1.57]	2.92**	2.37	0.60	[2.69, 3.16]	3.21	2.45	0.17	[2.78, 3.62]	2.05	1.26	0.05	[1.84, 2.27]
4. Point Play	−1.13**	1.01	0.88	[-0.79, −1.47]	1.93	2.15	0.13	[1.75, 2.12]	3.47	2.19	0.06	[3.13, 3.80]	2.06	1.33	0.04	[1.89, 2.24]
Matchplay	−0.56	1.63	–	[-0.25, −0.85]	2.11	2.51	–	[1.98, 2.23]	3.60	2.46	–	[3.35, 3.83]	2.09	1.32	–	[1.97, 2.21]

Note. Data are presented as estimated mean, standard deviations; d = Cohen's d effect size (small < 0.20, medium = 0.20 to 0.50, large > 0.80); CI = confidence interval.
*$p < .05$, **$p < .01$ between observed task and matchplay, within gender
†Significant 'gender' interaction ($p < .05$).
[a] -ve = behind baseline, +ve = inside baseline;
[b] Higher value = 'wider' (i.e., further from centre of court).

apprehensive about the consequence for making mistakes and as a result hit the ball more freely (i.e., faster and with more spin in practice). Coaches, therefore, need to consider how to better simulate the psychological aspect of matchplay in practice and/or support athletes in the development of techniques for coping with negative emotions and performance anxiety (Glazier & Davids, 2009; Hanin, 2010; Hanin & Hanina, 2009; Headrick et al., 2015).

Beyond providing considerations for the goal of each task it is equally important to consider the inter-relatedness between different performance characteristics (e.g., how changes in ball speed effects a players movement). Accompanying the increase in ball speed, the players were also found to be making contact with the ball approximately 0.5 m further behind the baseline. It is predicted that this is the result of players scaling their movements (i.e., moving further behind the baseline) as to comfortably maintain higher ball speeds, spins and a high level of success. Similar movement scaling to changes in incoming ball speeds (discussed as changes in movement kinematics) has also been described in simple one-handed catching tasks (Tijtgat, Bennett, Savelsbergh, De Clercq, & Lenoir, 2010) and batting in baseball (Hubbard & Seng, 1954; Ranganathan & Carlton, 2007). In the baseball example, hitters scaled the speed of their swing and/or stepping patterns relative to incoming ball speed (Hubbard & Seng, 1954; Ranganathan & Carlton, 2007). This presents a significant implication as the athletes may have been attempting to mitigate time-pressures by acquiring defensive court positions further behind the baseline as compared to maintaining more aggressive positions closer to the baseline, a playing strategy that is unlikely to be a successful for most players in a match. An alternative argument is that the requirement to hit specific patterns (e.g., crosscourt, crosscourt, line in task 2 or crosscourt only for the returner in task 3) altered the cognitive load experienced by players (Runswick et al., 2017). This could have occurred in two ways (a) cognitive cost increased whereby the requirement to remember specific hitting and movement patterns (rather than reacting to the play) meant players moved further behind the baseline to allow more time for appropriate action planning or (b) cognitive cost decreased whereby advanced knowledge of ball locations provided more certainty for actions (i.e., the players were able to hit the ball harder which resulted in players moving further behind the baseline). Given the players were likely familiar with these tasks however the later explanation appears more likely in this cohort. Regardless this reinforces that small changes in task constraints (e.g., prescribing a hitting pattern) can lead to changes in key performance characteristics such as ball speed, spin and/or court position.

Notwithstanding that the forehand groundstroke is the most dominant shot among most tennis players (i.e., professional players hit approximately 25% more forehands than backhands groundstrokes during a match, Reid et al., 2016), the constraints of each practice task also appeared to encourage forehand dominance. That is, task 1 restricted players to hit forehand shots only, every rally in task 2 commenced on the forehand side of the court and in task 3 the server had prior knowledge that their opponent could only return the ball crosscourt affording them to move early to their dominant forehand side. This was certainly evidenced in comparing the frequency of forehands played in practice (67–99%) versus matchplay (52–56%) for both genders. Similar, given the logical progression from task 1 having the most prescribed constraints to task 4 having the least prescribed constraints, it was predicted that practice variability would increase systematically across tasks 1 to 4. Variability between (i.e., swapping between forehand and backhands) and within skills (i.e., hitting middle, cross or line with topspin or slice) however remained relatively consistent differing ≤ 10% across tasks and matchplay. Perhaps, the natural variation between skills and movements when two players are required to rally is enough to ensure players are variable in both between and within shot selections. Accordingly, calls for increased practice variability may be more relevant in basket-fed drills whereby the ball feed is controlled by the coach (Buszard et al., 2017; Lee, 2012; Van Rossum, 1990).

Rallies were longer for all practice tasks (except task 3 in females) compared to matchplay, this finding was only significant for males in task 1 and task 3 which equated to just over half a shot more each rally. Similarly, a 1–5% reduction in the number of winners hit in practice compared to matchplay (albeit only significant for males in tasks 1–3 and females tasks 1 and 2) highlights the practice tasks included in the current study seemingly promoted 'cooperative' (longer rallies and less winners) rather than 'combative' strategies. It is anticipated these key differences are again reflective of the constraints (i.e., prescribed patterns of play in practice versus the sole focus of playing to win a point in a match). Collectively, this suggests that coaches may need to provide more context-specific affordances (opportunities) enabling the athlete to anticipate and prepare efficient movement responses that promote pro-active rather than defensive game tactics (Loffing et al., 2016; Loffing & Hagemann, 2014), or provide task designs which reduce the restrictions on movement and decision-making.

It is known that during professional tennis matches, males hit the ball and traverse across the court significantly faster than females (Kovalchik & Reid, 2017; Reid et al., 2016) however it is unknown whether these differences translate into practice performances. Interestingly, this study found a lack of gender specific differences related to ball and movement speeds in matchplay and practice for elite junior players. Initially, it was perceived that pubertal status may have contributed to these differences but given the males were older than the females this appears unlikely (Tanner & Whitehouse, 1976). Generalizations of the practice performances of each gender across all four tasks highlights two potential tactical differences between males and females. Namely, females preferred to try and 'out hit' their opponent down the centre of the court while males attempted to 'out work' their opponents. Specifically, females made initial ball contact 0.6 m deeper and were landing their shots 0.4 m closer to their opponent's baseline while males averaged an additional shot each rally. Differences across measured HawkEye performance characteristics between male and females therefore supports the notion that practice, or rather the types of instructions provided, may need to be gender-specific (Reid et al., 2016). For example, coaches may need to explore constraints that encourage females to be more aggressive with their court positioning and ball placement.

4.3. Implications for coaches and practitioners

This study demonstrated how in situ analysis could be used to highlight differences between practice and matchplay performances. Three key recommendations can be provided for coaches and practitioners:

1. **The RPAT provides a useful assessment for coaches to evaluate the representative design of their practice tasks in the absence of HawkEye data.** While the design of each task closely aligned with its intended learning outcomes, RPAT assessments of the tasks representativeness provided further scope for improvement. The requirement for enhanced representatives was also confirmed by the HawkEye data validating, at least to some extent, that coaches can subjectively identify how the design of the task could be improved (Krause et al., 2018; Pinder et al., 2011).
2. **Similar types of analysis using in-situ data could be useful in setting criterion for coaches when designing practice tasks.** For example, placing a non-intrusive court marker approximately 0.5 m behind the baseline for females (depth players typically contact during matches) and encouraging payers to 'recover in front of' and/or 'not be forced behind' this marker could be a solution to enhancing action fidelity (Davids, Araújo, Vilar, et al., 2013; Pinder et al., 2011) by discouraging players from moving deeper in the court. Subsequently, ball speed and spin rates may also align more closely to those expected in skill-appropriate matchplay and/or enhance the

development of anticipation skills under significant time constraints (Shim et al., 2005).

3. **Players should be encouraged to 'exploit' rather than 'conform' to practice task rules and constraints.** While attempting to out hit an opponent through quality of forehand is the logical solution in task 1, and the solution the players preferred, it may not be the most effective. For example, despite hitting the ball hard and with lots of spin, less than 2% of all points ended in a winner. More effective solutions could include, forcing the opponent to hit a backhand (given this would directly result in a winner) or approaching the net to play a forehand volley with the knowledge the opponent can only hit the ball in one direction (i.e., crosscourt). As such, encouraging players to 'exploit' the rules and constraints of a task rather than 'conforming' to what is comfortable/logical will assist in the continual development of adaptive problem solving and decision-making (Araujo et al., 2006; Correia et al., 2012; Davids, Araújo, Correia, et al., 2013).

Using the framework of RLD can provide a means of assessing a whole range of practice and experimental designs (Pinder et al., 2011; Pinder et al., 2015; Pinder, Renshaw, & Davids, 2013). This study provided a practical example using the concepts from RLD to compare tennis practice tasks to matchplay as a means to support improved practice design. These assessments focused on treating each player independently, future research should therefore look to investigate the dynamics between two players (e.g., positional advantage, see Carvalho et al., 2013) in matchplay and practice. Future research could also investigate weighting certain performance characteristics based on the task goal (i.e., it is unlikely that all characteristics would be equally important across different types of practice task). The logical next step is to use this knowledge in applied learning studies, and empirically demonstrate the impact of improved task design. Equally further consideration should be given to how closely practice tasks can simulate the emotions of competition performances (e.g., via the sports emotion questionnaire developed by Jones, Lane, Bray, Uphill, & Catlin, 2005). There were some limitations in the current study that should also be considered in future experimental work. It was not feasible to extract the matchplay data from tournament matchplay rather simulated tournament play was used. Commentary from coaches and players did however suggest that the knowledge of being recorded by HawkEye lifted the intensity of both practice and matchplay. Further, given matchplay always occurred last, an order effect and/or fatigue across tasks was a concern. Nonetheless, the randomization of all four practice tasks reduced the likelihood for an order effect while no observed differences in any of the performance characteristics across the duration of matchplay suggests fatigue was also unlikely to be an influential factor. The small sample of points per practice task also limited analysis to within gender groups. Accordingly, future research should focus on obtaining a volume of data large enough to undertake individual comparisons.

5. Conclusion

This study highlighted key differences in HawkEye performance characteristics between practice tasks and matchplay. Namely, significant differences in key ball and movement characteristics suggest that the observed practice tasks typically promoted more 'cooperative' rather than the 'combative' behaviours expected during matchplay. Specifically, despite players hitting the ball faster and with more spin, they also had longer rallies, contacted the ball further behind the baseline and hit fewer winners during most practice tasks. The presence of some differences in response to task constraints between genders also reinforces that task design needs to be sensitive to gender-specific representativeness (Reid et al., 2016). Recommendations for enhancing the design of practice tasks in this study could be applied to a larger range of tasks in tennis and other racquet sports.

Author contributions

LK, DF, MR, TB and RP all provided a significant contribution to the design and interpretation of the data. LK collected and analyzed the data. LK also drafted the work, which was revised critically by DF, MR, TB and RP. Collectively all authors approved the final version for submission and agreed to be accountable for all aspects of the work.

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Conflicts of interest

There are no conflicts of interest to be reported.

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