ORIGINAL ARTICLE

Short-term effects of light and heavy load interventions on service velocity and precision in elite young tennis players

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Objective: This study was conducted to investigate the acute effects of a complex throwing intervention set-up, with light or heavy loads, on the service velocity of elite junior tennis players.
Methods: On 3 separate test days, 13 elite juniors (mean (SD) 12.3 (0.8) years, 149 (9) cm, 37.5 (5.5) kg) performed four sets of six serves with different between-set conditions. In a cross-over design, the players performed respectively 6, 4 and 2 maximum effort throws with a 200 g ball (LI, light intervention), 6, 4 and 2 maximum effort throws with a 600 g ball (HI, heavy intervention) and no throws (NI, no intervention) during the 2 min in between-set period. Participants were instructed to serve, with maximum speed, to a target near the midline of the deuce court service box. A two-factor analysis of variance was used to determine the effects of intervention type and set number on ''service velocity'', ''service precision'' (eg, percentage of serves in) and ''service touch'' (11 point rating scale).
Results: Mean (SD) service velocity decreased significantly in HI (124.3 (7.8) km/h) as compared to NI (126.6 (9.3) km/h, $p<0.05$, effect size $d=0.26$), yet no such differences were found between LI (125.2 (7.9) km/h) and NI. Service velocity also remained constant between sets ($p=0.406$). Service precision and service touch were unaffected by the interventions.
Conclusions: Under the conditions of our study, a heavy throwing intervention during service training has no beneficial effect on service velocity in young elite tennis players (under 14).

Several studies have focused on the kinematics of the tennis service, on the importance of service speed in determining match outcomes and on different training concepts to improve the service performance.[1–3] The major contributors to the linear velocity of the racquet head at serve impact are reported as internal rotation of the upper arm (54.2%) and flexion of the hand (31%).[3] Similar mechanics are seen in other overhead throwing actions,[4] reinforcing the strong and established link between service and throwing velocity in tennis players.

Modern training concepts highlight the value of complex exercise programming during the same training unit.[5 6] Short-term improvements in movement speed through contrast or complex training methods invoking ''post-activation potentiation'' and increased muscle stiffness have been observed.[7] There remain, however, two conflicting theories regarding the optimum loads that should be used for the improvement of mechanical power and movement speed.[8 9] That is, where heavy loads are reported to induce greater recruitment of the high-threshold fast type II motor units, via the size principle,[10] light loads are suggested to better allow for the assimilation of high-speed movement velocities and thus maximise the mechanical power output.[11]

Several tennis coaching experts have advanced the use of complex training, with light and heavy loads, to immediately increase the serve velocity and therefore combine technical skill development with the training of overhead power and throwing performance.[12 13] However, the exact short- or long-term effects of such protocols on the functional tennis serve performance have not yet been investigated. Therefore, in this study we have addressed the question of whether a light or a heavy throwing intervention should be advocated for young elite players during a complex service training setting.

METHODS

Subjects

A total of 13 elite junior tennis players (7 boys and 6 girls; 12 right-handed players and 1 left-handed player) from the Flemish Training Centre (FTC), aged 11–13 years, participated in the study (mean (SD) 12.3 (0.8) years, 149 (9) cm, 37.5 (5.5) kg, BMI 16.8 (1.2)). We included all players that were ranked in the top 30 nationally for the respective age group and trained at least twice a week at the FTC. On 2 days/week the tennis training was accompanied by physical conditioning training including co-ordination, speed and strength exercises. The strength-training units focused on preventive neuromuscular control (functional stabilisation training), strength training techniques and core strength. Data collection was undertaken at the usual practice location as part of the training sessions. The players were familiar with all test procedures and the testing surroundings.

Experimental conditions

On three experimental days (A, B, C) separated by 1 week, all players completed 4 sets of 6 services (a total of 24 services) with a recovery period of 10 s between each service and 2 min between the sets (fig 1). The players were asked to serve from the deuce court side ''an ace with maximum speed to the target zone'' near the ''T'' of the deuce court service box (fig 2).

On the three experimental days the players completed different training interventions (I) consisting of 6 (I1: between first and second set of services), 4 (I2: between second and third set) and 2 (I3: between third and fourth set) maximum-effort throws with either a 200 g ball (LI, light intervention, 8 cm ball diameter) or a 600 g ball (HI, heavy intervention, 11 cm ball diameter). The players were asked to perform all-out throws over the net to the target zone from their personal service position on the deuce court side (fig 2). No further instructions were given in relation to the movement execution. On one experimental day (A) no intervention was taken during

Abbreviations: ANOVA, analysis of variance; FTC, Flemish Training Centre; HI, heavy intervention; LI, light intervention; NI, no intervention; PAP, post-activation potentiation

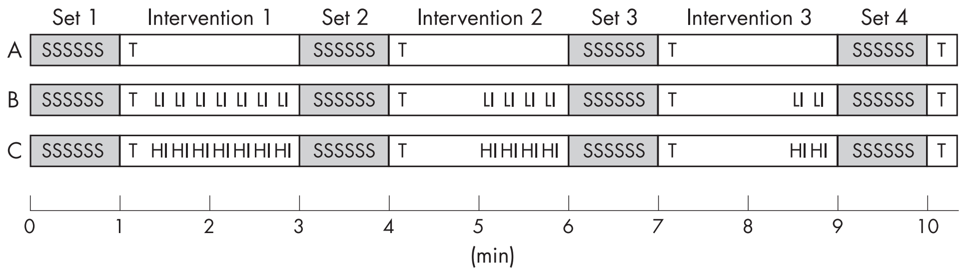

Figure 1 Experimental design. S = service; T = service touch rating; LI = 200 g ball throw; HI = 600 g ball throw.

the recovery period between the sets (NI, no intervention). The different interventions (A, B, C) were given in a cross-over design (fig 1).

The respective ball weights were chosen after testing for practical application with the players. We decided to choose a clear contrast between the light and the heavy intervention. Therefore we determined the minimum and maximum of the range of ball weights that (1) did not inhibit the throwing action and allowed all players to throw the HI ball from the baseline over the net (upper limit), and (2) were assessed by the players to be clearly lighter than the racquet (mean (SD) racquet weight of the subjects was 282 (19) g) (lower limit).

The environmental conditions, ambient temperature, tennis balls (24 new Dunlop Pro balls, Hanau, Germany) and warm-up routines were identical on each test day. The warm-up consisted of a 30 s dynamic service imitation followed by 10 warm-up services of increasing velocity (5×60%, 2×70%, 1×80%, 1×90%, 1×100% of the maximum value) from the respective testing position.

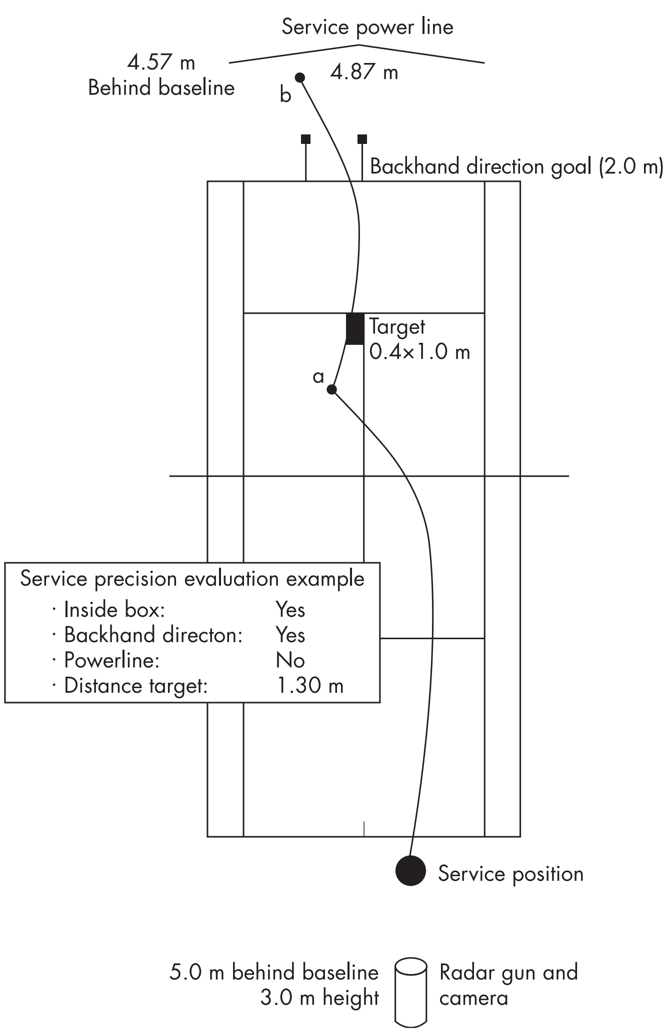

Figure 2 Experimental on court assessment for the measurements of service velocity and precision. The precision details (see evaluation examples) were analysed per videotape.

Measurements

Service and throwing velocity were measured by a radar gun (Stalker, Plano, Texas, USA) from a standardised position 5 m behind the baseline and 3 m above the ground (fig 2). The radar gun was aligned to the advised stroke direction. Peak ball velocity during the ball flight was recorded.

Service precision was determined afterwards by video analysis (the camera position corresponded to the radar gun position) of services 7–24 (second to fourth set of services). For that, two independent tennis experts marked the bouncing location and the ball flight direction into a true scaled observation sheet. We distinguished four different criteria (fig 2):

- Inside box: percentage of services with a first bounce of the ball inside of the required service box (let serves were repeated).
- Net error: percentage of net error services.
- Backhand direction: percentage of services passing through a 2 m goal at the opposite baseline directed to the right-handed backhand.
- Powerline: percentage of services with a second bounce behind the International Tennis Number (ITN) powerline (http://www.itftennis.com).
- Distance to target: distance of the first bounce of the ball (net errors excluded) from a target zone (40×100 cm) placed in the service box.

Service touch was recorded during the 2 min rest between the service sets. The players were asked to quantify their feeling of rhythm and co-ordination during service with the help of a 11 point "touch scale" ranked by the following categories (10 = very, very good; 8 = very good; 6 = good; 4 = poor; 2 = very poor; 0 = very very poor). The scale was not evaluated. A post hoc calculation of the mean intra-individual correlation between the service velocity and the touch scale rating showed a small positive effect (r = 0.29).

Statistical analysis

Data are presented as mean values with SD. A two-factor analysis of variance (ANOVA) for repeated measurements was calculated to compare the mean values of service velocity and service touch for the different interventions (factor 1) and the different measurement points (service sets, factor 2). A one-factor ANOVA was used for statistical analysis of the service precision items. In case of significance, simple effects were verified by means of a Newman-Keuls test. Effect size was calculated according to Robert Coe (CEM Centre, Durham University, UK). Heterogeneous variances were adjusted

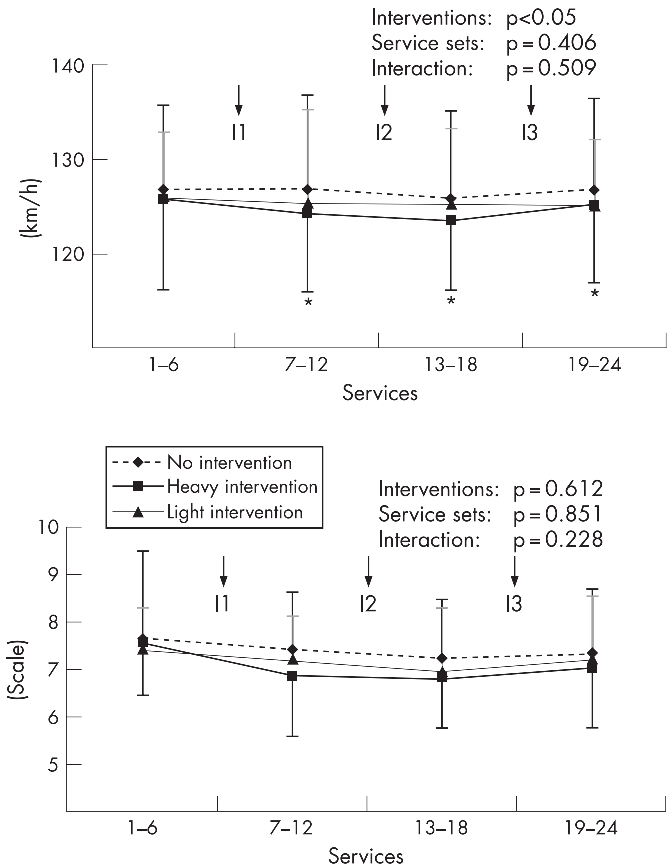

Figure 3 Acute effects of light (200 g balls) and heavy (600 g balls) maximum throwing interventions (I 1: 6 throws; I 2: 4 throws; I 3: 2 throws) during service training on service velocity and service touch (11 point scale: 10 = very very good; 8 = very good; 4 = poor; 2 = very poor; 0 = very, very poor). The ANOVA calculations for the independent factors ''intervention'', ''service sets'' and for the interaction of ''intervention × service sets'' are indicated. *$p<0.05$ for no intervention vs heavy intervention.

(Huyn-Feldt and Box procedure). Significance level was set at $p<0.05$.

RESULTS

The service velocity was significantly decreased during the heavy intervention (mean (SD) 124.3 (7.8) km/h) compared to the no intervention trial (126.6 (9.3) km/h). The effect size of this finding tended to be low ($d = 0.29$). No differences were found between the light intervention (125.2 (7.9) km/h) and the no intervention service velocity (fig 3). Service velocity remained constant between sets. The rating of service touch revealed no statistical differences. Players tended to perceive more touch without throwing intervention (fig 3).

The service precision remained unchanged on all experimental days (table 1). About a third of the services were inside the service box. The percentage of net errors remained constant on each test day. About half of the services were directed to the backhand side (right handed opponent) and showed a second bounce behind the defined power line. The mean distance of the first bounce of the ball to the target zone was 145 cm.

The mean (SD) throwing velocity was 65.8 (1.5) km/h with the light intervention 200 g ball and 49.1 (1.3) km/h with the heavy intervention 600 g ball.

DISCUSSION

In this study we analysed the acute effects of a load-controlled complex throwing intervention training on the functional service performance. More specifically, we wanted to compare the influence of an ''overload'' and ''underload'' intervention (compared to the racquet load) as both methods are recommended to coaches based on different theories.[8–11] To date, there have been no findings about the sport-specific efficiency of these training methods in tennis.

In contrast to the theory of the post-activation potentiation (PAP) induced by complex training methods, our findings did not show any positive effects of both interventions on all observed parameters (velocity and precision) of the service performance (fig 3 and table 1). These results question the applicability of the PAP on the service training in elite junior tennis players under these conditions.

Post-activation potentiation refers to a phenomenon by which acute muscle force output is enhanced as a result of the contractile history and is the premise upon which complex training is based.[7] It has been postulated that explosive movements might be enhanced if they are preceded by heavy resistance exercise.[5 14] This is explained by a ''loading of the neuromuscular system'' in terms of a greater ''effectiveness of stimulus transmittance in the excitatory synaptic junctions''.[15] Güllich and Schmidtbleicher[15] found increase of H-reflex amplitude between 3 and 11 min after a maximum voluntary contraction.

We suggest two main possibilities to explain our contradicting results: (1) fatigue of the working muscles, and (2) temporary impairment of the intermuscular co-ordination.

Positive acute effects of complex training were predominantly found in male subjects and in lower body exercises.[16] Improvements of the upper body plyometric performance induced by complex training were strongly correlated with the maximum strength of the athletes.[16] These results suggest that a heavy intervention complex training should be advised only for stronger individuals. Contractile activity always produces fatigue and PAP, and it is the balance between the two that determines the power output.[7] In our study, muscle fatigue could be speculated after the first heavy intervention including six maximum throws. In addition, this complex training set-up, with only a 20–30 s recovery period following the throwing intervention, was possibly too short for inducing any potentiation.

Complex training research usually examine the effects of very simple compound exercises (eg, combination of squats and counter movement jumps).[16] The functional performance of the

Table 1 Service precision during service training without interventions (NI) and with heavy (HI) or light throwing interventions (LI)

Service precision	NI	HI	LI	p Value
Inside box [%]	31.0 (10.2)	30.6 (12.9)	34.8 (11.1)	0.378
Net errors (%)	24.5 (17.5)	24.7 (16.4)	24.4 (12.4)	0.073
Backhand direction (%)	55.5 (14.1)	65.0 (12.9)	53.3 (20.9)	0.192
Behind powerline (%)	45.7 (28.1)	43.4 (29.6)	46.6 (21.5)	0.931
Distance target (cm)	146 (56)	145 (52)	144 (43)	0.994

Values are mean (SD); ANOVA p values are given.

What is already known on this topic

- Several tennis coaching experts have advanced the use of complex training, with light and heavy loads, to immediately increase the serve velocity and therefore combine technical skill development with the training of overhead power and throwing performance.
- The exact short- or long-term effects of such protocols on functional tennis serve performance have not yet been investigated.

What this study adds

- The results of the present study indicate that a heavy ball throwing intervention causes a slight acute decrease in service velocity for 11–13 years old elite tennis players.
- The investigated complex training methods aiming at a post-activation potentiation failed to have short-term benefits in this age group at this performance level.
- Such training methods should therefore be applied carefully, especially during the main tournament periods.

tennis serve however, is the result of an effective force transfer throughout a complex kinetic chain that depends on intermuscular co-ordination and muscle strength.[1 17] Both interventions in the present study, the light and the heavy one, can lead to a temporary impairment of co-ordination. The slight decrease of the ratings of service touch on the intervention days is in line with this conclusion (fig 3).

The present data do not allow a general refusal of complex service training interventions. This decision should individually consider age, gender, muscle strength and technical establishment of the serve. Moreover, one should distinguish between acute- and long-term training interventions. In the course of a 6 week training intervention with junior tennis players, a significant increase of service velocity was found that was similar for a light and a heavy weight training group (from 130–135 km/h).[18] These data show that an enormous adaptive potential for service speed exists in elite junior tennis, independent of the training methods used (underload or overload intervention).

CONCLUSION

The results of the present study indicate that a heavy ball throwing intervention causes a slight acute decrease in service velocity of 11–13 years old elite tennis players. The investigated complex training methods aiming at a post-activation potentiation failed to have short-term benefits in this age group at this performance level, and should be applied carefully, especially during the main tournament periods.

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REFERENCES

1 **Elliot BC**, Marshall RN, Noffal GJ. Contributions of upper limb segment rotations during the power serve in tennis. *Am J Sports Med* 1995;**20**:455–8.
2 **Treiber FA**, Lott J, Duncan J, *et al.* Effects of theraband and lightweight dumbbell training on shoulder rotation torque and service performance in college tennis players. *Am J Sports Med* 1998;**26**:510–5.
3 **Kraemer WJ**, Ratamess N, Fry AC, *et al.* Influence of resistance training volume and periodization on physiologcal and performance adaptations in collegiate women tennis players. *Am J Sports Med* 2000;**28**:626–33.
4 **Miyashita M**, Tsunoda T, Sakurai S, *et al.* Muscular activities in the tennis serve and overhand throwing. *Scand J Sports Sci* 1980;**2**:52–8.
5 **Baker D**. The acute effect of alternating heavy and light resistance upon power output during upper body complex power training. *J Strength Cond Res* 2003;**17**:493–7.
6 **Baker D**, Newton RU. Acute effect on power output of alternating an agonist and antagonist muscle exercise during complex training. *J Strength Cond Res* 2005;**19**:202–5.
7 **Robbins DW**. Postactivation potentiation and its practical applicability: a brief review. *J Strength Cond Res* 2005;**19**:453–8.
8 **Surakka J**, Alanen E, Aunola S, *et al.* Effects of external light loading in power-type strength training on muscle power of the lower extremities in middle-aged subjects. *Int J Sports Med* 2006;**27**:448–55.
9 **McBride JM**, Triplett-McBridge T, Davie A, *et al.* The effect of heavy- vs. light-load jump squats on the development of strength, power, and speed. *J Strength Cond Res* 2002;**16**:75–81.
10 **Sale DG**. Influence of exercise and training on motor unit activation. *Exerc Sport Sci Rev* 1987;**15**:95–151.
11 **Wilson GJ**, Newton RU, Murphy AJ et al. The optimal training load for the development of dynamic athletic performance. *Med Sci Sports Exerc* 1993;**25**:1279–86.
12 **Born P**. Aufschlag trainieren. *TennisSport* 2002;**13**:12–4.
13 **Goebel R**. Werfer und Schläger – eine Symbiose? *TennisSport* 2004;**15**:20–4.
14 **Young WB**, Jenner A, Griffiths K. Acute enhancement of power performance from heavy load squats. *J Strength Cond Res* 1998;**12**:82–4.
15 **Güllich A**, Schmidtbleicher D. MVC-induced short-term potentiation of explosive force. *New Stud Athletics* 1996;**11**:67–81.
16 **Ebben WP**. Complex training: a brief review. *J Sports Sci Med* 2002;**1**:42–6.
17 **Fleisig G**, Nicholls R, Elliott B et al. Kinematics used by world class tennis players to produce high-velocity serves. *Sports Biomech* 2003;**2**:51–64.
18 **Bastiaens K**, Müller M, Braun D, *et al.* Short and long term effects of a throwing intervention during complex service training in elite childrens tennis. In: Raab M, Arnold A, Gärtner K, Köppen J, Lempertz C, Tielemann N, Zastrow H, eds. *Zukunft der Sportspiele: fördern, fordern, forschen*. Flensburg, Germany: University Press, 2006:115–8.

COMMENTARY

Worldwide, there are only a few descriptions and results in the literature of field experiments arranged under scientifically-accepted conditions that are helpful in clarifying meaningful questions from the world of tennis practice. This applies in particular to tennis training with children and juveniles.

That is why it is extraordinary to come across authors working on a methodically-correct experimental study with 13 national ranked junior tennis players (6 girls), at pre-pubertal age, covering important questions in relation to tennis practice; specifically, on whether a light or a heavy throwing intervention can be advocated for young tournament players during the typical course of a complex service training setting.

The statistic attestable evidence of the authors, that heavy intervention causes an acute decrease in service velocity, should invariably lead to avoidance of post-activation potentiation theory service velocity training in elite tennis player under the age of 14 years.

Whether this cognition is also appropriate for training with adult masculine elite tennis players, who have a hormonal- and training-dependent power increment as well as a resistance to fatigue and strong service execution, needs more research (in longitudinal- and cross-section) with adequate selected participants.

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