Effects of scaling task constraints on emergent behaviours in children's racquet sports performance

FITZPATRICK, Anna, DAVIDS, Keith <http://orcid.org/0000-0003-1398-6123> and STONE, Joseph <http://orcid.org/0000-0002-9861-4443>

Published version

FITZPATRICK, Anna, DAVIDS, Keith and STONE, Joseph (2018). Effects of scaling task constraints on emergent behaviours in children's racquet sports performance. Human Movement Science, 58, 80-87.

Copyright and re-use policy

Effects of scaling task constraints on emergent behaviours in children's racquet sports performance

Anna Fitzpatrick[1], Keith Davids[2] & Joseph. A. Stone[1]

[1]Academy of Sport and Physical Activity, Sheffield Hallam University, Sheffield, UK

[2]Centre for Sports Engineering Research, Sheffield Hallam University, Sheffield, UK

Corresponding author: Joseph Stone, A213, Collegiate Hall, Collegiate Crescent, Sheffield Hallam University, Sheffield, S10 2BP. Tel: +44 (0)114 225 5413.
E-mail: Joseph.stone@shu.ac.uk.

Abstract

Manipulating task constraints by scaling key features like space and equipment is proposed as an effective method for enhancing development and refinement of movement patterns in sport. Despite this, it is currently unclear whether scaled manipulation of task constraints would impact emergent movement behaviours in young children, affording learners opportunities to develop functional movement behaviours. Here, we sought to investigate how scaling task constraints during 8-weeks of mini tennis training shaped emergent movement behaviours, such a backhand stroke development. Two groups, control (n = 8, age = 7.2 ± 0.6 years) and experimental (n = 8, age 7.4 ± 0.4 years), underwent practice using constraints-based manipulations, with more specific affordances for backhand strokes designed for the latter group. To evaluate intervention effects, pre- and post-test match-play characteristics (e.g. forehand and backhand percentages) and measures from a tennis-specific skills test (e.g. forehand and backhand technical proficiency) were examined. Post intervention, the experimental group performed a greater percentage of backhands out of total number of shots played (46.7 ± 3.3%), and a significantly greater percentage of backhand winners out of total backhand strokes observed (5.5 ± 3.0%), compared to the control group during match-play (backhands = 22.4 ± 6.5%; backhand winners = 1.0 ± 3.6%). The experimental group also demonstrated improvements in forehand and backhand technical proficiency and the ability to maintain a rally with a coach, compared to the control group. In conclusion, scaled manipulations implemented here elicited more functional performance behaviours than standard Mini Tennis Red constraints, suggesting how human movement scientists may scale task constraint manipulations to augment young athletes' performance development.

Keywords: Scaling task constraints, intervention, tennis, affordances, emergent behaviours

1.0. Introduction

Racquet sports, like tennis, are characterised by repeated, dynamic interceptive actions, and participants require a high level of technical and physical proficiency to be able to generate and maintain effective movement patterns (Farrow & Reid, 2010a). With elements such as motor coordination, on court movement and game tactics to consider, inexperienced participants can find the sport's demands particularly challenging (Breed & Spittle, 2011). Consequently, tennis federations have developed modified versions of the sport, theoretically underpinned by Newell's (1986) constraints-led approach, designed to augment skill development and enable inexperienced participants' performance behaviours to more closely reflect those required in the full version of the game (Timmerman et al., 2015). The British Lawn Tennis Association's Mini Tennis (MT) is one such scaled game version (Hammond & Smith, 2006). MT comprises three structured, progressive stages (Red, Orange and Green), with scoring format, court dimensions, net height and ball characteristics modified at each stage to facilitate participants' functional movement behaviours (Fitzpatrick, Davids, & Stone, 2016). However, many scaled formats of tennis, including MT, have been implemented based on expert practitioner opinion and experiential knowledge, requiring empirical evidence to affirm potential functional benefits (Buszard, Farrow, Reid & Masters, 2014). Accordingly, recent research has strived to substantiate the implementation of MT constraints for enhancing children's skill acquisition (Timmerman et al., 2015; Kachel, Buszard & Reid, 2015).

Constraints are boundaries pertaining to the performer, the task or environment which confine and/or facilitate the behavioural movement patterns that a complex dynamical system can adopt (Newell, 1986). Adapting task constraints encourages performers to explore how manipulations shape available affordances (possibilities for action). Research has suggested that effective manipulation of constraints in children's sport can facilitate emergence of functional coordinative movements (Arias et al., 2012). In tennis, scoring format, court dimensions, net height and ball characteristics are considered key task constraints that can be scaled to influence movement behaviours. Modifying these aspects, through scaling, enables inexperienced participants to perform, without the need to contend with the challenging constraints of Full Ball tennis. However, it is important that the modifications simplify movement demands while maintaining perception-action couplings that are functional in the full version of the game (Buszard, Reid, Masters, & Farrow, 2016). For example, a reduced compression tennis ball that bounces lower facilitates inexperienced participants' groundstroke performance, by allowing them to adopt a swing height that is scaled to their physical dimensions. It has been proposed that this re-scaling of movement is more conducive to skill development than the swing height needed to strike a higher-bouncing, standard tennis ball (Kachel et al., 2015).

Evidence suggests that the constraints employed within MT influence participants' emergent behaviours; for example, low compression balls positively influence children's forehand groundstroke performance (Buszard et al., 2014; Larson & Guggenheimer, 2013). Low compression balls also enable participants to maintain control of rallies for longer, facilitating the development of a wider range of strokes (Martens and de Vylder, 2007). Timmerman et al. (2015) investigated effects of modifying court dimensions and net height on emergent behaviours, showing that, although average rally length did not differ between conditions, reducing court dimensions and net height created an enhanced learning environment for children. A 5-week intervention study with four groups (scaled court-modified ball, scaled-court-standard ball, standard court-modified ball, standard court-standard ball) (Farrow & Reid, 2010b) demonstrated that, while stroke proficiency of all groups improved, participants in the two scaled-court groups were afforded more hitting opportunities during practice sessions and demonstrated greater hitting success and rally ability than the standard court-standard ball group. Farrow and Reid (2010b) concluded that the *standard court-standard ball* group underwent a poorer overall learning experience, and that scaled conditions can be used to effectively simplify tennis for children.

MT was designed to reduce the speed of the game, such that children's emergent behaviours closely reflect those needed in the full version of the sport (Buszard et al., 2016). Despite considerable evidence to suggest that MT task constraints augment children's technical and tactical development, claims that MT evokes emergent behaviours that closely resemble those of the full game have, thus far, been largely speculative. Fitzpatrick et al. (2016) investigated this concept, examining effects of MT and Full Ball task constraints on children's movement behaviours; MT Red constraints elicited longer rallies and fewer errors than Full Ball constraints. Thus MT Red participants were afforded more opportunities to perform strokes in a relevant performance environment. However, findings also indicated that MT Red participants performed considerably more forehands than backhands (i.e. 2:1 ratio) during match-play; in contrast, the ratio of forehands performed compared to backhands in Full Ball is closer to 1:1 (Reid, Morgan, & Whiteside, 2016). The disparity may be even greater within MT coaching sessions; in Farrow and Reid's (2010b) intervention study, the scaled court-modified balls condition elicited a mean ratio of approximately 6:1 in favour of the forehand. This focus on the forehand is reflected within the literature, with several studies examining the effects of MT constraints on forehand performance (Buszard et al., 2014; Hammond & Smith, 2006; Larson & Guggenheimer, 2013), but few investigating the impact on backhand performance.

Fitzpatrick et al. (2016) noted that this disparity between forehand and backhand performance at MT Red may lead to a skill imbalance over time, to the possible detriment of performance development. For example, if MT Red constraints do not afford participants sufficient opportunity to perform backhands, the stroke may not adequately develop, thus potentially affecting development by allowing weaknesses to emerge. It is currently not known whether a constraints-based intervention can alleviate this asymmetry in groundstroke performance. Hence, based on application of Newell's (1986) constraints-led approach, we developed a movement intervention designed to enhance skill acquisition, while simultaneously accounting for the asymmetry between groundstrokes at MT Red. The aim was to investigate the effects of an 8-week constraints-based movement intervention on children’s match-play behaviours and tennis-specific skills test performances, with a focus on backhand stroke development.

2.0. Methods

2.1. Participants

Sixteen participants, each of an appropriate age for MT Red, and with a minimum of 6 months of tennis playing experience, participated voluntarily and were randomly assigned to one of two groups: control (n = 8, age = 7.2 ± 0.6 years, tennis playing experience = 1.9 ± 0.6 years) and experimental (n = 8, age = 7.4 ± 0.4 years, tennis playing experience = 2.1 ± 0.6 years). Informed consent was provided by all participants and their parents or legal guardians, and ethical approval was granted by the Local University ethics committee.

2.2. Procedure

2.2.1. Pre-Test

The pre-test protocol comprised two elements: match play and tennis-specific skills testing (TSST). All sessions took place on standard, Plexipave hard courts, and were recorded using a Panasonic HC-V550 video camera (Panasonic, Osaka, Japan), positioned unobtrusively, behind the court. For match-play, each participant completed three standard MT Red matches of ‘first to 10 points’ (LTA, 2017), against three randomly assigned participants. All matches were umpired by a qualified coach.

During the TSST, participants were required to maintain three consecutive groundstroke rallies (i.e. forehands and backhands) for as long as possible with the coach. The coach controlled the pace and direction of their feeding throughout, to ensure consistency between participants. The mean number of consecutive strokes that travelled over the net and landed in the court, including those of the coach, was recorded, giving a rally performance score. Video replay enabled the qualitative assessment of participants’ technical proficiency, independently by two LTA Level 3 accredited tennis coaches. They each had at least 6 years of experience coaching MT players and were not aware of the specific research objectives. The coaches qualitatively assessed four aspects of stroke production for forehands and backhands, respectively: (i) preparation (including movement to the ball), (ii) backswing, (iii) ball impact and follow-through, and (iv), recovery, using a 7-point scale (Farrow & Reid, 2010b). The four scores were summed for each player's forehand and backhand, producing a maximum achievable score of 28 points per stroke. Both coaches performed the assessment on two separate occasions, 3 days apart, to facilitate reliability calculations; the interclass correlation coefficient between the two coaches was 0.88, defined as excellent by Cohen (1988).

2.2.2. Intervention

Both groups attended an 8-week tennis movement programme (1 hour coaching per week). Wilson MT Red balls were used for all sessions (Farrow & Reid, 2010b). Both groups were taught by the same LTA Level 4 accredited coach, who was unaware of the specific research objectives. All intervention sessions followed the same format and included recovery breaks. The design was adapted from Hammond and Smith (2006) and included an introduction and group warm-up (6 minutes); skill practice one (12 minutes); skill practice two (12 minutes); competition/points-based activity (15 minutes); fun, skill-based games (10 minutes); session review and cool down (5 minutes). Both groups performed the same drills and activities throughout, with the only difference being the specific additional constraints applied to the experimental group's learning environment. The number of strokes played per participant during each coaching session, irrespective of whether the ball landed in or out of the court, was recorded (Farrow & Reid, 2010b). The control group played 117.0 (± 7.7) strokes per session, the experimental group played 120.3 (± 8.3) strokes per session (no differences were detected $t(14) = -0.811$, $p > 0.05$). Therefore, differences in outcome variables were not attributable to differences in frequency of actions practised.

Pre-test match-play data supported the earlier findings of Fitzpatrick et al. (2016), revealing that MT Red players performed a disproportionately high number of forehands and low number of backhands compared to Full Ball players. This information, alongside a comprehensive understanding of commonly used tennis coaching drills (Brown & Soulier, 2013; Bryant, 2012; Hopper, 2011), facilitated the design of constraints-based pedagogical adaptations that were implemented during the experimental group's intervention sessions, to influence their emergent behaviours. Adaptations included manipulations of: (i) internal court dimensions, (ii) recovery box location, and (iii), practice match-play rules and scoring format, as follows:

(i) *Internal playing space dimensions* (Hopper, 2011): an adjusted centre line, slightly to the right of the standard centre line (for right-handed players), running from the baseline to the net, was applied using masking tape, as shown in Figure 1, for the duration of the intervention. Participants were asked to attempt to perform a backhand if the incoming ball landed to the left of the adjusted centre line.

(ii) *Recovery box location*: for the duration of the intervention, recovery boxes were applied using masking tape (Brown & Soulier, 2013; Bryant, 2012), approximately 0.2 m behind and 0.3 m to the right of the centre of the baseline (for right-handed players), as shown in Figure 1. Players were asked to attempt to return to the recovery box after each stroke.

(iii) *Match-play rules and scoring format*: during the experimental group's points-based activities (i.e. 15 minutes per session), bonus points were awarded by the coach if a participant created a perturbation (e.g. hit a winner or forced their opponent out of position) using their backhand (Hopper, 2011).

(Figure 1)

2.2.3. Post-test

Replicating the pre-test procedure, each participant completed three standard MT Red matches, against the same three opponents as pre-testing (Kachel et al., 2015), and underwent the TSST process. The same two coaches who evaluated the pre-test TSST evaluated the post-test TSST.

2.3. Data processing

Match-play video data were coded using a SportsCode Elite (v10.3, Sportstec, Australia) custom-notational analysis system. The key performance indicators (KPIs) are defined in Table 1. Intra-operator and inter-operator reliability of the system demonstrated Cohen's kappa coefficients of $k = 0.97$ and $k = 0.95$, respectively, defined as very good (O'Donoghue, 2010). Coded data from each match were exported from SportsCode into Microsoft Excel (Microsoft, USA). Frequency data were then normalised to percentages for all match-play outcome measures, except rally length, as reported in Table 1. Rally length, TSST forehand and backhand scores, and rally performance scores were reduced to mean values (*SD*).

(Table 1)

2.4. Data analysis

Parametric assumptions were verified in SPSS (v23.0, SPSS Inc, USA). Preliminary analysis (independent t-tests) on pre-test data for all variables detected no differences between groups. A two-way, mixed design analysis of variance (ANOVA) was then performed on all outcome measures, with the independent measures being practice condition (control and experimental) and time (pre-test and post-test). Alpha levels were set *a priori* at $p < 0.05$. Pearson's correlation coefficient effect sizes were calculated; magnitudes are defined as r = 0.1 = small, 0.3 = medium, 0.5 = large (Cohen, 1988).

3.0. Results

3.1. Shot type

3.1.1. Forehand

Analysis revealed main effects for time $F(1,22) = 23.41$, $p < 0.001$, r = 0.72, and group $F(1,22) = 77.77$, $p < 0.001$, r = 0.88, and a group x time interaction $F(1,22) = 26.62$, $p < 0.001$, r = 0.74. Figure 2 shows the percentage of forehands performed by the experimental group decreased by 17.3% after the intervention; the percentage performed by the control group did not differ.

3.1.2. Backhand

There were main effects for time $F(1,22) = 22.00$, $p < 0.001$, r = 0.71, and group $F(1,22) = 81.75$, $p < 0.001$, r = 0.89, and a group x time interaction $F(1,22) = 33.91$, $p < 0.001$, r = 0.78. Figure 2 illustrates that the percentage of backhands played by the experimental group increased by 17.0% after the intervention; the percentage performed by the control group decreased by 1.8%.

(Figure 2)

3.2. Winners and errors

Forehand winners analysis revealed no main effects for time $F(1,22) = 0.25$, $p > 0.05$, r = 0.11, or group $F(1,22) = 0.03$, $p > 0.05$, r = 0.04, and no group x time interaction $F(1,22) = 2.71$, $p > 0.05$, r = 0.33. There were no main effects for time $F(1,22) = 3.35$, $p > 0.05$, r = 0.36, or group $F(1,22) = 3.45$, $p > 0.05$, r = 0.37, and no group x time interaction $F(1,22) = 0.14$, $p > 0.05$, r = 0.08 for forehand errors.

Backhand winners analysis showed no main effects for time $F(1,22) = 0.03$, $p > 0.05$, r = 0.04, or group $F(1,22) = 0.19$, $p > 0.05$, r = 0.09, but there was a group x time interaction $F(1,22) = 10.12$, $p < 0.01$, r = 0.56. The intervention elicited an increase in the percentage of backhand winners performed by the experimental group, but a decrease in the control group (see Table 2). Backhand errors revealed main effects for group $F(1,22) = 5.65$, $p < 0.05$, r =

0.45, and time $F(1,22) = 30.77$, $p < 0.001$, r = 0.76. The group x time interaction approached significance $F(1,22) = 4.06$, $p = 0.056$, r = 0.39. The percentage of backhand errors performed by the experimental group decreased by 14.9% from pre- to post-test; the percentage performed by the control group decreased by 7.0%

(Table 2)

3.3. Rally length

Rally length demonstrated a main effect for time $F(1,22) = 4.99$, $p < 0.05$, r = 0.43, but not for group $F(1,22) = 1.40$, $p > 0.05$, r = 0.24, and no group x time interaction $F(1,22) = 0.01$, $p > 0.05$, r = 0.02. Average rally length increased by 0.7 and 0.6 strokes for the control and experimental groups, respectively, after the intervention (see table 2).

3.4. Tennis specific skills testing (TSST)

There was a main effect for rally performance score on time $F(1,14) = 38.91$, $p < 0.001$, r = 0.86, but not group $F(1,14) = 2.41$, $p > 0.05$, r = 0.38. There was a group x time interaction for rally performance score $F(1,14) = 8.09$, $p < 0.05$, r = 0.61. Both groups' average rally performance scores increased; however, the experimental group had greater improvements (7.6 strokes), compared to the control group's (2.9 strokes).

There was a main effect for TSST forehand on time $F(1,14) = 52.74$, $p < 0.001$, r = 0.89, but not for group $F(1,14) = 0.98$, $p > 0.05$, r = 0.26. There was a group x time interaction $F(1,14) = 8.55$, $p < 0.05$, r = 0.62. The experimental group's average score improved by 3.3 points between pre- and post-testing, whereas the control group's improved by 1.5 points, as illustrated in Figure 3.

Analysis of TSST backhand revealed a main effect for time $F(1,14) = 70.23$, $p < 0.001$, r = 0.91, but not for group $F(1,14) = 2.66$, $p > 0.05$, r = 0.40. There was a group x time interaction $F(1,14) = 30.81$, $p < 0.001$, r = 0.83. The experimental group's average score improved by 4.0 points from pre- to post-test; the control group's improved by 0.8 points.

(Figure 3)

4.0. Discussion

This study examined how scaled task constraint manipulations, applied to MT Red coaching sessions, influenced children's emergent movement behaviours during match-play and tennis-specific skills testing. Results showed that the performance of the two groups did not differ during pre-testing; the forehand was the dominant shot selected by both groups, resulting in an asymmetry between backhand and forehand performance. During post-testing, differences became apparent; the experimental group's behaviours resulted in a greater symmetry of stroke performance, with more backhands (46.7 ± 3.3%) and fewer forehands (50.8 ± 3.8%) performed, compared to the control group's continued asymmetry. The experimental group's movement behaviours corresponded closely to the forehand-to-backhand ratios seen in adult tennis (1:1, Reid et al., 2016). It is crucial for learners to develop both groundstrokes if they are to successfully transition through the stages of tennis. Shot selection in tennis is determined by factors including ball velocity, ball trajectory, ball proximity, and court positioning of the participant and their opponent (McGarry & Franks, 1996). Standard MT Red constraints afford participants sufficient time to move around the ball to perform a forehand, when a backhand may otherwise be played (Fitzpatrick et al., 2016). Locating the recovery box slightly towards the forehand side of the court during the intervention, made this behaviour less likely to emerge, as participants were constrained to move a greater distance to position themselves to the left of the ball (for a right-handed player) and perform a forehand. The manipulations effectively re-designed the affordance landscape for the experimental group, requiring them to adapt and explore different movement solutions (Davids, Güllich, Shuttleworth, & Araujo, 2017). In this context, where standard MT Red constraints had enabled participants to perform forehands during the pre-test, the scaling manipulations applied during the intervention appear to have constrained this emergent behaviour, instead facilitating active exploration of the backhand stroke.

Analysis of the percentage of winners and errors performed by each group during match-play demonstrates a further benefit of the adapted constraints. The experimental group's backhand success rates improved more substantially than the control group's. Specifically, the experimental group's backhand error percentage decreased by 14.9% after the intervention, suggesting augmented consistency. Notably, the intervention increased the percentage of backhand winners performed by the experimental group, without eliciting a concomitant, negative effect on forehand performance. The absence of interaction effects in terms of forehand success rates offers strong support for the manipulations applied here, since a movement intervention that enhances backhand performance to the detriment of forehand performance would not be of practical benefit. The manipulations also created a perceptibly larger area of free space on the court, due to the adjusted recovery box location; further research is needed to understand how this re-scaling may stimulate participants' tactical awareness as they learn to exploit the free space in an attempt to acquire a tactical advantage during a rally (Hopper, 2011).

The TSST rally performance scores confirmed that, while both groups demonstrated improvements after the intervention, the experimental group's rally performance improved more than that of the control group, when rallying with a coach. In contrast, the match-play element elicited similar increases in rally length for both groups. In a functional context, rallying in tennis requires an ability to control both the pace and direction of the ball (Van Daalen, 2017). Accordingly, maintaining a rally with a coach, who is capable of such control, is easier for young participants, as illustrated by the higher mean rally lengths during the TSST element compared to the match-play element. Thus, it appears the experimental group's enhanced capacity to control the pace and direction of the ball, was sufficient to elicit longer rallies with the coach than the control group, but insufficient to replicate this during match-play rallies with fellow participants. An interesting issue for future research concerns whether the superior rally capacity demonstrated by the experimental group during the TSST would have eventually been translated into enhanced match-play rally ability, with a longer intervention period.

TSST data showed that the experimental group’s forehand and backhand technical proficiency also improved to a greater extent than the control group’s. It should be highlighted that the technical proficiency scoring system incorporated participants’ movement to the ball and their recovery, as well as back- and forward-swing patterns. So, with the experimental group’s superior TSST scores, the possibility that the intervention enhanced both their movement around the court and their swing technique should not be discounted. As previously observed, rallying in tennis requires good ball control (Van Daalen, 2017), and good ball control indicates competent movement and stroke technique (Rive & Williams, 2012). Considering the three TSST variables collectively suggests that the superior post-test rally ability of the experimental group, may be, in part, attributable to their improved technical proficiency. Furthermore, when participants move around an incoming ball and perform a forehand, when a backhand would be more appropriate, the forehand action elicited is unlikely to be functional (Hodgkinson, 2015). So, if the temptation to move around the ball is reduced by the constraint manipulations, the experimental group may be more likely to perform and acquire a functional action response by electing to play a backhand instead.

Results suggested that the movement intervention implemented effectively complemented the structured MT format, by ameliorating the asymmetry between the percentage of forehands and backhands that emerged during match-play. This intervention was developed primarily to address issues regarding groundstroke development within MT Red. Further studies, whereby additional constraints are designed to encourage a greater range of strokes (e.g. serve, net-play, slice, drop shots) are implied by the data, for participants in all stages of MT. Such investigations may facilitate active exploration and thus, reduce the time required to successfully progress through the MT stages and into Full Ball, with a more comprehensive repertoire of strokes.

In conclusion, the experimental movement intervention implemented here ameliorated the disparity between the percentage of forehands and backhands performed during match-play. Simultaneously, greater backhand success rates, improved rally capacity when rallying with a coach, and enhanced technical proficiency emerged. Movement scientists may wish to implement similar adaptations during scaled versions of tennis sessions, to augment the technical and tactical development of players, and negate the disparity between the number of forehands and backhands typically performed.

5.0. Acknowledgements

The authors would like acknowledge and thank the Lawn Tennis Association accredited coaches for their expertise and facilitation of this study.

6.0. References

Arias, J. L., et al. (2012). Effect of ball mass on dribble, pass, and pass reception in 9-11-year-old boys' basketball. *Research Quarterly in Exercise and Sport*, *83*, 407-412. doi:10.1080/02701367.2012.10599875

Breed, R., & Spittle, M. (2011). *Developing game sense through tactical learning: a resource for teachers and coaches*. Cambridge: Cambridge University Press.

Brown, J. & Soulier, C. (2013). *Tennis: steps to success.* (4th ed.). Champaign: Human Kinetics.

Bryant J. E. (2012). *Game/set/match: a tennis guide*. (8th ed.). Boston: Cengage Learning.

Buszard, T., Farrow, D., Reid, M., & Masters, R. S. W. (2014). Modifying equipment in early skill development: a tennis perspective. *Research Quarterly for Exercise and Sport*, 85, 218-225. doi:10.1080/02701367.2014.893054

Buszard, T., Reid, M., Masters, R., & Farrow, D. (2016). Scaling the equipment and play area in children's sport to improve motor skill acquisition: a systematic review. *Sports Medicine*, 1-15. doi:10.1007/s40279-015-0452-2

Cohen, J. (1988). *Statistical power analysis for the behavioural sciences*. (2nd ed.), Hillsdale: Erlbaum.

Davids, K., Shuttleworth, R., Araújo, D. & Gullich, A. (2017). Understanding environmental and task constraints on athlete development: Analysis of micro-structure of practice and macro-structure of development histories. In J. Baker, S. Cobley, J. Schorer & N. Wattie (Eds.). *Routledge Handbook of Talent Identification and Development in Sport*. pp.192-206. Routledge: London.

Farrow, D. & Reid, M. (2010a). Skill acquisition in tennis, equipping learners for success. In I. Renshaw, K. Davids., & G. J. P. Savelsbergh, (eds.), *Motor learning in practice: a constraints-led approach*. (pp. 231-252) Oxon: Routledge.

Farrow, D. & Reid, M. (2010b). The effect of equipment scaling on the skill acquisition of beginning tennis players. *Journal of Sports Sciences, 28*, 723-732. doi: 10.1080/02640411003770238

Fitzpatrick, A., Davids, K., & Stone, J. A. (2016). Effects of Lawn Tennis Association Mini Tennis as task constraints on children’s match-play characteristics. *Journal of Sports Sciences, 22,* 2204-2210. doi: 10.1080/02640414.2016.1261179

Hammond, J. & Smith, C. (2006). Low compressions tennis balls and skill development. *Journal of Sports Science and Medicine*, *5*, 575-581.

Hodgkinson, M. (2015). *Game, set and match: secret weapons of the world’s top tennis players*. London: Bloomsbury.

Hopper, T. (2011). Game-as-teacher: modification by adaptation in learning through game-play. *Asia-Pacific Journal of Health, Sport and Physical Education*, *2*, 3-21. doi: 10.1080/18377122.2011.9730348

Kachel, K., Buszard, T. & Reid, M. (2015). The effect of ball compression on the match-play characteristics of elite junior tennis players. *Journal of Sports Sciences, 33*, 320-326. doi: 10.1080/02640414.2014.942683

Larson, E J. & Guggenheimer, J D. (2013). The effects of scaling tennis equipment on the forehand groundstroke performance of children. *Journal of Sports Science and Medicine, 12*, 323-331.

LTA. (2017). LTA – Mini Tennis. Retrieved from http://www3.lta.org.uk/LTA-Mini-Tennis

Martens, S. & de Vylder, M. (2007). The use of low compression balls in the development of high performance players. *ITF Coaches Review*, *42*, 3-5.

McGarry, T. & Franks, I. M. (1996). In search of invariant athletic behaviour in competitive sport systems: an example from championship squash match-play. *Journal of Sports Sciences*, 14, 445-456. doi: 10.1080/02640419608727730

Newell, K M. (1986). Constraints on the development of coordination. *Motor development in children: aspects of coordination and control*, *34*, 341-336.

O'Donoghue, P. (2010). *Research methods for sports performance analysis*. (2nd ed.). Oxon: Routledge.

Reid, M., Morgan, S., & Whiteside, D. (2016). Matchplay characteristics of Grand Slam tennis: implications for training and conditioning. *Journal of Sports Sciences, 34,* 1791-1798. doi: 10.1080/02640414.2016.1139161

Rive, J. & Williams, S C. (2012). *Tennis skills and drills*. Champaign: Human Kinetics.

Timmerman, E., de Water, J., Kachel, K., Reid, M., Farrow, D. & Savelsbergh, G. (2015). The effect of equipment scaling on children's sport performance: the case for tennis. *Journal of Sports Sciences*, *33,* 1093-1100. doi: 10.1080/02640414.2014.986498

Van Daalen, M. (2017). *Teaching tennis volume 2: the development of advanced players*. Bloomington: Xlibris.

Table 1. Match-play key performance indicators, operational definitions and outcome measure calculation, derived from Fitzpatrick et al. (2016).

KPI and Outcome Measure	Operational Definition and Calculation
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
Successful shot	A shot that lands inside the relevant court boundaries
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 in which the opponent is not able to make contact with the ball, resulting in the point being won
Rally	The series of shots once a point has begun; a rally continues until the point has been won or lost
Forehand %	(Number of forehands / total shots played after the serve) x 100
Backhand %	(Number of backhands / (total shots played after the serve) x 100
Forehand winners (%)	(Number of forehand winners / total number of forehands) x 100
Backhands winners (%)	(Number of backhand winners / total number of backhands) x 100
Forehand errors (%)	(Number of forehand errors / total number of forehands) x 100
Backhand errors (%)	(Number of backhand errors / total number of backhands) x 100
Average rally length	(Rally length$_1$ + rally length$_2$... + rally length$_n$) / total number of rallies

Table 2. Groundstroke winner and error percentages and rally length, displayed as mean (*SD*), and differences between pre- and post-testing.

	Forehand winners (%)		Forehand errors (%)		Backhand winners (%)		Backhand errors (%)		Rally length (strokes)	
	Control	Experimental	Control	Experimental	Control	Experimental	Control	Experimental	Control	Experimental
Pre-test	3.5 (3.2)	1.6 (2.0)	25.0 (14.8)	17.2 (10.2)	5.0 (6.5)	2.0 (3.8)	41.7 (19.2)	31.1 (12.1)	4.5 (1.6)	5.3 (1.9)
Post-test	2.2 (4.5)	4.0 (2.7)	19.6 (11.5)	13.6 (5.2)	1.0 (3.6)	5.5 (3.0)	34.7 (16.0)	16.2 (5.9)	5.2 (1.9)	5.9 (1.2)
Difference	-1.3	2.4	-5.4	-3.6	-4.0	3.5	-7.0	-14.9	0.7	0.6

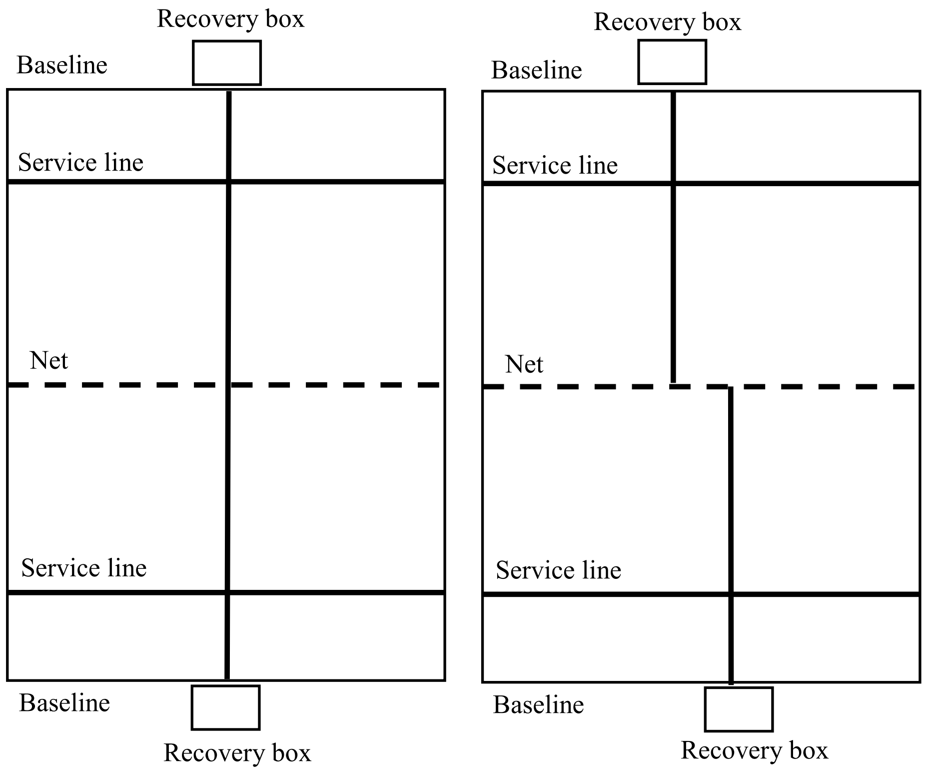
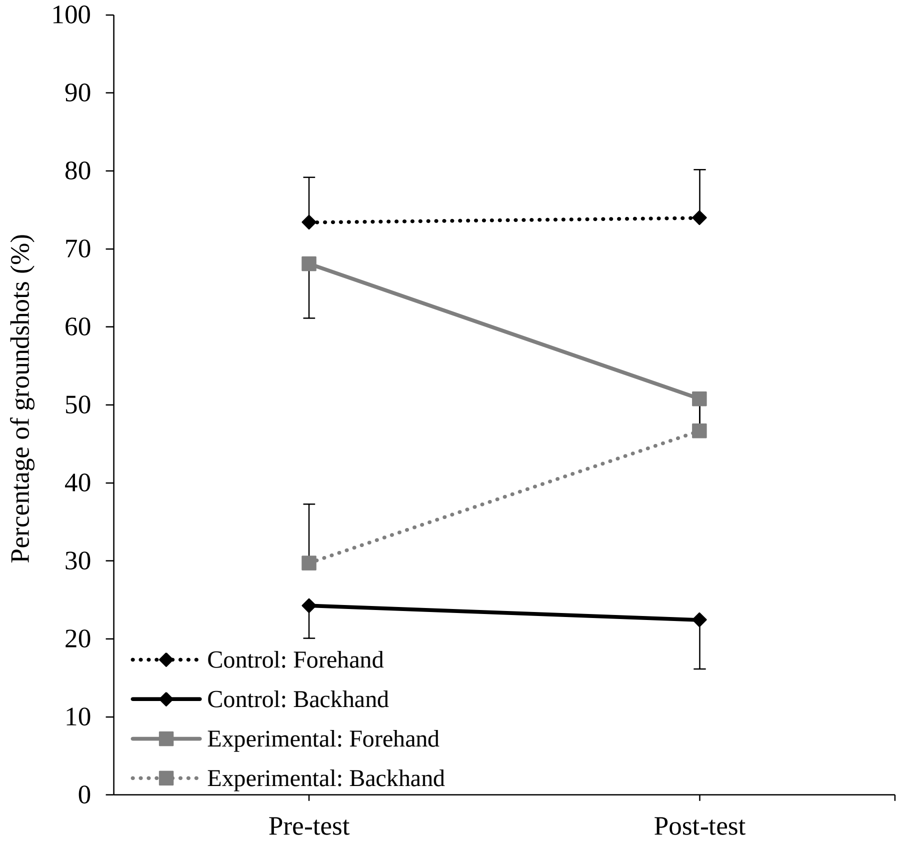


Figure 1. Recovery box locations and centre lines for the control group (left) and experimental group (right).



462

463 **Figure 2.** Percentage of forehands and backhands performed by each group during pre and post testing

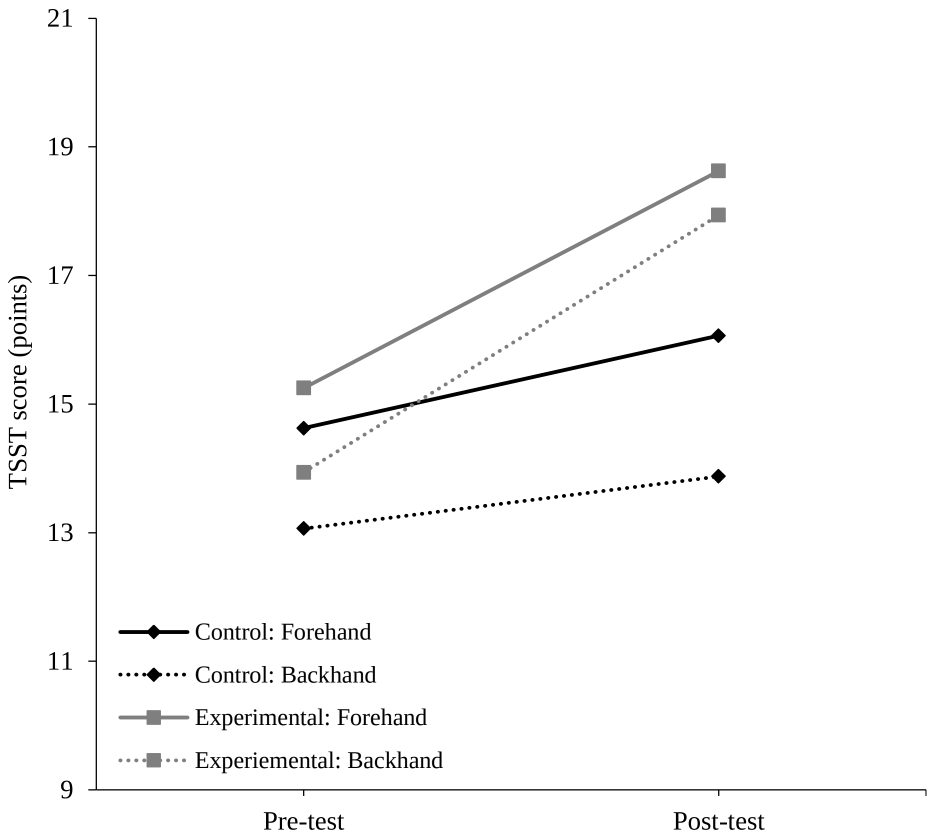


Figure 3. Pre and Post TSST forehand and Backhand scores for each group.