Impact of eight weeks of plyometric training on jump parameters in junior badminton players

Demonstrated with D- and D/C-squad players

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Abstract

Introduction

Plyometric training is popular among individuals involved in dynamic sports, and plyometric exercises such as jumping, hopping, skipping and bounding are executed with the goal of increasing dynamic muscular performance, especially jumping. Much less information is available on the effectiveness of plyometric training (PT) in badminton, where jumping height (e.g. forehand overhead jump-smash) is important for success. The aim of the study was to investigate the effects of an eight-week periodized PT program on jumping height, agility and power among male and female junior badminton players, using high-impact bilateral plyometric exercises.

Methods

Starting and finishing with the biomechanical diagnostics of the squat jump (SJ), counter movement jump (CMJ), and drop jump (DJ) on force plates, kinematic analysis of forehand overhead smashes, anthropometric data as well as force data for pre- and post-test were analyzed. Before and after the biomechanical diagnostics, the players (n=11) undertook an eight week period of plyometric training (2 units per week) with a total of 2286 jumps. Eight male and three female junior badminton players (age: 16.0 ± 1.6 years, height: 175.5 ± 9.9 cm, mass: 69.3 ± 11.4 kg) were tested in jumping height and forehand overhead jump-smashes performance.

Results

The effect of the eight-week plyometric training in junior badminton players significantly increased height of the squat jump ($p<0.05$; $d_z=0.8$) and the drop jump ($p<0.05$; $d_z=1.1$). The height of the counter movement jump increased non-significantly ($p > 0.05$; $d_z = 0.3$). Consequently, this form of training is considered essential for the development of junior badminton players. Moreover, the study has shown that the contact height of the overhead smash was not increased with improved plyometric strength training ($p>0.05$). Therefore, in complex movements, like the badminton smash, the focus must also be on technical training.

Conclusion

This study provides information on a physical increase in performance in combination with a technical component (jump-smash). It is considered to be important to include short-term plyometric programs during in-season preparation in order to improve these kinds of complex

badminton-specific dynamic performance. The results of this study can directly be assimilated into specific badminton training.

Introduction

Besides table tennis and tennis, badminton is one of the fastest Olympic racket and net sports in the world. World-class athletes are able to achieve short-term, maximum shuttlecock speeds in the range of 288 km/h to 365 km/h (Kollath et al., 1986; Luke & Schwab, 2008; Tsai & Chang, 1998). This competitive sport is also characterized by badminton-specific running paths, jumps, and lunges, as well as by the continuous change between accelerated and decelerated movements (Diehl & Kohl, 1999). During an entire match, a player covers a distance of approx. 1800-1900 m (Liddle et al., 1996). The average match and break time is approximately 6.4s and 12.9s (table 1), and the average number of shots is 6.1 per rally (Cabello & González-Badillo, 2003).

Table 1: Typical badminton match characteristics (from Faude et al., 2007)

Rally time (s)	Rest time (s)	Work density	Number of shots per rally	Shots per rally time (s^{-1})	EPT (%)
5.5 ± 4.0	11.4 ± 6.0	0.51 ± 0.34	5.1 ± 3.9	0.92 ± 0.31	31.2 ± 2.8

Data as mean ± SD; EPT = effective playing time

The physiological demands of badminton are of an interval type, which results in high demands of energy provision over short periods of time. Accordingly, a badminton player's lactate values are usually above the aerobic-anaerobic threshold for continuous activity with values of 3.8-4.7 mmol/l (Cabello & González-Badillo, 2003; Majumdar et al., 1997). The corresponding heart rates values are specified in the range of 80-95 % of the maximum heart rate (Cabello & González-Badillo, 2003; Faude et al., 2007; Liddle et al., 1996; Majumdar et al., 1997). Table 2 shows the physiological requirements for badminton from various sources.

Table 2: Physiological requirements profile in badminton

Parameter	Result	Author(s)
Heart rate in percent of the maximum heart rate	80-85 % HR_{max} Ø 86 % HR_{max} Ø 93 % HR_{max} 78.3-99.8 % HR_{max}	Docherty, 1982 Majumdar et al., 1997 Liddle et al., 1996 Faude et al., 2007
Lactate concentration during a badminton match	3.8-4.7 mmol/l	Cabello & Gonzales-Badillo, 2003 Majumdar et al., 1997 Weiler et al., 1997
VO_{2max} in percent of the maximum VO_{2max}	Ø 60.4 % VO_{2max} Ø 73.7 % VO_{2max} 45.7-100.9% VO_{2max}	Faccini & Dal Monte, 1996 Cabello & Gonzales-Badillo, 2003 Faude et al., 2007

At the technical level, the forehand overhead smash is most important in terms of maximum shuttlecock speeds (Tang et al., 1995). With an occurrence of approximately 20 % it is also the second-most frequent shot in badminton (Hong & Tong, 2000). The objective of the forehand overhead smash is a direct winner or the aggressive preparation for a winner. The higher the athlete hits the shuttlecock – i.e., indirectly, the higher the height of the jump – the steeper the trajectory and the shorter the path of the shuttlecock (figure 1). This enables the player to optimize the utilization of the court size (Rambely et al., 2005).

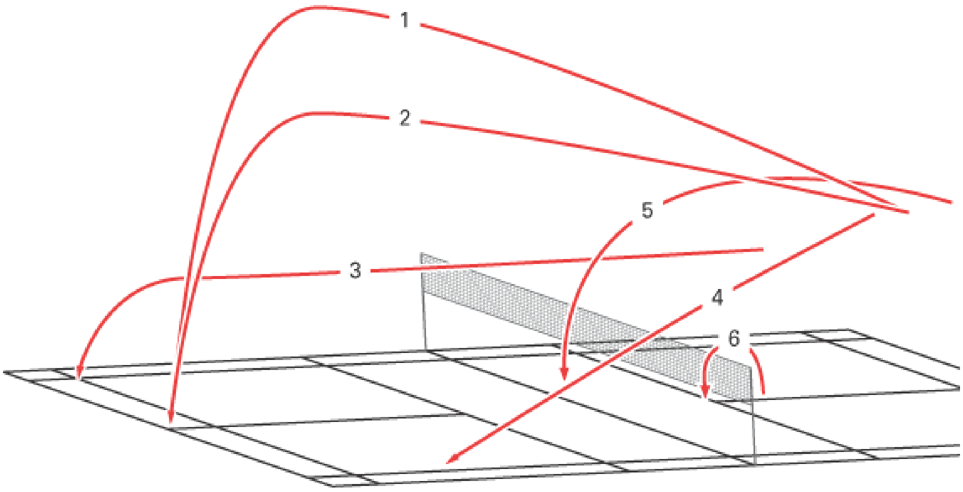

Figure 1: Trajectories of shot techniques (1 = defense clear, 2 = standard or attacking clear, 3 = drive/swipe, 4 = smash, 5 = drop shot, 6 = net play (modified by Poste & Hasse, 2002, 106)

The technical difficulty of the forehand overhead smash becomes apparent when observing the shot technique in detail. The height of the hitting point depends on various factors, such as jump ability, spatiotemporal perception, flight behavior of the incoming shuttlecock, as well as the temporal interconnection of sub-segments. The optimum hitting point is achieved when the entire body is stretched, which means an optimally coordinated stretching of the upper body and the playing arm. An even higher hitting point can be achieved when performing the shot as a jump smash, which requires optimum jumping power and jumping height (Tsai & Huang, 1998; Tsai et al., 2000). As effective as the forehand overhead smash may for winning points, this type of shot requires mastering the specific technique to a high degree and coordinative spatiotemporal and temporal precision (Hong, 1993). The technical complexity of the forehand overhead smash can be described as follows. To perform a forehand overhead smash, the player must go through various movement and orientation patterns. First, the player needs to analyze the shuttlecock trajectory in order to position the body optimally under the shuttlecock. Then, the player needs to select the optimal timing for the jump. During the jump, the racket must be positioned in the best position to build up the body tension required (figure 2). If these factors are perfectly coordinated, a forehand overhead jump smash can be performed with a precise hitting point at the highest point possible.

Figure 2: Forehand overhead jump smash (accessed on May 9, 2013 at http://badminton-coach.co.uk)

Relative force is a major factor in achieving the highest possible shuttlecock hitting point. Therefore, maximum strength training, speed training, and various forms of plyometric training, such as jumps, jump sequences, and jump combinations show significant advantages over methods used to increase strength by increasing the muscle cross section area (Blatter & Noble, 1979; Bobbert, 1990). Elastic and neurophysiologic (reactive) mechanisms can result in increased strength development (Enoka, 1994).

The combination of eccentric and subsequent concentric muscle action represents a frequent movement pattern (e.g., a jump), also known as stretch shortening cycle (SSC) (Komi, 1984). Contractions during the SSC generate a higher movement impulse in the concentric phase (take-off phase, in a narrower sense) than a purely concentric contraction. The reasons for this are thought to lie in the storage of elastic energy and the triggering of muscle stretching reflexes during the eccentric phase (Enoka, 1994; Komi, 1984; Schmidtbleicher & Gollhofer, 1985). The ability to realize a highly concentric strength impulse within the shortest time span possible from within an eccentric (decelerating) movement is called reactive movement behavior ("fast SSC" within 90-200 ms) (Schmidtbleicher & Gollhofer, 1985). Factors limiting or influencing factors include:

a) elastic energy storage,
b) short-range elastic stiffness (SRES),
c) interconnection time,
d) stretch strain and stretch amplitude,
e) stretch speed, and
f) neuronal factors (Komi, 2003).

Numerous authors describe training effects in terms of jump height improvement through SSC training (reactive training, plyometric training) (see Bubeck & Gollhofer, 2000, 2001; Bosco & Pittera, 1982; Schmidtbleicher, 1989; Kyröläinen & Komi, 1994; Sialis, 2004). In summary, it can be stated that training of this type of contraction can have considerable impact on both muscular-skeletal (see Kato et al., 2006; Kubo et al., 2007; Witzke & Snow, 2000; Wu et al., 2010) and neuromuscular adaptations (see Grosset et al., 2009; Kyrolainen et al., 2005; Malisoux et al., 2006; Saez-Saez de Villaereal et al., 2010; Taube et al., 2011), as well as on jumping behavior, even if ambiguous statements stemming from detailed observations (exhaustion behavior, dosage behavior, pause design, etc.) exist (Sialas 2004).

In general, two (match-based) objectives apply to badminton jump movements:

a) achieving maximum height, and
b) achieving a specific point with part of the body/equipment (Ballreich & Kulow-Ballreich, 1992).

Both objectives are of utmost significance in badminton and are therefore to be taken into account in terms of practical training work and technique transfer. On the one hand, plyometric types of training can improve badminton-specific speed requirements and movement patterns, such as running and jump movements, lunges, steps, changes in direction, etc. (Joshi, 2012). On the other hand, at a muscle-physiological level, plyometric training exploits impulses of the pre-innervation and reflex potentiation during the stretch shortening cycle as well as the elastic component of the muscle (Gehri et al., 1998; Komi, 2003), which, in turn leads to an improvement of jump and speed performance (Kannas, 2012; Martinez-Lopez et al., 2012; Meylan & Malatesta, 2009). Using plyometric training in badminton is now considered key to boosting sport-specific capacities (Sturgess & Newton, 2008), with concrete training recommendations being only rarely given (Middleton et al., 2013).

Ultimately, it is assumed that plyometric training will result in higher speeds of take-off (de Varreal et al., 2009; Sialis 2004) and thus, implicitly, also in higher shot speeds – to minimize the time the shuttlecock spends in the air – for forehand overhead smashes. Based on these considerations, two questions should be examined:

1) Can an eight-week plyometric training program improve the jump performance of junior badminton players of D- and D/C squad level?
2) Can an eight-week plyometric training program improve the hitting point in forehand overhead smashes of junior badminton players in D- and D/C squad level?

Methods

Subjects

A total of eleven members of the D- or D/C-squad of the Saarland and German badminton association participated voluntarily in the explorative, quasi-experimental intervention study including pre- and post- treatment measurement[1]. The players were either under 15 or under 19 and had had no previous experience in systematic plyometric training. The average age of the eight boys and three girls was 16.0±1.6 years with an average height of 175.5±9.9 cm and an average body mass of 69.3±11.4 kg. Due to organizational reasons a control group was not implemented.

Operationalization of jump parameters

To operationalize the vertical jump power or reactive force behavior, the performances in squat jump (SJ), counter-movement Jump (CMJ), and drop jump[2] (DJ) were determined using a contact mat and micro controller (Wank & Heger, 2009). In all jump test forms, the hands were fixed at the hip during the entire jump. Each test person received technique instructions before testing started (jump demonstration and two familiarization test jumps). The individual jumps were performed in immediate succession with a one-minute break in between jump series. Subsequently, a 2-D video analysis (Utilius Easy Inspect) identified kinematic parameters of maximum jump height at the shuttlecock hitting point, and racket height during the forehand overhead smash. Technique instructions were given here, as well (jump demonstration and two test jumps). The forehand overhead smash was performed in intervals of 5 seconds. For all tests, the testers had the instruction of "maximum take-off". Figure 3 illustrates the individual kinematic parameters of the hitting technique for the forehand overhead smash.

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[1] Due to the explorative, quasi-experimental character of the study with pre- and post-measurement, learning, adaptation, development, test and interaction effects cannot be excluded besides the assumed intervention effects. Furthermore, due to the small size of the sample, the natural group, and the non-withholding of treatment, an assignment to treatment and control groups or other treatment groups was not applied. The treatment was not administered in intervals so that dosage-effectiveness interconnections cannot be excluded, either.

[2] For test-economic reasons, a standardized drop height of 32 cm was applied, in contrast to a drop height adapted to individual anthropometric or neurophysiological conditions (Faude et al.., 2010).

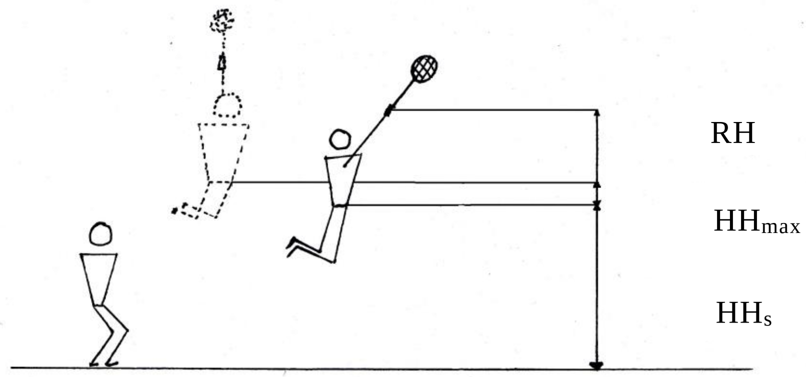

Figure 3: Kinematic jump and racket parameters of a forehand overhead smash at the optimal hitting point (RH = maximum racket height at shuttlecock hitting point, HH_{max} = maximum hip height during the jump, HH_s = jump height at shuttlecock hitting point)

A total of seven jumps were performed for all jump forms, with the best and poorest jump having been canceled so that in the end five jumps were included in the analysis (Faude et al., 2010). The arithmetic mean for pre- and post-test was then calculated based on these five jumps. To compare the DJ data for jump height and floor contact time the so-called landing parameter was calculated for economic reasons (drop height plus jump height divided by floor contact time) (Bartonietz & Eisele, 1994)[3].

[3] Various other parameterization procedures based on quotient calculations exist for dimensionless quantification of reactive abilities – for example, jump height divided by contact time or jump height plus take-off height, multiplied by 9.81 and then divided by the contact time, and the formula by Hamar (1994).

Treatment

The plyometric training was performed during an intervention period of eight weeks, twice a week. The duration of the individual training units was approximately 30 minutes and increased progressively over the number of jumps to be performed. The plyometric jump training took place before any badminton training. To avoid interaction effects between plyometric training and general badminton training endurance-specific strain was excluded. Nevertheless, interaction effects between jump training and general badminton training cannot be completely ruled out. A general warm-up program was followed by eight exercises (jumps, jump sequences, and jump combinations) for simple (jumps without additional load or equipment) and medium (jumps over obstacles) plyometrics one-legged or with both legs for SJ, CMJ, and DJ (table 3). Pauses between jumps and jump series and were kept constant and adjusted to the individual performance level. The exercise sequence was predefined and of a progressive character – the longer the training was performed, the more strain was added by eccentric and intensive-plyometric strain (bounces). The first week of training served as a familiarization phase with only 156 jumps to be carried out per training unit. To avoid physiological, biomechanical, and coordinative overload, DJs and medium-plyometric exercises were not performed in the first week of training. In the course of the weeks, the number of jumps was successively increased from 204 (second week) to 360 (seventh and eighth week). Thus, during the entire intervention phase, 2286 jumps were made.

Table 3: Plyometric training exercise overview

Exercise	Description
1. Squat jump (simple plyometrics)	Start position: • Start position in squat position approximately 90° • Feet at shoulder width • Hands placed on the hips Motion: • Maximum vertical take-off • Direct upward movement by stretching the legs • Landing position identical with take-off position
2. Counter movement jump (simple plyometrics)	Start position: • Upright standing position • Feet at shoulder width • Hands placed on the hips Motion: • Swing movement (knees flexed at approximately 90°) • Eccentric initial movement followed by maximum take-off • Landing position identical with take-off position

3. Drop jump (medium plyometrics)	Start position: • Standing on vaulting box (32 cm) • Hands placed on the hips Motion: • One-legged step forward from the vaulting box • Landing with both legs with maximum reactive take-off up
4. Triple jump with both legs (simple plyometrics)	Start position: • Upright standing position • Feet at shoulder width • Arms are swinging Motion: • Swing movement (knees flexed at approximately 90°) • Maximum take-off forward-and-up with subsequent take-off
5. One-legged triple jump (simple plyometrics)	Start position: • Upright standing position on one leg • Hands are swinging Motion: • Swing movement (knees flexed at approximately 130°) • Maximum take-off from the ankle joint forward-and-up with subsequent one-legged (same leg) take-off Variation: • Use obstacles
6. Jump with both legs over the obstacle(s) (medium plyometrics)	Obstacles: • Front obstacle 15 cm, rear obstacle 30 cm Start position: • Upright standing position • Feet at shoulder width • Arms are swinging Motion: • Swing movement (knee flexed at approximately 90°) • Take-off forward-and-up with subsequent explosive take-off with both legs from the ankle joint Variation: • Place obstacles further apart
7. Gym bench jumps (medium plyometrics)	Start position: • Upright standing position on gym bench • Feet at shoulder width • Hands placed at the hip Motion: • Drop jump from one bench to the next
8. Gym bench-obstacle jumps (medium plyometrics)	Start position: • Upright standing position on gym bench • Feet at shoulder width • Hands placed at the hip Motion: • Combination of drop jump and obstacle jump with both legs (obstacle 30 cm)

Statistics

The descriptive statistical analysis included factors such as the mean value (MV), standard deviation (SD), minimum and maximum values, as well as percentage and absolute changes. The interference-statistical calculation of significance was done using a T-test for paired samples. Pre-condition tests were carried out applying the usual methods (KS test for Gaussian distribution, Levené test for homogeneity of variance). The effect size (d_z) was calculated as the mean value difference divided into $s_{Baseline}$ (Bühner & Ziegler, 2009). The significance level was set to a total of $p < 0.05$ with the Bonferroni correction applied.

Results

Squat jump, counter movement jump, and drop jump

The eight-week plyometric training significantly increased the squat jump performance by 4.4 cm from an average 32.9 ± 5.4 cm to 37.3 ± 6.2 cm ($p < 0.05$; $d_z = 0.8$). The average performance increase was 13.7% (0.6% minimum and 26. % maximum).

For the CMJ, performance increase non-significantly ($p > 0.05$; $d_z = 0.3$) from an average of 40.7 ± 7.6 cm to 43.2 ± 7.5 cm (6.0%). Individual performances showed a broad range with values between -7.2% and +14.8%.

For the DJ, taken as a measure for the reactive force performance, a significant improvement of the landing parameter from 3.9 ± 0.4 to 4.4 ± 0.6 was demonstrated ($p < 0.05$; $d_z = 1.1$). The average improvement was 12.1% with a range between 1.1% and 24.2%.

The values identified using videographic means for maximum jump height (HH_{max}), jump height at shuttlecock hitting point (HH_s), and racket height (RH) during the forehand overhead smash are shown in Table 4 . The maximum jump heights increased considerably between pre- and post-test ($p < 0.05$; $d_z = 0.3$), while the jump height at shuttlecock hitting point ($p > 0.05$; $d_z = 0.2$) and the maximum racket height at shuttlecock hitting point ($p > 0.05$; $d_z = 0.1$) did not show any significant changes. Absolute jump height improvements were measured at 4.4 cm (HH_{max}), 3.3 cm (HH_s), and 2.8 cm (RH).

Table 4: 2D video analysis results of the pre- and post-test

Player	1	2	3	4	5	6	7	8	9	10	11	MV	SD
HH_{max}-E	131.4	170.4	149.6	152.2	128.4	151.2	146.8	166.2	175.6	149.2	165.8	**153.3**	**15.1**
HH_{max}-A	139.6	177.4	152.8	158.8	130.8	155.6	147.8	174.8	172.4	154.6	170.4	**157.7**	**15.0**
HH_s-E	130.4	165.4	147.6	147.2	127.4	150.6	144.4	158.8	173.6	146.2	163.0	**150.4**	**14.1**
HH_s-A	138.2	173.6	150.4	152.8	129.8	146.2	146.2	168.0	169.2	150.2	166.4	**153.7**	**14.0**
RH-E	248.0	291.6	252.2	276.2	230.2	249.8	249.0	274.6	298.2	256.4	265.8	**262.9**	**20.5**
RH-A	260.6	300.2	256.8	281.2	230.6	252.2	250.2	289.6	285.0	254.6	262.2	**265.7**	**20.7**

HH_{max} = maximum hip height during jump, HH_s = jump height at shuttlecock hitting point, RH = maximum racket height at shuttlecock hitting point, E =pre-test, A = post-test

Discussion

The results of this study point to the conclusion that additional plyometric training can positively influence the performance of junior athletes of the D- and C/D badminton squad in terms of various jump parameters in squat and drop jumps. The positive performance improvement in squat jumps can be explained by the selection of individual exercises of simple and medium plyometrics within the training units. Since most exercises, jumps, or jump sequences of the training intervention did not require any swing movement – the actual jump was executed mostly from a concentric movement with a knee angle of more than 90 degrees – a high degree of congruence between dynamic training exercise and test modality can be assumed for the SJ. Due to the relatively low drop heights, short floor contact times can be assumed, which in turn, leads to the assumption of a high degree of congruence between test and training requirements for the DJ. In contrast, no significant improvement was found for the CMJ based on the selected treatment – dynamic jumps mostly without swing movement and in the SSC. Overall, the varied jump training resulted in a performance increase of an average of 13.7 % for SJ, 6.0 % for CMJ, and 12.3 % for DJ although individual participants did exhibit performance degradation. This can be explained *inter alia* by development and learning-based influences, sports-specific training age, neuronal and tendomuscular values, interaction with other training content of regular badminton training, for example.

When considering the videographically analyzed HH_{max}, HH_s, and RH parameters, the eight-week training resulted in a significant increase (jump power) only for the maximum jump height (with the hip being the reference point). The two parameters jump height at shuttlecock hitting point and maximum racket height at shuttlecock hitting point – both representing a highly coordinative and spatiotemporal challenge – do not differ majorly in pre-test and post-test results. Thus, it could be concluded that the plyometric training applied improved jump power or jump height, while its influence on the technical component of the forehand overhead smash in the sense of a spatio-temporal improvement is negligible. This would mean that the influence of the optimal technique applied to the forehand overhead smash in the sense of a suitable combination of sub-segments outweighs pure jump force improvement. Nevertheless, this study does not provide any estimation to what extent the technical implementation may represent a corresponding limitation within the group examined. Furthermore, it may be presumed that plyometric training may have improved both general agility – as a relevant characteristic for changes of direction on the court – (Joshi, 2012) and anaerobic capacity (Liu, 2009), which contributes as a collateral training effect (Vescovi & McGuigan, 2008) to further optimize playing skill.

It is presumed that plyometric training content can positively influence the badminton-specific court speed (for example, by reducing floor contact time), which in turn has positive effects on competitive performance.

An opportune point in time for additional plyometric training for performance-oriented badminton players would be the preparation phase, which is usually scheduled in May and August. During this time, the physical foundation is established for the entire competitive sports season that runs from August to April including several seasonal peaks. Using plyometric training after a hypertrophy training block for the lower extremities is conceivable, with the training completed one to two weeks before the competitions start so that the players recover in time for the competitive phase.

Moreover, plyometric training should be based on individual preconditions. It is essential to ensure that the extent of stimulation and the training scope do not result in overstraining the tendomuscular structures. Since the extent of stimulation or strain intensity in plyometric training is decisively determined by drop height and predefined jump height in jump forms and combinations, it is important to make sure that, for example, the heel does not touch the floor during a drop jump. The training scope can be intensified progressively with the number of jumps in line with performance increase. In principle, increasing the number of jumps is recommended to be implemented as a means of progression before increasing the drop height. However, it is important to assure that the complexities of plyometric training match the overall movement requirements of badminton and that no negative interaction effects with regular badminton training occur. Because of the high amount of mechanical and neuromuscular strain/fatigue, which can lead to an increased deterioration of cellular structures, regeneration is of key importance (Macaluso et al., 2012). To minimize the risk of injury by plyometric training, warm-up training is recommended to prepare the athlete in terms of coordination and muscle pre-stress for the challenges ahead. Rests are of major significance here. A rest of between one and two minutes (Weineck, 2003) is suggested. Also, reactive jumps on the court floor are recommended because on the one hand, this surface provides adequate buffer for the joints, and on the other hand, it is sufficiently hard for not reducing the stretch strain. Frequent pre-, intermediate, and post-tests as well as continuous training controls should be included in planning and executing a plyometric training in order to be able to evaluate the quality of the training program. Suitable reliable and valid test procedures are available: squat jump, counter movement jump, and drop jump, all performed on a contact mat.

Conclusions pertaining to practical training

The analysis showed that an eight-week, systematic, progressively increasing plyometric training can improve the jumping power of junior athletes of the D- and D/C squad. Even though maximum jump height is not explicitly required in performance-oriented badminton, it is likely that improvement of jumping power and jump height influences badminton-specific hitting techniques, such as smashes and on badminton-specific running techniques, such as short, quick steps that mainly put strain on the forefoot.

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