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1 Do serve distance and net height modify serve biomechanics in young tennis 2 players?

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2 Cantin^b, Caroline Martin^{a*}

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1 The aim of this study was to determine whether decreasing serving distance and
2 net height would immediately influence serve biomechanics and performance in young
3 intermediate tennis players. Ten young tennis players (9 to 12 years) performed maximal
4 effort flat serves from three court conditions (“red”, “orange” and “green”: serving
5 distance at 6.40, 9.00 and 11.89 m from the net and net height at 0.80 m, 0.80 m and
6 0.91m, respectively). A radar measured ball speed while serve kinetics and kinematics
7 were calculated with a 20-camera optical motion capture system. Repeated measures
8 ANOVAs were used to analyze the effect of the three conditions on ball speed, serve
9 kinematics and kinetics. No significant differences in shoulder and elbow kinetics were
10 observed between the three conditions. Ball speed, maximal flexion angle of the back
11 knee and maximal angular velocities of back knee extension and trunk flexion
12 significantly improved when players serve from the red conditions in comparison with
13 green ones. This study shows that reducing serve distance and net height may be an
14 effective coaching strategy to immediately increase ball speed, leg drive and trunk flexion
15 in young tennis players.

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1 **Keywords:** kinetics, performance, motion analysis

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38 Introduction

39 The serve is one of the most important strokes in tennis. In high-level players, the ability to
40 produce high ball speed and first serve percentage is a key element of successful play because
41 it puts the opponent under stress and may hinder its return¹. Many years of training are required
42 to develop an accurate and consistent high-speed tennis serve. Reaching elite or professional
43 levels often requires players to begin tennis training at a young age.

44 In accordance with studies showing beneficial effects of child-specific tennis scaling on
45 skills development^{2 3 4 5}, the International Tennis Federation and national tennis organizations
46 have proposed tennis programs with equipment (racket, ball, net and court sizes) adaptations in
47 recent years (International Tennis Federation's "Tennis 10s Program"⁶, French Tennis
48 Federation's "Galaxie Tennis"⁷, Lawn Tennis Association's Tennis for Kids Programme⁸,
49 Tennis Australia's "MLC Tennis Hot Shots"⁹) to facilitate the long-term development of tennis
50 players and the strokes learning. These programs proposed different tennis stages for young
51 players based on different ball colors, court dimensions and net height. In the French Tennis
52 Federation's Galaxie Tennis program, the "white" stage is recommended for 5 years players
53 who roll a white ball (20 cm in diameter, no rebound) on a small "white" court (length: 8.00 m;
54 without net). The "purple" stage is recommended for 5-6 years players who use purple balls (20
55 cm in diameter, no rebound) on a small "white" court (length: 11.00 m; net height: 0.50 m).
56 The "red" stage is recommended for 6-8 years players who use red balls (75% slower than
57 yellow ones) on a small "red" court (length: 12.80m; net height: 0.80 m). The "orange" stage
58 is recommended for 8-10 years players who use orange ball (50% slower than yellow ones) on
59 an intermediate "orange" court (length: 18m, net height: 0.80 m). The "green" stage is
60 recommended for 9-10 years players who use green balls (25% slower than yellow ones) on a
61 traditional court (length: 23.77 m, net height: 0.91 m). The "yellow" or traditional stage is

62 recommended for players from 10 – 12 years who use the traditional balls on a traditional court
63 (length: 23.77 m, net height: 0.91 m)⁶.

64 From a general perspective, reducing court size and lowering net height allows children
65 to play tennis in a manner that more closely represents the adult or professional game¹⁰: more
66 aggressive play with more groundstrokes winners^{11 12}, volleys and shots played at a comfortable
67 height¹³. Gimenez-Egido et al., (2019) evaluated the immediate effect of reducing net height
68 (from 0.91 to 0.80 m) and court dimensions (from “green” / traditional court – 23.77 m to
69 “orange” court – 18 m) on serve effectiveness in under 10 (U10) tennis players. They reported
70 a greater serve effectiveness in “orange” court¹⁴. Moreover, other studies reported a lack of
71 adaptation at the “green” court for under 10 years old (U10) players and at the “yellow” court
72 for under 12 years old (U12) players. Fitzpatrick et al. (2017) compared progressive stages in
73 simulated matches (U7 “red”, U9 “orange”, U10 “green” and U12 “yellow”)¹⁵. They noticed
74 that the lowest success rate on first serves was at the U10 “green” stage. Moreover, Schmidhofer
75 et al. (2014) compared serve statistics (aces, 1st serve percentage, double faults, 1st and 2nd serve
76 points won) between professional players (ATP) and the best Austrian kid players of the U9,
77 U10 and U12 age categories¹⁶. U9 played on an “orange” court with orange balls, U10 played
78 on a “green” court with green balls and U12 played on a “yellow” regular court with regular
79 balls. Results demonstrated that the U9 “orange” players have higher values in the percentage
80 of 1st serve points won (%) than the U10 “green” (+7.6%) and U12 “yellow” players (+7.1%)¹⁶.
81 These results indicate lower serve effectiveness for U10 and U12 players on “green” and
82 “yellow” courts.

83 Tennis coaches spend considerable time advancing specific interventions or drills in the
84 hope of improving serve biomechanics to enhance performance and to reduce injury risks¹⁷.
85 Among all the possible interventions, coaches prescribe drills with scaling constraints in the
86 environment to facilitate skill acquisition^{10 18}. During training sessions, they often ask U10 and

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2
3 87 U12 tennis players to serve closer from the net and with a lower net height¹⁸ than recommended
4
5 88 by the different tennis programs for kids (Tennis 10s, Galaxie Tennis, MLC Tennis Hot Shots).
6

7 89 While coaches are encouraged to decrease the serving distance and the height of the net
8
9 90 to favor serve acquisition, effectiveness and offensive intentions in young tennis players¹⁸, the
10
11 91 immediate effect of these scaling constraints on serving kinematics, joint kinetics, and injury
12
13 92 risks is largely unknown and need to be considered. Consequently, the aim of this study was to
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15 93 determine the influence of serving conditions (serving distance and height of the net) on the
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17 94 serve biomechanics in young tennis players. We hypothesize that ball speed, racket velocity,
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19 95 upper and lower limb joint kinematics would be increased and upper limb joint kinetics would
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21 96 be decreased when the serving distance and the height of the net are reduced.
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28 98 **Materials and Methods**

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30 99 Ten young intermediate competitive tennis players (five boys and five girls, age: $10.2 \pm$
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32 100 1.4 years, height: 1.41 ± 0.09 m, weight: 31.8 ± 6.7 kg), with an International Tennis Number
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34 101 between 6 and 9 and at least 3 years of practice, participated voluntarily in this study. Eight
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36 102 were right-handed and two were left-handed. All the players were involved in a local training
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38 103 program coordinated by the Ille-et-Vilaine departmental Committee of the French Tennis
39
40 104 Federation. All the players were used to train and compete on tennis courts with traditional
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42 105 dimensions (23.77×8.23 m) and with green balls. At the time of testing, all the players were
43
44 106 considered healthy, with no history of surgery on the dominant arm. Testing was conducted in
45
46 107 an indoor tennis court at the M2S Laboratory. Before experimentation, the players and their
47
48 108 parents provided informed consent, medical history and were fully informed of the procedures.
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50 109 The study was approved by the local ethics committee and conducted in accordance with the
51
52 110 1975 Declaration of Helsinki. No potential conflicts of interest exist.
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3 111 Forty-three retro-reflective markers were placed on the player's bony landmarks and
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5 112 five markers were located on the racket as described in a previous study¹⁹. After a warm-up of
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7 113 at least 15 minutes, including general warm-up and serve repetitions (as many repetitions as
8
9 114 needed to familiarize with the testing equipment), each player performed three successful flat
10 115 serves with "green" balls from three different serving distances corresponding to the "red",
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12 116 "orange" and "green" courts (respectively 6.40m, 9.00m and 11.89m from the net) to the deuce
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14 117 service box in a randomized order. Players were asked to hit the ball as fast as possible. For the
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16 118 red and orange courts, the height of the net was lowered at 0.80 m, as recommended²⁰. For the
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18 119 green court, the height of the net was fixed at 0.91m²⁰.

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23 120 A motion capture system with twenty cameras sampling at 200 Hz (Oqus, Qualisys AB.,
24 121 Göteborg, Sweden) was used to record the trajectories of the 3-dimensional (3D) anatomical
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26 122 landmarks. Players were shirtless or wore a bra and a tight short to limit movement of the
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28 123 markers. Post-impact ball speed was measured for each trial by using a radar (Stalker
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30 124 Professional Sports Radar, Applied Concepts, Plano, Texas, USA) fixed on tripod and placed
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32 125 2 m behind the players in the direction of the serve. Radar's height on the tripod was adjusted
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34 126 with impact height for each player. After the capture, 3D coordinates of the landmarks were
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36 127 reconstructed with QTM software Qualisys AB., Göteborg, Sweden) with a residual error of
37
38 128 less than 1 mm. The 3-D motions of each player were expressed in a right-handed inertial
39
40 129 reference frame R1 whose origin was at the center of the baseline. X represented the baseline,
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42 130 Y pointed forward, and Z was vertical and pointed upward. The 3-D coordinate data of the
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44 131 markers were smoothed with a Butterworth low-pass filter with a cutoff frequency of 12 Hz,
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46 132 determined by residual analysis²¹. Different serve kinematic variables were calculated as
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48 133 previously described²². An inverse dynamics approach was used to calculate the peak of joint
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50 134 kinetics (forces and torques)^{22 19}. The serving arm was modeled as a three-link kinetic chain
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3 135 composed of the racket/hand segment, forearm, and upper arm. For the purpose of the study,
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5 136 shoulder proximal, anterior, posterior and superior forces, shoulder internal rotation torque,
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7 137 elbow proximal, anterior and medial forces and elbow varus torque were analyzed. The joint
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9 138 forces and torques obtained were first computed in the reference frame R1 and were later
10
11 139 transformed to a series of anatomically relevant, righthanded orthogonal local reference frames
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13 140 at each joint. Mean kinetic peak values were normalized: forces were divided by body weight,
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15 141 and torques were divided by the product of body weight by height, and then multiplied by 100
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17 142 ¹⁹. The moment of inertia of the racket about its mediolateral axis was computed using the
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19 143 parallel axis theorem and published racket “swing weight” data as
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21 144 recommended in the literature ²³. Racket moment of inertia about the long axis was calculated
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23 145 as reported in the literature²⁴:

$$24 \quad \text{moment of inertia (kg} \cdot \text{m}^{-2}) = (\text{mass} \times \text{head width}^2)/17.75$$

25
26 147 Racket moment of inertia about its anteroposterior axis was defined as the sum of the racket’s
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28 148 other two principal moments of inertia²⁴.

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30 149 For each of the three serving conditions, the magnitudes of ball speed, kinematic and
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32 150 kinetic parameters were averaged for each player. One-way analysis of variance with repeated
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34 151 measures was used to analyze the effect of the three serving conditions on ball speed, serve
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36 152 kinematics and kinetics. When significant main effects were present, post hoc pairwise
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38 153 comparisons were undertaken using a Holm correction to determine the source of difference.
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40 154 Where data were not normally distributed, significance was determined using a Friedman
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42 155 analysis of variance with repeated measures on ranks and a post hoc Durbin-Conover test. Post-
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44 156 hoc analysis with Durbin-Conover tests was conducted with a Bonferroni correction for
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46 157 multiple comparisons. The level of significance was set at $P \leq .05$. Furthermore, effect sizes
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48 158 using partial eta squared (η^2_p), defined as small (.10–.24), moderate (.25–.39), or large ($\geq .40$),
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50 159 Kendall’s W, defined as small (.10-.29), moderate (0.30-0.49) and large (≥ 0.50), and Cohen d ,
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3 160 defined as trivial (<0.20), small ($0.20-0.49$), moderate ($0.50-0.79$), or large (≥ 0.80), according
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5 161 to the cutoffs suggested by Cohen²⁵ were also calculated.
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10 163 **Results**

11 12 164 **Shoulder and elbow kinetics**

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14 165 No significant differences and trivial or small effect sizes were observed among the
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16 166 three serving distances for shoulder and elbow kinetics among the three serving conditions
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18 167 (Table 1).
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23 24 169 **Ball speed and racquet head velocity**

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26 170 The serving conditions significantly and moderately affected ball speed ($\chi^2(2) = 8.36$;
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28 171 $P = .014$; $W = 0.418$) that was significantly lower in green compared with red conditions ($P =$
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30 172 $.006$; $d = -.636$, moderate effect). There was also a tendency toward a difference concerning
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32 173 ball speed between green and orange conditions ($P = .084$; $d = -.745$, moderate effect).
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35 174 The results showed a significant and moderate main effect of the serving conditions on
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37 175 maximal racquet head velocity ($F(2,18) = 5.02$, $P = .018$, $\eta^2_p = .358$). Post hoc analysis revealed
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39 176 a moderate but not significant effects for maximal racquet head velocity between red and orange
40
41 177 conditions ($P = .104$; $d = .734$, moderate effect) and between red and green conditions ($P = .104$;
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43 178 $d = .786$, moderate effect) (Table 2).
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47 48 49 180 **Kinematics**

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51 181 The serving conditions significantly and moderately affected the angle of maximal back knee
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53 182 flexion ($\chi^2(2) = 8.60$; $P = .014$; $W = 0.430$). Maximal back knee flexion was significantly lower
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55 183 in green conditions than in red conditions ($P = .006$; $d = .782$, moderate effect) (Table 2). Post
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57 184 hoc analysis revealed also a tendency toward a large difference concerning the angle of maximal
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3 185 back knee flexion between green and orange conditions ($P = .111$; $d = .891$, large effect) (Table
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5 186 2).

7 187 The results showed a significant and moderate main effect of the serving conditions on
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10 188 maximal velocity of back knee extension ($F(2,18) = 3.99$, $P = .037$, $\eta^2_p = .307$). The maximal
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12 189 velocity of back knee extension was significantly lower in green conditions compared with
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14 190 orange ($P = .048$; $d = -.935$, large effect) and red conditions ($P = .050$; $d = -.745$, moderate
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16 191 effect).

19 192 The results showed a significant and large main effect of the serving conditions on
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22 193 maximal velocities of trunk flexion ($F(2,18) = 9.39$, $P = .002$, $\eta^2_p = .511$). The maximal velocity
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24 194 of trunk flexion was largely lower in green conditions compared with red conditions ($P = .004$;
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26 195 $d = -1.48$, large effect). There was also a tendency toward a difference concerning maximal
27
28 196 velocities of trunk flexion between green and orange conditions ($P = .060$; $d = -.815$; large
29
30 197 effect) (Table 2).

33 198 No significant differences and trivial or small effect sizes were displayed between
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35 199 serving conditions for maximal angles of back and front ankle flexion, maximal angle of front
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37 200 knee flexion, maximal velocities of front knee extension, back and front ankle extension, upper
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39 201 trunk longitudinal rotation, pelvis longitudinal rotation, upper arm pronation, shoulder over
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41 202 shoulder rotation, elbow extension, wrist flexion and shoulder internal rotation (Table 2).
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47 204 **Discussion and implications**

49 205 *Red conditions*

51 206 The study supported the hypothesis that serve ball speed, maximal back knee angle
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53 207 flexion, maximal velocities of back knee extension and trunk flexion are affected by a red
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55 208 smaller court and net sizes (length 12.80 m, net height 0.80 m) in a sample of 9 to 12 years old
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57 209 tennis players. Indeed, our results show a moderate and immediate increase in ball speed (+1.3
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3 210 m.s⁻¹, +5 %) when players serve in comparison with the green one. This result is in line with
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5 211 previous results showing that reducing court dimensions contributes to improve the stroke
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7 212 performance of young tennis players (i.e. high increase in a velocity-precision score, +13.0 %
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9 213 of overall success rate in groundstrokes²⁶ and +12.8 % of total serve points won²⁷).

10 214 The rationale for scaling sport is predominantly underpinned by an ecological dynamics
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12 215 viewpoint of human movement and skill acquisition²⁸. Ecological dynamics advocates that an
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14 216 individual's behavior emerges from the self-organization of perception and action under
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16 217 interacting constraints (organismic, environmental, and task). Indeed, the constraints imposed
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18 218 by sport (e.g., court size, net height, balls and racket properties in tennis) determine the
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20 219 boundaries of what actions are possible²⁹. Vaverka et al. ³⁰ (2013) hypothesized that young and
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22 220 shorter tennis players intuitively increase the ball speed based on their individual experience
23
24 221 because they perceive that the service area into which the ball can land is higher and increases
25
26 222 their probability of successful execution in red and orange conditions. This phenomenon could
27
28 223 be related to the study of Whiteside et al. (2013) that underlined that tennis serve outcome
29
30 224 appears most closely related to the projection angle of the ball³¹. At a given forward and impact
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32 225 height, the margin for error in the projection angle decreases as ball velocity increases. As a
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34 226 consequence, young tennis players need more to adjust projection angle-ball speed
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36 227 combinations to overcome the net than adults due to their lower stature and impact height³¹. In
37
38 228 our study, ball impact was not measured but it is well known that when the ball is hit at a higher
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40 229 and/or forward contact point into the court, there will be a larger "window" of initial projection
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42 230 angles for the serve to clear the net and land in the service box^{32 31}. Concerning the window of
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44 231 initial projection angles, the proportion between the red serve positions and the players' body
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46 232 height is more favorable³³. The mean body height of U12 players is only 78 % of the adults'
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48 233 body size and the distance between the net and the red baseline is respectively 46 % of the
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50 234 distance between the net and the traditional court baseline²⁷. As a consequence, in red
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3 235 conditions, the margin for error in the projection angle for a given impact height would be
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5 236 increased^{32 34} allowing young players to hit more powerful serve. Conversely, due to their
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7 237 smaller body height, young tennis players are not able to intend and produce movements
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9 238 corresponding to an aggressive serve when they serve from the green court.
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12 239 The higher ball speed measured in red conditions is probably also the result of kinematic
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14 240 changes measured between serving distances. Our results show that both reducing serving
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16 241 distance and net height promote a more dynamic engagement of the back leg in young tennis
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18 242 players, which is reflected in increases in maximal back knee extension velocity ($+61^{\circ}\cdot\text{s}^{-1}$, i.e.
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20 243 $+15.8\%$ in red) and higher knee flexion angle ($+4^{\circ}$ in red) in comparison with green conditions.
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22 244 These kinematical parameters have previously been related to effective lower limb involvement
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24 245 and higher ball speed^{35 36}. Indeed, to improve ball speed, tennis players need to produce an
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26 246 efficient leg drive based on an effective back knee flexion and then a vigorous knee extension³⁵
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28 247 ³⁶. One may hypothesize that the storage of elastic energy and muscle preload in the back leg
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30 248 may be improved during red conditions. By increasing the action of the leg drive, young tennis
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32 249 players could be able to transfer a little bit more force to the trunk and the dominant upper limb.
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34 250 Optimizing leg drive and vertical ground reaction forces may have also favored and help the
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36 251 trunk forward rotation³⁷. Our findings support this hypothesis because they show a significant
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38 252 and large main effect of the serving conditions on maximal velocities of trunk flexion. Effect
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40 253 size reveals that maximal angular velocities of trunk flexion is largely improved in red
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42 254 conditions ($+11.3\%$). The immediate improvements in maximal back knee extension and trunk
43
44 255 flexion velocities and in maximal knee flexion angle measured in “red” conditions appear
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46 256 pragmatically meaningful in serve skill development. Indeed, Whiteside et al. (2013) showed
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48 257 an evolution in the tennis serve kinematics from prepubescence to adulthood in female tennis
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50 258 players. Specifically, maximal back leg extension velocity and trunk variables increase with
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3 259 age between pre-pubescents, pubescents and adults, allowing players to achieve higher ball
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5 260 speeds in the serve³⁸.
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8 261 Reducing the serve distance and net height has only small effects on shoulder internal
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10 262 rotation, shoulder-over-shoulder rotation and upper arm pronation angular velocities. This can
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12 263 be explained by the immature serve technique of the young tennis players in our study. Indeed,
13
14 264 it has been reported that shoulder-over-shoulder and shoulder internal rotation were reduced in
15
16 265 pre-pubescent players who relied more on twist rotation of the trunk³⁸. This is the case in our
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18 266 study as evidenced by the maximal value of pelvis and shoulder longitudinal angular velocities
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20 267 higher than those reported for adult players in the literature³⁸. Even if the back leg drive is
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22 268 moderately improved for red conditions, it still be insufficient for inducing an efficient and
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24 269 significant shoulder-over-shoulder and shoulder internal rotations in young tennis players.
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28 270 Results show that serve conditions demonstrated only trivial or small effects on shoulder
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30 271 and elbow kinetics in young tennis players. This contrasts with our initial hypothesis (i.e.
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32 272 decreases in upper limb joint kinetics with decreases in serving distance and net height) and the
33
34 273 study of Fleisig et al. (2018)³⁹ reporting that an increased pitching distance was associated with
35
36 274 higher shoulder kinetics in young baseball players. The difference of findings may be related
37
38 275 to the fact that the pitching distances in young baseball players were much more extreme
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40 276 (14.02m, 16.46m and 18.44m from the home plate) than our serving distances (6.40 m, 9.00 m
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42 277 and 11.89 m from the net). Fleisig et al. (2018)³⁹ reported that at farther distances youth pitchers
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44 278 significantly increased their effort, and as a consequence, their shoulder kinetics to reach the
45
46 279 home plate. However, the current finding is congruent with another study in baseball that did
47
48 280 not find relationship between varying pitching distance (18.44m, 19.05 and 19.41m) and joint
49
50 281 kinetics in adult players⁴⁰. Our results show that in red conditions, young tennis players are
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52 282 more efficient because they reach higher ball speed without overloading both their shoulder and
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54 283 elbow compared to green condition.
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3 284 Our current data show an immediate ball speed increase in our sample of 9 to 12 years
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5 285 old boy and girl tennis players when they serve from the red court. This result is consistent with
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7 286 previous results showing that U10 players serving from the baseline (11.89m from the net) won
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9 287 a lower percentage of serve points, hit less aces and unreturned serves than U10 players serving
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11 288 inside the tennis court (9m and 10.39 from the net)^{27 41}. The results of the current study provide
12
13 289 preliminary support for the use of a reduced serve distance and net height as a coaching tool in
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15 290 young tennis players to moderately increase ball speed (+ 1.3 m.s⁻¹) and to moderately or largely
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17 291 improve maximal angular velocity of trunk flexion as well as leg drive. Moreover, we could
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19 292 assume that the improved serve performance (ball speed and efficiency) in red conditions may
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21 293 logically have a positive impact on young tennis players' confidence and motivation, enhancing
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23 294 participation and engagement, as explained in the literature^{13 26 3}. Decreasing serve distance
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25 295 and net height during training and/or competitions may be helpful in long-term skill
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27 296 development because, without increasing the loads on their dominant upper limb, it would help
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29 297 players to start the points with more aggressive tactical intentions from the serve, which are
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31 298 typical of professional tennis game⁴². However, this hypothesis requires future longitudinal
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33 299 research to confirm this. A reduced serve distance and net height would also decrease the time
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35 300 available to the returner to see and react to the serve and to develop crucial skills (i.e., reaction
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37 301 time, visual strategy, and anticipation) for an efficient return in young tennis players: reaction
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39 302 time, visual strategy, and anticipation. When they serve from a closer distance from the net and
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41 303 with a lower net height (especially in "red" conditions), our results show that young tennis
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43 304 players experience a more mature serve technique for which several kinematical values (angular
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45 305 velocities of knee extension and trunk flexion) are closer than those measured for older ages
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47 306 and higher practice level^{43 38}. However, we do not know if regularly practicing the serve in
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49 307 reduced distance and net height conditions could accelerate the acquisition of a more correct
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3 308 and mature serve technique and would have a beneficial effect on retention and transfer to
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5 309 “green” conditions. Further works are needed to evaluate this question.
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8 310 ***Orange conditions***

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10 311 Concerning the orange court, the statistical analyses show only one significant and large
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12 312 increase in maximal velocity of back knee extension in comparison with green court. Our results
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14 313 also show moderate and large increases in ball speed, maximal angle of back knee flexion and
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16 314 maximal velocity of trunk flexion but these differences are not statistically significant; only
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18 315 tendencies are observed for these variables with P values close to the level of significance. This
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20 316 probably happens because our sample size is too small.
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25 318 ***Limitations of the study***

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28 319 In addition to decrease the ability to detect differences across the court conditions
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30 320 (orange vs. green), the small sample size of this exploratory study also increases the chance of
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32 321 type II errors and decreases statistical power. The current sample size is limited because we
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34 322 included only young tennis players; moreover, their participation was voluntary and submitted
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36 323 to their parents’ consent. Similarly, given the small sample size, the current study lacks
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38 324 generalizability and thus serves to encourage future work to examine and confirm the
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40 325 immediate and positive effect of the orange court on ball speed and serve kinematics on larger
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42 326 or different tennis playing cohorts.
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47 328 ***Perspectives and future directions***

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50 329 In the literature, it is known that serve kinematics and kinetics are different between flat,
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52 330 slice and kick serves⁴⁴. Further research should examine the kinematic and kinetic changes for
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54 331 other serve types from varying distances. In this study, we decided to test the combined effect
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56 332 of three serve distances and two net heights in accordance with the different scaled courts
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3 333 (“red”, “orange”, “green”) from different tennis training programs²⁰. In the literature, previous
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5 334 research analyzing the playing structure in young players identifies a severe problem at the
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7 335 transition from the “orange” court to the “green” court¹⁶. Consequently, an intermediate stage,
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10 336 called “lime” court with a baseline located at 10.39 m from the net (between orange and green
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12 337 courts) was introduced in the Austrian Tennis System but not in the ITF Tennis Play & Stay
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14 338 Program²⁷. Future research should take into account this new serve distance and should evaluate
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17 339 the effect of an ideal resized serve distance based on the average body heights of the players
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19 340 involved in the experimentation. In this study, we decided that players served only with “green
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21 341 balls” which are 25% slower than yellow ones. A previous study showed that the use of a green
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23 342 balls increased rally speed, allowed players to strike the ball at a lower (more comfortable)
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25 343 height on their groundstrokes and increased the number of balls played at the net⁴⁵. However,
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27 344 this study showed that ball compression had no effect on the relative number of winners,
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29 345 forehands, backhands, first serves in and double faults. It would be interesting for future
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31 346 researches to evaluate the combined effect of different ball types (“red”, “orange”, “green” and
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33 347 “yellow”) and different court dimensions on upper limb joint kinematics (shoulder internal
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35 348 rotation, upper arm pronation, wrist flexion...) and upper limb kinetics at impact.
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42 350 *Practical applications*

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44 351 From a practical point of view, our results show that reducing the serve distance and the net
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46 352 height appears to be a relevant drill to use when a young player has difficulty pushing upwards
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48 353 with the legs and/or rotating forwards with the trunk during the serve. Smaller serve distance
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50 354 and lower net height could also be used when young players fail to hinder the returner because
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52 355 their serves lack of speed. For example, to create a positive dynamic about the serve, a new
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54 356 experimental rule has been created and tested (“the forward serve”) by the Tennis Brittany
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56 357 League (France) during the 2022 local Galaxie Tennis competitions for young players called
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3 358 the “Breizh Tour”⁴⁶. In these competitions, young tennis players at “orange” and “green” stages
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5 359 were allowed to serve from the “red” and “orange” serve lines, respectively. During some of
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7 360 these competitions, the number of aces per match has been counted. For example, during an
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9 361 “orange” and a “green” Galaxie Tennis competition of the Breizh Tour with the permission to
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11 362 serve closer from the net (“forward serve”), the young players hit on average 0.97 / match and
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13 363 0.38 aces / match, respectively⁴⁷. Although these results have not been published, they are
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15 364 strongly higher than those of Schmidhofer et al. (2014) who reported 0.21 ± 0.51 aces / match
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17 365 for “orange” competitions and 0.04 ± 0.20 aces / match for “green” competitions in young
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19 366 tennis players without specific serve distance adaptations. This new initiative of “forward
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21 367 serve” is very encouraging with regard to serve efficiency and motivation in young tennis
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23 368 players and could be subject to scientific studies in the future.
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31 **Conclusion**

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33 371 In conclusion, the current study shows that a decrease in serving distance and net height has
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35 372 trivial or small effects on serve kinetics but moderate positive effects on ball speed in the serves
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37 373 of 9 to 12 years old tennis players. Moderate positive effects are also observed for leg drive
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39 374 kinematics when young tennis players serve closer to the net from the red court. A large positive
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41 375 effect is also reported for maximal velocities of trunk flexion for the red conditions. As
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43 376 hypothesized by Gimenez-Egido (2020)⁴¹, our study shows that modifying key constraints of
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45 377 the environment (smaller serve distance and lower net height) constitute a favorable approach
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47 378 for practitioners that simplifies serve action, improve serve performance and provides more
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49 379 learning opportunities to explore new movements patterns and kinematics as happens at other
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51 380 ages and stages.
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387 **Declaration of interest statement**

388 The authors report there are no competing interests to declare

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	Green	Orange	Red	$F(2,18)$	P value	Effect size η_p^2
Shoulder kinetics						
Proximal force (N.kg ⁻¹)	3.5 ± 1.0	3.6 ± 0.9	3.8 ± 1.1	1.430	0.275	0.137
Anterior force (N.kg ⁻¹)	2.3 ± 0.6	2.5 ± 0.5	2.4 ± 0.5	0.929	0.150	0.094
Posterior force (N.kg ⁻¹)	2.3 ± 0.5	2.5 ± 0.6	2.5 ± 0.5	0.315	0.734	0.034
Superior force (N.kg ⁻¹)	2.6 ± 1.0	2.9 ± 0.9	2.7 ± 0.7	1.85	0.186	0.171
Internal rotation torque (N.m.kg ⁻¹ .m ⁻¹)	45.2 ± 7.6	47.0 ± 8.1	48.2 ± 8.0	0.464	0.636	0.049
Elbow kinetics						
Proximal force (N.kg ⁻¹)	4.2 ± 0.8	4.2 ± 0.6	4.2 ± 0.8	0.062	0.940	0.007
Anterior force (N.kg ⁻¹)	1.2 ± 0.3	1.3 ± 0.5	1.3 ± 0.5	2.34	0.125	0.206
Medial force (N.kg ⁻¹ .m ⁻¹)	1.9 ± 0.7	2.0 ± 0.3	2.0 ± 0.5	0.137	0.873	0.015
Varus torque (N.m.kg ⁻¹ .m ⁻¹)	49.2 ± 8.0	49.0 ± 8.2	50.7 ± 7.8	0.057	0.944	0.006

Table 1. Maximum shoulder and elbow kinetic values for different serve conditions (mean ± SD).

	Green	Orange	Red	Main effect <i>P</i> value	Effect size η_p^2 or <i>W</i>
Ball speed and racquet velocity					
Ball speed (m.s⁻¹) *	26.5 ± 3.7 [§]	27.6 ± 3.3	27.8 ± 3.2	0.014	0.418
Maximal racquet head velocity (m.s⁻¹) *	26.6 ± 2.9	27.1 ± 2.8	28.1 ± 3.0	0.018	0.358
Maximal angles					
Back ankle flexion (°)	80 ± 6	80 ± 6	81 ± 5	0.736	0.033
Front ankle flexion (°)	78 ± 6	79 ± 8	79 ± 7	0.363	0.106
Back knee flexion (°) *	127 ± 21 [§]	124 ± 20	123 ± 19	0.014	0.430
Front knee flexion (°)	119 ± 10	118 ± 11	121 ± 11	0.135	0.199
Maximal velocities					
Back ankle extension (°·s ⁻¹)	531 ± 174	531 ± 164	527 ± 163	0.981	0.002
Front ankle extension (°·s ⁻¹)	460 ± 131	478 ± 92	473 ± 118	0.421	0.045
Back knee extension (°·s⁻¹) *	385 ± 221 ^{&§}	442 ± 235	446 ± 226	0.037	0.307
Front knee extension (°·s ⁻¹)	458 ± 174	484 ± 167	464 ± 167	0.311	0.122
Trunk flexion (°·s⁻¹) *	247 ± 63 [§]	263 ± 54	275 ± 66	0.002	0.511
Upper trunk longitudinal rotation (°·s ⁻¹)	626 ± 138	638 ± 136	661 ± 154	0.378	0.102
Pelvis longitudinal rotation (°·s ⁻¹)	534 ± 135	549 ± 144	576 ± 154	0.176	0.176
Shoulder internal rotation (°·s ⁻¹)	1603 ± 569	1644 ± 613	1771 ± 546	0.273	0.130
Upper arm pronation (°·s ⁻¹)	1331 ± 696	1407 ± 749	1473 ± 739	0.263	0.174

Shoulder-over-shoulder rotation (°.s ⁻¹)	136 ± 59	150 ± 59	141 ± 63	0.376	0.103
Elbow extension (°.s ⁻¹)	1027 ± 333	1057 ± 339	1081 ± 321	0.194	0.167
Wrist flexion (°.s ⁻¹)	1581 ± 174	1614 ± 224	1601 ± 214	0.546	0.065

Table 2. Serve performance and kinematics for the different serve conditions (mean ± SD).

*: significant main effect between serve conditions ($P < 0.05$). \$: significantly different from green and red ($P < 0.05$). &: significantly different from green and orange ($P < 0.05$)

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