

**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>>

Available from Sheffield Hallam University Research Archive (SHURA) at:

<http://shura.shu.ac.uk/18553/>

---

This document is the author deposited version. You are advised to consult the publisher's version if you wish to cite from it.

**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**

See <http://shura.shu.ac.uk/information.html>

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

3 Anna Fitzpatrick<sup>1</sup>, Keith Davids<sup>2</sup> & Joseph. A. Stone<sup>1</sup>

4 <sup>1</sup>Academy of Sport and Physical Activity, Sheffield Hallam University, Sheffield, UK

5 <sup>2</sup>Centre for Sports Engineering Research, Sheffield Hallam University, Sheffield, UK

6

7 Corresponding author: Joseph Stone, A213, Collegiate Hall, Collegiate Crescent,  
8 Sheffield Hallam University, Sheffield, S10 2BP. Tel: +44 (0)114 225 5413.

9 E-mail: Joseph.stone@shu.ac.uk.

10

11

12

13

14

15

16

17

18

19

20

21

22 **Abstract**

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

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

45

46 **1.0. Introduction**

47 Racquet sports, like tennis, are characterised by repeated, dynamic interceptive  
48 actions, and participants require a high level of technical and physical proficiency to be able  
49 to generate and maintain effective movement patterns (Farrow & Reid, 2010a). With elements  
50 such as motor coordination, on court movement and game tactics to consider, inexperienced  
51 participants can find the sport's demands particularly challenging (Breed & Spittle, 2011).  
52 Consequently, tennis federations have developed modified versions of the sport, theoretically  
53 underpinned by Newell's (1986) constraints-led approach, designed to augment skill  
54 development and enable inexperienced participants' performance behaviours to more closely  
55 reflect those required in the full version of the game (Timmerman et al., 2015). The British  
56 Lawn Tennis Association's Mini Tennis (MT) is one such scaled game version (Hammond &  
57 Smith, 2006). MT comprises three structured, progressive stages (Red, Orange and Green),  
58 with scoring format, court dimensions, net height and ball characteristics modified at each  
59 stage to facilitate participants' functional movement behaviours (Fitzpatrick, Davids, &  
60 Stone, 2016). However, many scaled formats of tennis, including MT, have been  
61 implemented based on expert practitioner opinion and experiential knowledge, requiring  
62 empirical evidence to affirm potential functional benefits (Buszard, Farrow, Reid & Masters,  
63 2014). Accordingly, recent research has strived to substantiate the implementation of MT  
64 constraints for enhancing children's skill acquisition (Timmerman et al., 2015; Kachel,  
65 Buszard & Reid, 2015).

66 Constraints are boundaries pertaining to the performer, the task or environment which  
67 confine and/or facilitate the behavioural movement patterns that a complex dynamical system  
68 can adopt (Newell, 1986). Adapting task constraints encourages performers to explore how  
69 manipulations shape available affordances (possibilities for action). Research has suggested  
70 that effective manipulation of constraints in children's sport can facilitate emergence of  
71 functional coordinative movements (Arias et al., 2012). In tennis, scoring format, court  
72 dimensions, net height and ball characteristics are considered key task constraints that can be

73 scaled to influence movement behaviours. Modifying these aspects, through scaling, enables  
74 inexperienced participants to perform, without the need to contend with the challenging  
75 constraints of Full Ball tennis. However, it is important that the modifications simplify  
76 movement demands while maintaining perception-action couplings that are functional in the  
77 full version of the game (Buszard, Reid, Masters, & Farrow, 2016). For example, a reduced  
78 compression tennis ball that bounces lower facilitates inexperienced participants'  
79 groundstroke performance, by allowing them to adopt a swing height that is scaled to their  
80 physical dimensions. It has been proposed that this re-scaling of movement is more conducive  
81 to skill development than the swing height needed to strike a higher-bouncing, standard tennis  
82 ball (Kachel et al., 2015).

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

99 MT was designed to reduce the speed of the game, such that children's emergent  
100 behaviours closely reflect those needed in the full version of the sport (Buszard et al., 2016).  
101 Despite considerable evidence to suggest that MT task constraints augment children's  
102 technical and tactical development, claims that MT evokes emergent behaviours that closely  
103 resemble those of the full game have, thus far, been largely speculative. Fitzpatrick et al.  
104 (2016) investigated this concept, examining effects of MT and Full Ball task constraints on  
105 children's movement behaviours; MT Red constraints elicited longer rallies and fewer errors  
106 than Full Ball constraints. Thus MT Red participants were afforded more opportunities to  
107 perform strokes in a relevant performance environment. However, findings also indicated that  
108 MT Red participants performed considerably more forehands than backhands (i.e. 2:1 ratio)  
109 during match-play; in contrast, the ratio of forehands performed compared to backhands in  
110 Full Ball is closer to 1:1 (Reid, Morgan, & Whiteside, 2016). The disparity may be even  
111 greater within MT coaching sessions; in Farrow and Reid's (2010b) intervention study, the  
112 scaled court-modified balls condition elicited a mean ratio of approximately 6:1 in favour of  
113 the forehand. This focus on the forehand is reflected within the literature, with several studies  
114 examining the effects of MT constraints on forehand performance (Buszard et al., 2014;  
115 Hammond & Smith, 2006; Larson & Guggenheimer, 2013), but few investigating the impact  
116 on backhand performance.

117 Fitzpatrick et al. (2016) noted that this disparity between forehand and backhand  
118 performance at MT Red may lead to a skill imbalance over time, to the possible detriment of  
119 performance development. For example, if MT Red constraints do not afford participants  
120 sufficient opportunity to perform backhands, the stroke may not adequately develop, thus  
121 potentially affecting development by allowing weaknesses to emerge. It is currently not  
122 known whether a constraints-based intervention can alleviate this asymmetry in groundstroke  
123 performance. Hence, based on application of Newell's (1986) constraints-led approach, we  
124 developed a movement intervention designed to enhance skill acquisition, while  
125 simultaneously accounting for the asymmetry between groundstrokes at MT Red. The aim

126 was to investigate the effects of an 8-week constraints-based movement intervention on  
127 children's match-play behaviours and tennis-specific skills test performances, with a focus on  
128 backhand stroke development.

## 129 **2.0. Methods**

### 130 2.1. Participants

131 Sixteen participants, each of an appropriate age for MT Red, and with a minimum of  
132 6 months of tennis playing experience, participated voluntarily and were randomly assigned  
133 to one of two groups: control ( $n = 8$ , age =  $7.2 \pm 0.6$  years, tennis playing experience =  $1.9 \pm$   
134  $0.6$  years) and experimental ( $n = 8$ , age =  $7.4 \pm 0.4$  years, tennis playing experience =  $2.1 \pm$   
135  $0.6$  years). Informed consent was provided by all participants and their parents or legal  
136 guardians, and ethical approval was granted by the Local University ethics committee.

### 137 2.2. Procedure

#### 138 2.2.1. Pre-Test

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

145 During the TSST, participants were required to maintain three consecutive  
146 groundstroke rallies (i.e. forehands and backhands) for as long as possible with the coach. The  
147 coach controlled the pace and direction of their feeding throughout, to ensure consistency  
148 between participants. The mean number of consecutive strokes that travelled over the net and  
149 landed in the court, including those of the coach, was recorded, giving a rally performance  
150 score. Video replay enabled the qualitative assessment of participants' technical proficiency,  
151 independently by two LTA Level 3 accredited tennis coaches. They each had at least 6 years

152 of experience coaching MT players and were not aware of the specific research objectives.  
153 The coaches qualitatively assessed four aspects of stroke production for forehands and  
154 backhands, respectively: (i) preparation (including movement to the ball), (ii) backswing, (iii)  
155 ball impact and follow-through, and (iv), recovery, using a 7-point scale (Farrow & Reid,  
156 2010b). The four scores were summed for each player's forehand and backhand, producing a  
157 maximum achievable score of 28 points per stroke. Both coaches performed the assessment  
158 on two separate occasions, 3 days apart, to facilitate reliability calculations; the interclass  
159 correlation coefficient between the two coaches was 0.88, defined as excellent by Cohen  
160 (1988).

### 161 2.2.2. Intervention

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



177 Pre-test match-play data supported the earlier findings of Fitzpatrick et al. (2016),  
178 revealing that MT Red players performed a disproportionately high number of forehands and  
179 low number of backhands compared to Full Ball players. This information, alongside a  
180 comprehensive understanding of commonly used tennis coaching drills (Brown & Soulier,  
181 2013; Bryant, 2012; Hopper, 2011), facilitated the design of constraints-based pedagogical  
182 adaptations that were implemented during the experimental group's intervention sessions, to  
183 influence their emergent behaviours. Adaptations included manipulations of: (i) internal court  
184 dimensions, (ii) recovery box location, and (iii), practice match-play rules and scoring format,  
185 as follows:

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

191 (ii) *Recovery box location*: for the duration of the intervention, recovery boxes were  
192 applied using masking tape (Brown & Soulier, 2013; Bryant, 2012), approximately  
193 0.2 m behind and 0.3 m to the right of the centre of the baseline (for right-handed  
194 players), as shown in Figure 1. Players were asked to attempt to return to the recovery  
195 box after each stroke.

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

200 (Figure 1)

201 2.2.3. Post-test



227 3.1.1. Forehand

228 Analysis revealed main effects for time  $F(1,22) = 23.41, p < 0.001, r = 0.72$ , and  
229 group  $F(1,22) = 77.77, p < 0.001, r = 0.88$ , and a group x time interaction  $F(1,22) = 26.62, p$   
230  $< 0.001, r = 0.74$ . Figure 2 shows the percentage of forehands performed by the experimental  
231 group decreased by 17.3% after the intervention; the percentage performed by the control  
232 group did not differ.

233 3.1.2. Backhand

234 There were main effects for time  $F(1,22) = 22.00, p < 0.001, r = 0.71$ , and group  
235  $F(1,22) = 81.75, p < 0.001, r = 0.89$ , and a group x time interaction  $F(1,22) = 33.91, p <$   
236  $0.001, r = 0.78$ . Figure 2 illustrates that the percentage of backhands played by the  
237 experimental group increased by 17.0% after the intervention; the percentage performed by  
238 the control group decreased by 1.8%.

239 (Figure 2)

240 3.2. Winners and errors

241 Forehand winners analysis revealed no main effects for time  $F(1,22) = 0.25, p > 0.05$ ,  
242  $r = 0.11$ , or group  $F(1,22) = 0.03, p > 0.05, r = 0.04$ , and no group x time interaction  $F(1,22)$   
243  $= 2.71, p > 0.05, r = 0.33$ . There were no main effects for time  $F(1,22) = 3.35, p > 0.05, r =$   
244  $0.36$ , or group  $F(1,22) = 3.45, p > 0.05, r = 0.37$ , and no group x time interaction  $F(1,22) =$   
245  $0.14, p > 0.05, r = 0.08$  for forehand errors.

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

251 0.45, and time  $F(1,22) = 30.77, p < 0.001, r = 0.76$ . The group x time interaction approached  
252 significance  $F(1,22) = 4.06, p = 0.056, r = 0.39$ . The percentage of backhand errors performed  
253 by the experimental group decreased by 14.9% from pre- to post-test; the percentage  
254 performed by the control group decreased by 7.0%

255 (Table 2)

### 256 3.3. Rally length

257 Rally length demonstrated a main effect for time  $F(1,22) = 4.99, p < 0.05, r = 0.43$ ,  
258 but not for group  $F(1,22) = 1.40, p > 0.05, r = 0.24$ , and no group x time interaction  $F(1,22) =$   
259  $0.01, p > 0.05, r = 0.02$ . Average rally length increased by 0.7 and 0.6 strokes for the control  
260 and experimental groups, respectively, after the intervention (see table 2).

### 261 3.4. Tennis specific skills testing (TSST)

262 There was a main effect for rally performance score on time  $F(1,14) = 38.91, p <$   
263  $0.001, r = 0.86$ , but not group  $F(1,14) = 2.41, p > 0.05, r = 0.38$ . There was a group x time  
264 interaction for rally performance score  $F(1,14) = 8.09, p < 0.05, r = 0.61$ . Both groups'  
265 average rally performance scores increased; however, the experimental group had greater  
266 improvements (7.6 strokes), compared to the control group's (2.9 strokes).

267 There was a main effect for TSST forehand on time  $F(1,14) = 52.74, p < 0.001, r =$   
268  $0.89$ , but not for group  $F(1,14) = 0.98, p > 0.05, r = 0.26$ . There was a group x time  
269 interaction  $F(1,14) = 8.55, p < 0.05, r = 0.62$ . The experimental group's average score  
270 improved by 3.3 points between pre- and post-testing, whereas the control group's improved  
271 by 1.5 points, as illustrated in Figure 3.

272 Analysis of TSST backhand revealed a main effect for time  $F(1,14) = 70.23, p <$   
273  $0.001, r = 0.91$ , but not for group  $F(1,14) = 2.66, p > 0.05, r = 0.40$ . There was a group x time  
274 interaction  $F(1,14) = 30.81, p < 0.001, r = 0.83$ . The experimental group's average score

275 improved by 4.0 points from pre- to post-test; the control group's improved by 0.8 points.

276 (Figure 3)

#### 277 **4.0. Discussion**

278 This study examined how scaled task constraint manipulations, applied to MT Red coaching  
279 sessions, influenced children's emergent movement behaviours during match-play and tennis-  
280 specific skills testing. Results showed that the performance of the two groups did not differ  
281 during pre-testing; the forehand was the dominant shot selected by both groups, resulting in  
282 an asymmetry between backhand and forehand performance. During post-testing, differences  
283 became apparent; the experimental group's behaviours resulted in a greater symmetry of  
284 stroke performance, with more backhands ( $46.7 \pm 3.3\%$ ) and fewer forehands ( $50.8 \pm$   
285  $3.8\%$ ) performed, compared to the control group's continued asymmetry. The  
286 experimental group's movement behaviours corresponded closely to the forehand-to-  
287 backhand ratios seen in adult tennis (1:1, Reid et al., 2016). It is crucial for learners to  
288 develop both groundstrokes if they are to successfully transition through the stages of tennis.  
289 Shot selection in tennis is determined by factors including ball velocity, ball trajectory, ball  
290 proximity, and court positioning of the participant and their opponent (McGarry & Franks,  
291 1996). Standard MT Red constraints afford participants sufficient time to move around the  
292 ball to perform a forehand, when a backhand may otherwise be played (Fitzpatrick et al.,  
293 2016). Locating the recovery box slightly towards the forehand side of the court during the  
294 intervention, made this behaviour less likely to emerge, as participants were constrained to  
295 move a greater distance to position themselves to the left of the ball (for a right-handed  
296 player) and perform a forehand. The manipulations effectively re-designed the affordance  
297 landscape for the experimental group, requiring them to adapt and explore different  
298 movement solutions (Davids, Güllich, Shuttleworth, & Araujo, 2017). In this context, where  
299 standard MT Red constraints had enabled participants to perform forehands during the pre-

300 test, the scaling manipulations applied during the intervention appear to have constrained this  
301 emergent behaviour, instead facilitating active exploration of the backhand stroke.

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

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

327 the superior rally capacity demonstrated by the experimental group during the TSST would  
328 have eventually been translated into enhanced match-play rally ability, with a longer  
329 intervention period.

330 TSST data showed that the experimental group's forehand and backhand technical  
331 proficiency also improved to a greater extent than the control group's. It should be  
332 highlighted that the technical proficiency scoring system incorporated participants' movement  
333 to the ball and their recovery, as well as back- and forward-swing patterns. So, with the  
334 experimental group's superior TSST scores, the possibility that the intervention enhanced  
335 both their movement around the court and their swing technique should not be discounted. As  
336 previously observed, rallying in tennis requires good ball control (Van Daalen, 2017), and  
337 good ball control indicates competent movement and stroke technique (Rive & Williams,  
338 2012). Considering the three TSST variables collectively suggests that the superior post-test  
339 rally ability of the experimental group, may be, in part, attributable to their improved  
340 technical proficiency. Furthermore, when participants move around an incoming ball and  
341 perform a forehand, when a backhand would be more appropriate, the forehand action elicited  
342 is unlikely to be functional (Hodgkinson, 2015). So, if the temptation to move around the ball  
343 is reduced by the constraint manipulations, the experimental group may be more likely to  
344 perform and acquire a functional action response by electing to play a backhand instead.

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

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

### 361 **5.0. Acknowledgements**

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

### 364 **6.0. References**

- 365 Arias, J. L., et al. (2012). Effect of ball mass on dribble, pass, and pass reception in 9-11-year-  
366 old boys' basketball. *Research Quarterly in Exercise and Sport*, 83, 407-412.  
367 doi:10.1080/02701367.2012.10599875
- 368 Breed, R., & Spittle, M. (2011). *Developing game sense through tactical learning: a resource*  
369 *for teachers and coaches*. Cambridge: Cambridge University Press.
- 370 Brown, J. & Soulier, C. (2013). *Tennis: steps to success*. (4th ed.). Champaign: Human  
371 Kinetics.
- 372 Bryant J. E. (2012). *Game/set/match: a tennis guide*. (8th ed.). Boston: Cengage Learning.
- 373 Buszard, T., Farrow, D., Reid, M., & Masters, R. S. W. (2014). Modifying equipment in early  
374 skill development: a tennis perspective. *Research Quarterly for Exercise and Sport*,  
375 85, 218-225. doi:10.1080/02701367.2014.893054
- 376 Buszard, T., Reid, M., Masters, R., & Farrow, D. (2016). Scaling the equipment and play area  
377 in children's sport to improve motor skill acquisition: a systematic review. *Sports*  
378 *Medicine*, 1-15. doi:10.1007/s40279-015-0452-2
- 379 Cohen, J. (1988). *Statistical power analysis for the behavioural sciences*. (2nd ed.), Hillsdale:  
380 Erlbaum.



- 381 Davids, K., Shuttleworth, R., Araújo, D. & Gullich, A. (2017). Understanding environmental  
382 and task constraints on athlete development: Analysis of micro-structure of practice  
383 and macro-structure of development histories. In J. Baker, S. Cobley, J. Schorer & N.  
384 Wattie (Eds.). *Routledge Handbook of Talent Identification and Development in*  
385 *Sport*. pp.192-206. Routledge: London.
- 386 Farrow, D. & Reid, M. (2010a). Skill acquisition in tennis, equipping learners for success. In  
387 I. Renshaw, K. Davids., & G. J. P. Savelsbergh, (eds.), *Motor learning in practice: a*  
388 *constraints-led approach*. (pp. 231-252) Oxon: Routledge.
- 389 Farrow, D. & Reid, M. (2010b). The effect of equipment scaling on the skill acquisition of  
390 beginning tennis players. *Journal of Sports Sciences*, 28, 723-732. doi:  
391 10.1080/02640411003770238
- 392 Fitzpatrick, A., Davids, K., & Stone, J. A. (2016). Effects of Lawn Tennis Association Mini  
393 Tennis as task constraints on children's match-play characteristics. *Journal of Sports*  
394 *Sciences*, 22, 2204-2210. doi: 10.1080/02640414.2016.1261179
- 395 Hammond, J. & Smith, C. (2006). Low compressions tennis balls and skill development.  
396 *Journal of Sports Science and Medicine*, 5, 575-581.
- 397 Hodgkinson, M. (2015). *Game, set and match: secret weapons of the world's top tennis*  
398 *players*. London: Bloomsbury.
- 399 Hopper, T. (2011). Game-as-teacher: modification by adaptation in learning through game-  
400 play. *Asia-Pacific Journal of Health, Sport and Physical Education*, 2, 3-21. doi:  
401 10.1080/18377122.2011.9730348
- 402 Kachel, K., Buszard, T. & Reid, M. (2015). The effect of ball compression on the match-play  
403 characteristics of elite junior tennis players. *Journal of Sports Sciences*, 33, 320-326.  
404 doi: 10.1080/02640414.2014.942683
- 405 Larson, E J. & Guggenheimer, J D. (2013). The effects of scaling tennis equipment on the  
406 forehand groundstroke performance of children. *Journal of Sports Science and*  
407 *Medicine*, 12, 323-331.
- 408 LTA. (2017). LTA – Mini Tennis. Retrieved from <http://www3.lta.org.uk/LTA-Mini-Tennis>
- 409 Martens, S. & de Vylder, M. (2007). The use of low compression balls in the development of  
410 high performance players. *ITF Coaches Review*, 42, 3-5.

- 411 McGarry, T. & Franks, I. M. (1996). In search of invariant athletic behaviour in competitive  
412 sport systems: an example from championship squash match-play. *Journal of Sports*  
413 *Sciences*, 14, 445-456. doi: 10.1080/02640419608727730
- 414 Newell, K M. (1986). Constraints on the development of coordination. *Motor development in*  
415 *children: aspects of coordination and control*, 34, 341-336.
- 416 O'Donoghue, P. (2010). *Research methods for sports performance analysis*. (2nd ed.). Oxon:  
417 Routledge.
- 418 Reid, M., Morgan, S., & Whiteside, D. (2016). Matchplay characteristics of Grand Slam  
419 tennis: implications for training and conditioning. *Journal of Sports Sciences*, 34,  
420 1791-1798. doi: 10.1080/02640414.2016.1139161
- 421 Rive, J. & Williams, S C. (2012). *Tennis skills and drills*. Champaign: Human Kinetics.
- 422 Timmerman, E., de Water, J., Kachel, K., Reid, M., Farrow, D. & Savelsbergh, G. (2015).  
423 The effect of equipment scaling on children's sport performance: the case for tennis.  
424 *Journal of Sports Sciences*, 33, 1093-1100. doi: 10.1080/02640414.2014.986498
- 425 Van Daalen, M. (2017). *Teaching tennis volume 2: the development of advanced players*.  
426 Bloomington: Xlibris.
- 427
- 428
- 429
- 430
- 431
- 432
- 433
- 434
- 435
- 436

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

<b>KPI and Outcome Measure</b>	<b>Operational Definition and Calculation</b>
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 %	$(\text{Number of forehands} / \text{total shots played after the serve}) \times 100$
Backhand %	$(\text{Number of backhands} / (\text{total shots played after the serve}) \times 100$
Forehand winners (%)	$(\text{Number of forehand winners} / \text{total number of forehands}) \times 100$
Backhands winners (%)	$(\text{Number of backhand winners} / \text{total number of backhands}) \times 100$
Forehand errors (%)	$(\text{Number of forehand errors} / \text{total number of forehands}) \times 100$
Backhand errors (%)	$(\text{Number of backhand errors} / \text{total number of backhands}) \times 100$
Average rally length	$(\text{Rally length}_1 + \text{rally length}_2 \dots + \text{rally length}_n) / \text{total number of rallies}$

439

440

441

442

443

444

445

446

447 **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

448

449

450

451

452

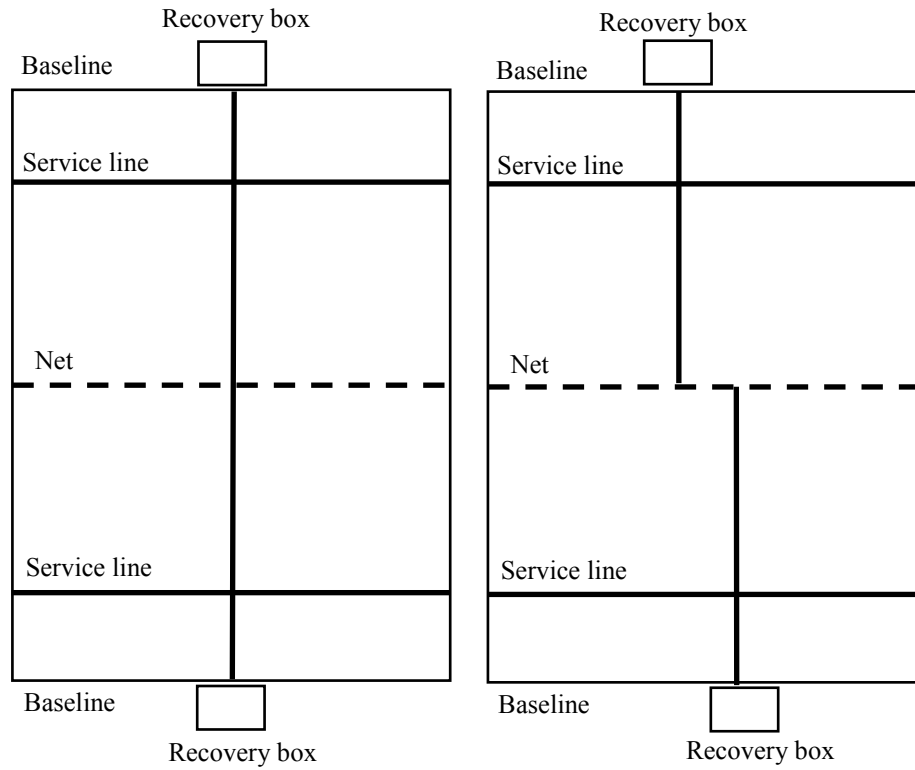
453

454

455

456

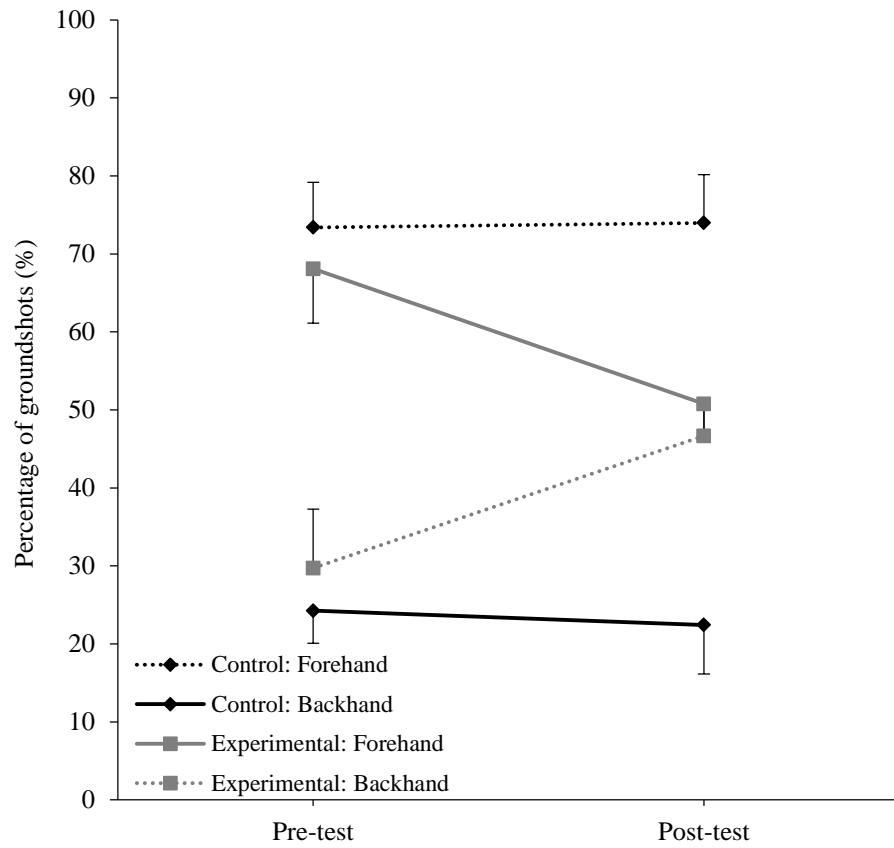
457



458

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

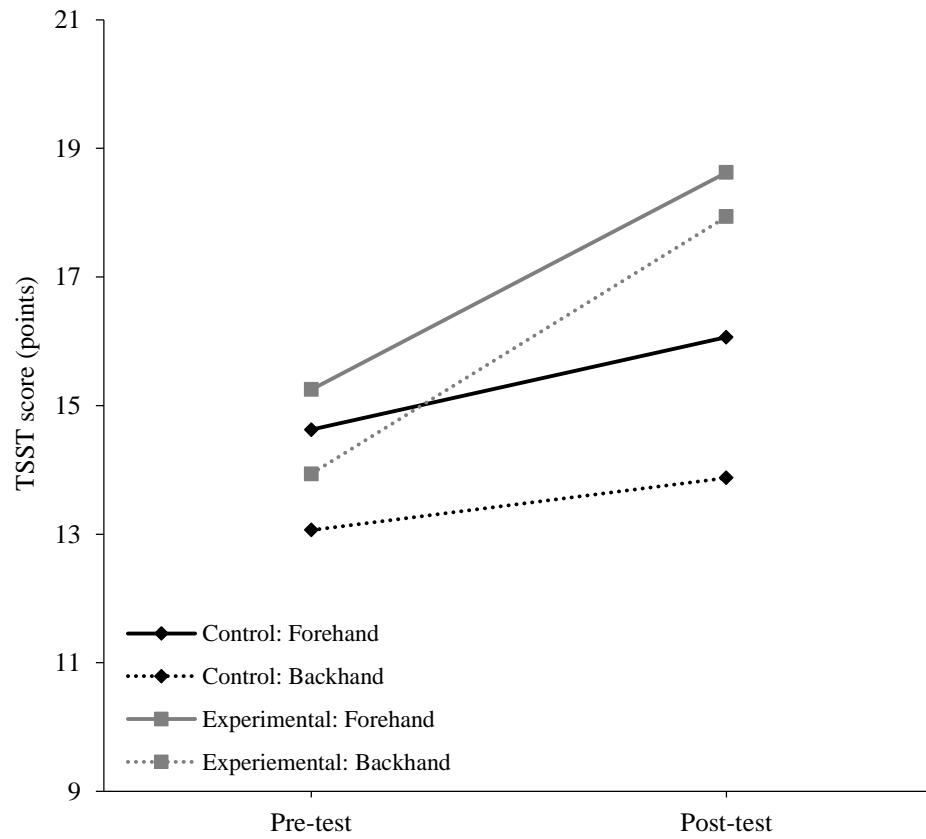
461



462

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

464



465

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

467

468

469

470

471