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**Effects of Lawn Tennis Association Mini Tennis as Task Constraints on  
Children's Match-play Characteristics**

Running Title: Mini Tennis Match-Play Characteristics

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## Abstract

The Lawn Tennis Association's (LTA) Mini Tennis (MT) is a modified version of tennis consisting of progressive stages, however, there have been few attempts to evaluate how MT might shape performance behaviours. Here, we examine effects of playing MT on the emergence of children's match-play behaviours in forty-eight junior tennis players. Performance in 1010 match-play points were filmed and coded across four tennis stages (MT Red, MT Orange, MT Green and Full Ball), using a notational analysis system. Recorded performance variables included rally length, first serve percentage and shot type, for the purpose of analysing inter-stage comparisons. Results showed a series of specific adaptations to playing characteristics across the stages, including rally length, shot variety and serve success. MT Red rallies ( $7.36 \pm 6.06$ ) were longer than Full Ball rallies ( $3.83 \pm 2.40$ ), and a higher percentage of forehands were played at MT Red ( $66.40\% \pm 8.49\%$ ) than at Full Ball stage ( $45.96\% \pm 6.47\%$ ). Findings suggested that MT stages can afford children more opportunities to develop their skills and elicit different match-play characteristics than Full Ball task constraints. Coaches, therefore, should consider the nature of emergent adaptations when designing practice environments to facilitate learning in young tennis players.

**Key Words:** Mini Tennis, task constraints, representative learning design, adaptations, emergent behaviours

## **Introduction**

Sports classified as ‘net and wall’ games can be challenging for young, inexperienced participants to learn (Breed & Spittle, 2011). These include tennis, which involves dynamic interceptive actions that require a significant level of physical competency to be attained by participants, in order to generate and maintain a stroke rally (Farrow & Reid, 2010a). With aspects such as coordination, movement on court, and tactics to consider, young and inexperienced participants can find initial participation challenging, possibly becoming discouraged from further involvement (Farrow & Reid, 2010a). The complex technical requirements of tennis actions, as well as an emphasis on winning rather than fun and skill development, have contributed to the sport’s high pre-adolescent drop-out rates (Buszard, Farrow, Reid, & Masters, 2014, Newman, 2012). To counter children’s drop-out and facilitate participants’ skill acquisition, many tennis federations have implemented specialised frameworks and modified versions of the sport (e.g. United States Tennis Association’s Project 36/60; Tennis Australia’s MLC Tennis Hot Shots and the International Tennis Federation’s Play and Stay programme). The aim is to design adapted learning environments that better correspond to the functional capacities of novice performers (Timmerman et al., 2015).

One such modified game is Mini Tennis (MT), introduced by the Great Britain Lawn Tennis Association (LTA) (Hammond & Smith, 2006). An adapted version of tennis, it consists of three progressive stages: MT Red (MTR), MT Orange (MTO) and MT Green (MTG). Characteristics of the sport, such as court dimensions, ball type and scoring format, have been modified at each stage, to enhance the functional performance behaviours of participating children. Applying these modifications is believed to facilitate participants’ transition through each

stage, putatively smoothing the performance pathway into Full Ball tennis (FB). However, the MT formats were introduced based on experiential knowledge and coaching opinions, with little consideration of additional empirical evidence to support their functionality (Buszard et al., 2014, Larson & Guggenheimer, 2013). Here, we specifically investigated whether a constraints-led approach (Newell, 1986) can establish whether and how MT modifications might shape movement behaviours during performance.

Constraints are boundaries that guide emergence of movement behaviours in humans considered as complex dynamical systems (Newell, 1986). They pertain to each individual, the task performed and the environment. In tennis, for example, task constraints refer to playing area dimensions, properties of a ball and scaling of equipment, such as the racquet and net. In tennis, scaling constraints such as equipment and playing areas enables young participants to learn in an enjoyable way, without needing to cope with the full task constraints of the adult game (i.e. FB). Five constraints have been modified in the LTA's MT framework (court dimensions, net height, racket length, ball type and scoring format). Some are considered to shape performance more than others, such as racket length, which is predominantly determined by, and proportionate to, a player's anthropometry (Gagen, 2003). Inter-stage differences in scoring format have also been designed to prevent participants becoming both physically and mentally fatigued. Some research suggests that court scaling (court dimensions and net height) and ball modification do affect movement behaviours (e.g., Timmerman et al., 2015). The practical rationale for court scaling and ball modification in tennis is clear; if a six year old child attempts to play on a standard court with standard tennis balls, they are likely to find the sport extremely challenging (Buszard, Reid, Master & Farrow, 2016). A

standard ball bounces high relative to a child's physical stature, forcing them to alter their swing and adopt a movement pattern that may not be conducive to long term performance development (Kachel, Buszard, & Reid, 2015).

Some studies have started to quantify effects of court scaling and ball modification on performance. Timmerman et al. (2015) investigated scaling court dimensions and net height on children's tennis performance, reporting that decreasing court dimensions resulted in fewer winners and a lower percentage of successful first serves, despite no changes in average rally length between conditions, with a lower net height increasing the number of winners that emerged. Despite concluding that scaled conditions elicited a more conducive learning environment for young players, findings in their study only pertain to skilled participants, since all players were of national level and approaching the appropriate age for FB tennis. Since MT is designed for beginners, further research is needed to examine specific effects of scaled task constraints on the emergent actions of less skilled participants.

Ball compression may also be an important task constraint to support skill development. For example, manipulation of ball compression from standard balls to 75% can result in increased net play, with contact of the ball at a more comfortable height (Kachel et al., 2015). Buszard et al. (2014) examined children performing a forehand hitting task, with 25% compression balls having the most positive influence on forehand stroke performance. Larson and Guggenheimer (2013) also observed that playing with low compression balls may increase children's control, velocity and success rate in performing forehand groundstrokes. Martens and de Vylder (2007) advocated the use of low compression balls, claiming that differences in ball trajectory (lower bounce and longer flight phase of low compression balls) facilitate

the development of a wider range of shots, and that the extra time afforded to players using a low compression ball allows them to maintain control of rallies for longer. Martens and de Vylder (2007) highlighted a potential issue with MT modifications, however, observing that once players progress to FB, it can take a transfer period of 2-3 years for them to feel comfortable attempting the full range of shots that they were able to perform at the MTR and MTO stages.

Farrow and Reid (2010b) have provided perhaps the most compelling evidence to advocate the use of court scaling and ball modification in children's tennis. Participants were assigned to one of four groups (scaled court-modified ball, scaled court-standard ball, standard court-modified ball or standard court-standard ball) during a 5-week skill acquisition intervention. Every group demonstrated improvements in stroke proficiency following the intervention. However, results showed that participants in the standard court-standard ball group were afforded fewer hitting opportunities and achieved poorer hitting success than those in both of the scaled court groups, implying that the standard court-ball group endured a poorer overall learning experience. Comparatively, the scaled conditions were deemed useful vehicles for effectively simplifying tennis for children.

Despite positive support for constraints manipulation in tennis, research has typically analysed the effects of only one constraint on performance at a time (for exception see Farrow and Reid 2010b). Limited literature has investigated the effects of a combination of constraints, like court scaling *and* ball modification, despite these constraints being employed worldwide. Although manipulating a single constraint increases control of experimental variables, both practical application and representative design (Brunswik, 1956) are limited as a result. Finally, although MT was designed to enhance the skill development of young participants, the LTA-

implemented version has been based solely on experiential knowledge of coaches, without being complemented by additional relevant empirical evidence (Buszard et al., 2014; Greenwood, Davids & Renshaw, 2014). Therefore, it is essential to ascertain whether: (i) skill development is augmented through MT, (ii) the stages successfully facilitate a smooth progression for children into FB tennis, and (iii), the task constraints of court scaling and ball modification influence performance. The aim of the current study, therefore, was to determine how court dimension scaling and ball modification task constraints, applied within the LTA's framework, affect the emergence of match-play behaviours in children. Based on theoretical principles of ecological dynamics, as MT was designed to afford children a greater number of hitting opportunities, it was expected that there would be inter-stage differences in percentage of points won on first serve, percentage of aces, amount of net-play compared to forehands and backhands, percentage of slice shots, and rally length. These assumptions were made due to the use of smaller court dimensions specifically at MTR decreasing the distance a participant has to move to retrieve an opponent's shot and approach the net. This would make it more difficult for participants to create sufficient court space to cause rally perturbations during a point which would shape these match-play characteristics.

## **Methods**

### **Participants**

Forty-eight participants were recruited and stratified into groups by their age appropriate tennis stage: MTR (n = 18, Age  $7.4 \pm 0.6$  years, tennis playing experience  $2.1 \pm 0.9$  years); MTO (n = 16, Age  $8.5 \pm 0.6$  years, tennis playing experience  $3.2 \pm 1.0$  years); MTG (n = 8, Age  $9.9 \pm 0.4$  years, tennis playing



experience  $3.8 \pm 0.8$  years) and FB ( $n = 6$ , Age  $13.7 \pm 0.5$  years, tennis playing experience  $6.4 \pm 2.5$  years). The uneven participant sample size was to account for the difference in inter-stage scoring, with the total sample size of points analysed being comparable, MTR (230 points); MTO (253 points) MTG (280 points) and FB (247 points); with values being uneven to avoid obtaining partial match data. Each participant had at least 4-months playing experience and a minimum of 8 competitive matches in their current MT stage. Ethical approval was granted by the Sheffield Hallam University ethics committee, with all participants and parents or legal guardians providing informed consent.

## **Procedure**

Performance analysis research process guidelines were adhered to for the duration of the study (O'Donoghue, 2010). A Panasonic NV-GS500 digital video camera was positioned on a tripod, perpendicular to the centre of the baseline, at a non-intrusive distance, 4 m above and 4 m behind the tennis court, to record matches from the four different tennis stages. 35 matches were filmed which equated to participants playing an average number of matches of 1.2 at MTR, 1.6 at MTO, 1.6 at MTG and 1.2 at FB. All matches were contested on a Plexipave hard court, using new, stage-appropriate Wilson tennis balls and adhered to the LTA MT modified Rules and Regulations (see Table 1).

\*\*\*\*Table 1 near here \*\*\*\*

After video recording of each match, a custom-notational analysis system was developed to examine key performance indicators (KPI) (see Table 2) using Sportscod (Sportstec, Australia). KPIs for this study were developed from Hughes

and Bartlett's (2004) 'factors that contribute to performance'. Intra-rater reliability of KPI's was obtained from analysis of 100 match points performed by the researcher on two separate occasions, 12 weeks apart. Intra-rater reliability using Cohen's Kappa coefficient was calculated as  $k = 0.96$ , identified as very good (O'Donoghue, 2010).

\*\*\*\*Table 2 near here \*\*\*\*

### **Data Processing**

The custom analysis system enabled a range of dependent measures to be calculated (see Table 3). Individual match data were exported from SportsCode into Microsoft Excel (Microsoft, USA), where dependent measures were calculated. Frequencies were normalised to produce percentage values for dependent variables in all cases except rally length.

\*\*\*\*Table 3 near here \*\*\*\*

### **Data Analysis**

Prior to use of parametric statistical procedures, the assumptions of normality were verified. One-way analyses of variance (ANOVA) were used to identify inter-stage contrasts in individual variables (e.g. first serve percentage). Mixed design ANOVAs were used to analyse contrasts of multiple variables simultaneously (e.g. percentage of forehands, backhands and net-play, respectively, out of total shots) and any interaction with tennis stage. If the assumption of sphericity was violated a

Greenhouse-Geisser correction was used. Where differences were identified, Gabriel's post-hoc test was implemented (Toothaker, 1993). Effect sizes are reported for one-way ANOVAs ( $\eta^2$ ), mixed design ANOVAs ( $\eta_p^2$ ) and post-hoc tests (Cohen's  $d$ ). The magnitude of effect sizes is defined as follows:  $\eta^2$  0.02 = small, 0.13 = medium, 0.26 = large (Teo 2013);  $\eta_p^2$  0.2 = small 0.5 = moderate, 0.8 = large (Cohen, 1988), Cohen's  $d$  0.2 = small, 0.5 = medium, 0.8 = large (Cohen, 1988).

## Results

### Rally Length

Tennis stage constrained rally length  $F(3, 511.915) = 30.45, p < 0.001, \eta^2 = 0.07$ . Post-hoc testing showed that MTR rallies ( $7.36 \pm 6.06$ ) were longer than MTG ( $4.34 \pm 3.82$ ) ( $p < 0.001, d = 0.56$ ) and FB rallies ( $3.83 \pm 2.40$ ) ( $p < 0.001, d = 0.68$ ), with MTO rallies ( $6.63 \pm 7.38$ ) being longer than MTG ( $4.34 \pm 3.82$ ) ( $p < 0.001, d = 0.38$ ) and FB rallies ( $3.83 \pm 2.40$ ) ( $p < 0.001, d = 0.48$ ). Results demonstrated a progressive decline in rally length throughout the MT stages (See Figure 1).

\*\*\*\*Figure 1 near here\*\*\*\*

### Shot Type

There was a main effect for shot type  $F(1.128, 34.980) = 376.68, p < 0.001, \eta_p^2 = 0.92$ . Post-hoc testing revealed there were more forehands ( $62.4\% \pm 10.2\%$ ) than backhands ( $34.98\% \pm 9.31\%, p < 0.001, d = 2.8$ ) and net-play ( $2.63\% \pm 2.60\%, p < 0.001, d = 8.03$ ). There were also more backhands ( $34.98 \pm 9.31$ ) played than net-play ( $2.63 \pm 2.60, p < 0.001, d = 4.73$ ). There was a shot type x tennis stage

interaction for percentage of total shots  $F(3.385, 34.980) = 7.85, p < 0.001, \eta_p^2 = 0.43$  (see Figure 2). Figure 2 shows as MT stage progressed forehand percentage decreased, MTR ( $66.40\% \pm 8.49\%$ ), MTO ( $64.98\% \pm 7.98\%$ ), MTG ( $61.62\% \pm 5.70\%$ ) and FB ( $45.96\% \pm 6.47\%$ ). Results revealed that backhand percentage increased as stages progressed: MTR ( $30.87\% \pm 8.45\%$ ), MTO ( $33.54\% \pm 7.36\%$ ), MTG ( $37.03\% \pm 6.03\%$ ) and FB ( $48.18\% \pm 6.14\%$ ). There was more net play during FB ( $5.86\% \pm 0.84\%$ ) than MTR ( $2.73\% \pm 2.63$ ), MTO ( $1.48\% \pm 2.38$ ) and MTG ( $1.35\% \pm 1.03\%$ ).

\*\*\*\*Figure 2 near here\*\*\*\*

### **Shot Variety**

Tennis stage had an effect on percentage of slice groundstrokes played  $F(3, 34) = 3.386, p < 0.05, \eta^2 = 0.25$ . Post-hoc testing revealed that more slices were played at FB ( $15.15\% \pm 3.26\%$ ) than MTR ( $9.39\% \pm 5.90\%$ ) ( $p < 0.05, d = 1.12$ ), MTO ( $6.63\% \pm 5.40\%$ ) ( $p < 0.01, d = 1.89$ ) and MTG ( $6.74\% \pm 3.18\%$ ) ( $p < 0.01, d = 2.92$ ). No differences in slice percentage were observed between MTR, MTO and MTG stages ( $p > 0.05$ .)

### **Winners and Errors**

Analyses revealed that tennis stage affected error percentage  $F(3, 11.856) = 5.22, p < 0.05, \eta^2 = 0.27$ , with post-hoc testing revealing that fewer errors were committed in MTR ( $13.30\% \pm 5.89\%$ ) than FB ( $21.76\% \pm 3.77\%$ ) ( $p < 0.05, d = 1.62$ ). Tennis stage did not affect winner percentages  $F(3, 34) = 2.22, p > 0.05, \eta^2 = 0.18$ .

## Serving

Tennis stage affected first serve percentage  $F(3, 34) = 8.18, p < 0.001, \eta^2 = 0.44$ . Post-hoc testing revealed first serve percentage was greater for MTR than MTO ( $p < 0.05, d = 1.21$ ) and MTG ( $p < 0.001, d = 2.51$ ) (see Table 4).

\*\*\*\*Table 4 near here\*\*\*\*

Analysis revealed that tennis stage influenced emerging ace percentages  $F(3, 34) = 4.32, p < 0.05, \eta^2 = 0.30$ . Cohen's  $d$  analysis showed that fewer aces emerged in MTR than MTG ( $d = 1.2$ ) and FB ( $d = 1.17$ ). Cohen's  $d$  analysis also showed that fewer aces emerged in MTO than MTG ( $d = 1.86$ ) and FB ( $d = 1.91$ ). Tennis stage had an effect on double fault percentage  $F(3, 34) = 3.32, p < 0.05, \eta^2 = 0.24$ . Post-hoc testing revealed that fewer double faults were performed at MTR than MTO, ( $p < 0.05, d = 1.10$ ), and the difference between MTR and MTG ( $p = 0.06, d = 1.10$ ) approached statistical significance levels. No inter-stage differences were detected for percentage of points won on first serve  $F(3, 34) = 0.332, p > 0.05, \eta^2 = 0.03$ , or percentage of points won on second serve  $F(3, 14.328) = 1.645, p > 0.05, \eta^2 = 0.04$ .

## Discussion

This study examined how task constraint manipulations applied within the LTA's MT framework affected the emergence of tennis match-play characteristics in children. Match-play performance variables were compared across four tennis stages of the LTA programme for regulating court dimensions and ball type. Unlike previous studies, which examined the same participants across specific variable manipulations (Timmermann et al., 2015), here we maintained representative design

by studying participants who were currently in appropriate LTA stages, investigating the functional movement patterns which emerged with adaptations to task constraints in line with LTA regulations. Results showed that MT constrained children's match-play behaviours, with matches played on smaller courts and using lower compression balls (i.e. MTR) resulting in longer rallies and fewer errors for serves, groundstrokes and net-play. Differences were also identified in emergence of shot types, with more shot variety evident at FB than the scaled stages (MTR, MTO and MTG). These results are in line with expectations of the constraints-led approach, that affordances (opportunities for action) provided for individuals will facilitate active exploration, generating emergent functional movement solutions, dependent on the unique combination of interacting constraints imposed on them (Chow, Davids, Button, & Renshaw, 2016).

The findings of the current study suggested how task simplification helped learners maintain information-movement couplings during performance, as key performance variables such as ball properties and size of playing areas were manipulated. Results demonstrated how task simplification, by rule adaptations, can afford children, early in tennis development, more opportunities to hit balls in a relevant performance environment. With the gradual decline in rally length, as the task became more difficult (e.g. increased court dimensions and ball compression), results supported outcomes of previous work showing how the strategy of task simplification, by scaling the court and ball compression properties, can increase rally lengths (Farrow, & Reid, 2010b; Martens, & de Vylder, 2007). Smaller courts reduced the distance a player is potentially required to move to retrieve each shot and lower compression balls travel through the air more slowly, changing the affordance landscape available for the players (Davids, Shuttleworth, Araújo &

Gullich, in press). Manipulating these constraints affords players more time to act (Martens & de Vylder, 2007), as well as providing a more comfortable hitting height for the ball (Kachel et al., 2015).

Adaptations to shot type across the four stages indicated the harnessing of emergent self organisation tendencies in the learners, shaped by interacting constraints (Renshaw, Davids, Shuttleworth & Chow, 2009). A relatively high percentage of forehands emerged from the task constraints, compared to backhands observed in all scaled stages. Analysis of players' interactions with the task and environment suggests that they elected to play forehands more often than backhands during matches in constrained task conditions. This behaviour is possibly due to the smaller court dimensions in MT reducing the distance a player had to move to get around the ball and play a forehand. This outcome implies that MT does not afford children as many opportunities to perform and develop backhands as it does forehands. However, as the development stages progressed, reliance on forehand shots (seen at MTR and MTO) declined until FB, where no differences between forehand and backhand shots were observed. The importance of developing both shot types is highlighted by elite level data, which demonstrates the ratio of forehands to backhands (male ratio 1.24; female ratio 1.22) used in match competition is similar, hence the need to develop both aspects of children's match play (Reid, Morgan & Whiteside, 2016).

If constraints remain the same then highly stable movement patterns may develop. However, adaptations to constraints such as a change in court size can lead to some functional instabilities in learners resulting in motor system re-organisation, and new patterns of behaviour emerging. As players' skill level increased across the playing stages, individuals seemed to be adapting by using a wider range of shots to

satisfy the constraints being imposed on them. Hence, it is important for coaches to recognise that being over-reliant on one set of constraints can lead participants to become dependent on a specific technique or skill, which may result in other skills (i.e. backhand) not being developed sufficiently. Creativity in manipulating task constraints is needed in pedagogical practice to facilitate continuous adaptations of learners to changes in an affordance landscape (Davids et al., in press).

Net-play increased as stages progressed, a finding which contradicts previous results showing that more net-play emerged under scaled conditions than full ball conditions (e.g. Kachel et al., 2015; Timmerman et al. 2015). Our results suggested that, as participants became more skilled, they adapted their performance and used more varied shots during match play to exploit the increasing space available. These findings concur with previous research in boxing, which showed how changes to an affordance landscape can facilitate emergence of a rich range of performance behaviours in learners, without specific, prescriptive instructions being provided (Hristovski, Davids, Araújo & Button, 2006). Hence, our data suggested how the LTA framework might be implemented in an effective way to gradually increase each player's functional performance behaviours, for example, in moving from a stable forehand shot to using backhands and net play.

MTR players hit more successful first serves than MTO and MTG players. Developing an accurate but powerful serve is a priority for most tennis players (Reid, Whiteside, Gilbin & Elliott, 2013). However, the serve is the most complex shot biomechanically, as well as the hardest for coaches to teach and the most challenging for novices to learn (Reid, Elliott & Whiteside 2010). The resultant lack of technical proficiency on the serve, coupled with the smaller court dimensions (i.e. smaller service box target area) at MTR, could encourage children to 'tap' the ball



over the net as a means of starting the point, as opposed to utilising the serve as an attacking tactical tool, as in FB (Rive & Williams 2012). This was suggested in observations of fewer aces performed at MTR and MTO than MTG and FB respectively. Further research, examining changes in serve velocity across tennis stages, is required to confirm this hypothesis. The smaller court dimensions and decreased service box target area at MTR suggests that, even if a serve lands at the very edge of the service box (i.e. an accurate serve), the returner does not have to move very far to retrieve the ball. Previous research found that reducing court dimensions actually decreased successful first serve percentage (Timmerman et al., 2015), and lower ball compression did not affect this variable (Kachel et al., 2015). These previous studies, with elite players, may have resulted in emergence of attacking first serves with the reduced service box size, which could have resulted in reduced success. The findings in our study highlight the importance of the representative sampling of participants (Brunswik, 1956), when examining how ball modification and court scaling interact with the individual and the task design, to shape emergent behaviours. If researchers wish to examine the effect of specific interacting constraints manipulations, careful sampling of the affordance landscape and participants is required.

In conclusion, this study provides a base from which to further investigate the effects of court scaling and ball modification on skill acquisition in tennis. Despite a representative design that examined children within their age-appropriate LTA stage, a limitation is that variations in skill level and experience of the different age group participants could have contributed to the changes in match play characteristics observed. In future research, increased participant sample size, and a longitudinal design, would facilitate more extensive insights into the effects of MT task

constraints on children's match-play characteristics. Such a research design would allow a larger cohort of participants to be regularly monitored during match-play as they grow and develop through the MT stages at an appropriate pace. This would provide a more comprehensive representation of individuals' progression from MTR, to MTO, to MTG, and finally to FB. An issue that we have highlighted here is the need for a comprehensive theoretical framework to complement experiential knowledge of coaches and sport pedagogists in designing skill acquisition programmes for young children (Greenwood et al., 2014), in sports like tennis.

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**Table 1.** LTA MT rule and regulation modifications for each stage (MTR, MTO, MTG and FB)

Stage	Court Dimensions (m)	Service Box Dimensions (m)	Net Height (m)	Average Racket Length (m)	Ball Type	Match-play Scoring Format
<b>MTR</b>	11.0 x 5.5	4.0 x 2.5	0.8	0.5	Red felt or sponge; 75 % slower and 6% bigger than FB	Match-tiebreak; first to 10 points
<b>MTO</b>	18.0 x 6.5	6.4 x 3.25	0.8	0.6	Orange; 50 % slower than FB	Best of 3 tiebreaks (first to 7 points)
<b>MTG</b>	23.8 x 8.2	6.4 x 4.12	0.91	0.65	Green; 25 % slower than FB	Best of 3 sets; each set is first to 4 games
<b>FB</b>	23.8 x 8.2	6.4 x 4.12	0.91	0.69	Yellow; regular FB	Best of 3 tiebreak sets; each set is first to 6 games

**Table 2.** Key performance indicator and action operational definitions

<b>KPI/Action</b>	<b>Operational Definition</b>
1st serve	The shot played at the start of every point
2nd serve	The shot played at the start of the point, if the first serve is not successful
Forehand	Stroke played with the palm of the hand facing the direction of the strike, in front of or to the right of the body for a right-handed player
Backhand	Stroke played across the body with the back of the hand facing the direction of the strike, in front of or to the left of the body for a right-handed player
Net-play	Striking the ball before the bounce (volley, drive-volley or smash)
In	A successful shot, landing inside the relevant court boundaries
Net/out (i.e. error)	An unsuccessful shot, or error, landing in the net or outside of the designated lines of the court, resulting in loss of the point.
Winner	A shot after which the opponent is not able to make contact with the ball, resulting in the point being won
Ace or serve winner	A winning service shot, in which the receiver is unable to make contact with the ball
Double fault	Both the first serve and the second serve are unsuccessful, resulting in loss of the point
Slice	A stroke that applies backspin to cause the ball to swerve in the air and/or stay low after the bounce
Topspin	The ball is hit with a rising action, causing it to dip in flight and drop into court sooner than it would otherwise. This also increases the speed and bounce of the ball on striking the ground
Rally	The series of shots, including the serve, once a point has begun; a rally continues until the point has been won or lost
Server won 1st serve	Point was started with a 1st serve, and the server won the point
Server lost 1st serve	Point was started with a 1st serve, and the server lost the point
Server won 2nd serve	Point was started with a 2nd serve, and the server won the point
Server lost 2nd serve	Point was started with a 2nd serve, and the server lost the point

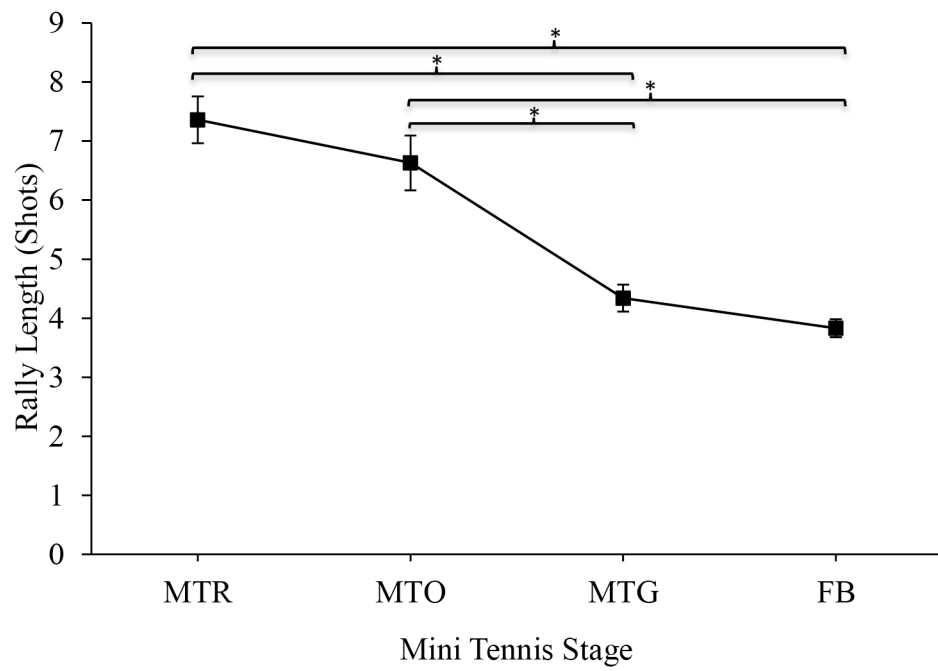
**Table 3.** Calculated dependent measures and equations

Dependent Variable	Equation
Average rally length	$(\text{Rally length}_1 + \text{rally length}_2 \dots + \text{rally length}_n) / \text{total number of rallies}$
Forehand %	$[\text{Number of forehands} / (\text{total forehands} + \text{total backhands} + \text{total net-play shots})] \times 100$
BH %	$[\text{Number of backhands} / (\text{total forehands} + \text{total backhands} + \text{total net-play shots})] \times 100$
Net-play %	$[\text{Number of net-play shots} / (\text{total forehands} + \text{total backhands} + \text{total net-play shots})] \times 100$
Spin variety (%)	$[(\text{Number of slice forehands} + \text{number of slice backhands}) / (\text{total forehands} + \text{total backhands})] \times 100$
Winners (%)	$(\text{Forehand winners} + \text{backhand winners} + \text{net-play winners}) / (\text{total forehands} + \text{total backhands} + \text{total net-play shots}) \times 100$
Errors (%)	$(\text{Forehand errors} + \text{backhand errors} + \text{net-play errors}) / (\text{total forehands} + \text{total backhands} + \text{total net-play shots}) \times 100$
Successful 1st serve (%)	$(\text{Number of successful 1st serves} / \text{total number of 1st serves}) \times 100$
Ace %	$(\text{Number of aces} / \text{total number of serves}) \times 100$
Double fault %	$(\text{Number of double faults} / \text{total number of 2nd serves}) \times 100$
Points won on 1st serve (%)	$(\text{Number of points won on 1st serve} / \text{total points played on 1st serve}) \times 100$
Points won on 2nd serve (%)	$(\text{Number of points won on 2nd serve} / \text{total points played on 2nd serve}) \times 100$

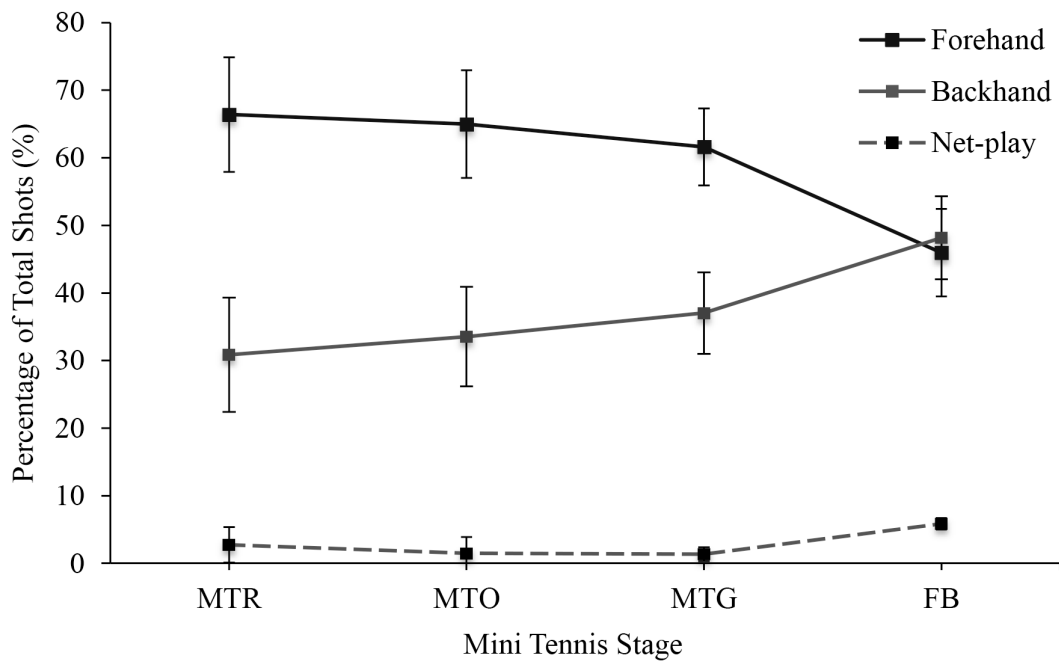


**Table 4.** Serve characteristics across MT Stages (M  $\pm$  SD)

	Successful first serves (%)	Aces (%)	Double faults (%)	Points won on first serve (%)	Points won on second serve (%)
MTR	77.08 $\pm$ 13.75	0.79 $\pm$ 2.19	9.29 $\pm$ 14.32	55.85 $\pm$ 16.39	43.50 $\pm$ 34.16
MTO	60.84 $\pm$ 14.47	0.33 $\pm$ 1.05	26.07 $\pm$ 17.81	59.10 $\pm$ 16.39	35.56 $\pm$ 11.58
MTG	47.70 $\pm$ 4.94	3.48 $\pm$ 2.87	23.55 $\pm$ 11.32	61.97 $\pm$ 6.94	47.48 $\pm$ 8.49
FB	61.73 $\pm$ 8.09	3.34 $\pm$ 2.62	11.60 $\pm$ 6.92	61.32 $\pm$ 5.48	43.23 $\pm$ 5.80



**Figure 1.** Average rally length for each tennis stage



**Figure 2.** Shot type breakdown for each tennis stage