EFFECTS OF JUMP EXERCISES WITH AND WITHOUT STRETCH-SHORTENING CYCLE ACTIONS ON COMPONENTS OF PHYSICAL FITNESS IN PREPUBERTAL MALE SOCCER PLAYERS

Short title: Effects of different jump exercises in youth athletes' physical fitness

Submission type: original article

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ABSTRACT

Objective: This study examined the effects of 8 weeks stretch-shortening-cycle-based (SSC-based) versus non-SSC-based jump exercises on physical fitness in prepubertal male soccer players. *Methods:* Twenty-six participants were randomly assigned to either a SSC-based using countermovement-jump (CMJ_G; n=13) or a non-SSC-based jump group using squat-jump (SJ_G; n=13). Pre- and post-training, tests were conducted to assess measures of muscle power (countermovement-jump, reactive-strength-index), speed (5-m, 20-m), change-of-direction (CoD), and sport-specific performance (maximal-kicking-distance). To establish the effect of the interventions on the dependent variables, a 2 (group: CMJ_G and SJ_G) × 2 (time: pre, post) ANOVA with repeated measures was determined for each parameter. *Results:* Findings demonstrated a main effect of time for countermovement-jump, reactive-strength-index, and maximal-kicking-distance ($p<0.05$, effect size [ES]=0.56-0.71). Group × time interactions were identified for (5-m, 20-m, and reactive-strength-index ($p<0.05$, ES=0.59-0.64) in favor of CMJ_G. Particularly, pre-post performance improvements have been observed for 5-m (Δ1.6%; p=0.04; ES=0.54) and 20-m (Δ5.3%; p<0.01; ES=1.00) in the CMJ_G. For SJ_G, 5-m (Δ-5.5%; p=0.01; ES=-1.12) and 20-m (Δ-3.7%; p=0.01; ES=-0.82) pre-post performance declines were observed. Regarding reactive strength index, pre-post improvement was noted for CMJ_G only (Δ-40.1%; p<0.01; ES=3.7). In addition, a tendency toward a group × time interaction was found for CoD (p=0.06, ES=0.54) with a performance decrement for SJ_G (Δ-6.0%; p<0.01; ES=-1.8) and no pre-post changes for CMJ_G (Δ0.15%; p>0.05; ES=0.05). *Conclusion:* Overall, jump exercises which utilise the SSC seem to be more effective in improving measures of speed and muscle power performance in young athletes. However, jump exercises that do not involve the SSC appear to negatively affect CoD performance in young athletes.

KEY WORDS: ground contact-time, reactive strength, athletic performance, youth, football

INTRODUCTION

High levels of physical fitness, such as change of direction (CoD) ability, sprinting and jumping are needed to successfully meet the diverse demands of soccer. Indeed, it has been shown that the level of these physical qualities (i.e., CoD, sprinting, and jumping) largely influence young soccer match performance [1, 2]. Accordingly, the early development of CoD, sprinting, and jumping performances is needed to prepare young players for the increased training and competition demands of modern soccer [3]. Plyometric training is a frequently applied, safe and effective mean to improve high-intensity actions such as CoD, linear sprint and jump performances in young soccer players [4].

Recently published studies have addressed different variables relating to plyometric training volume [5] and frequency [6] in prepubertal male soccer players. In these studies, larger training volumes (i.e., number of foot contacts) [5] and higher frequencies (i.e., number of sessions per-week) [6] were not associated with additional increases in physical fitness. Despite the growing number of studies related to jump training in young athletes, there is a void in the literature as to the most effective *type* of jump training exercise, particularly in prepubertal athletes [4]. Of note, jump training can either be reactive using the stretch-shortening cycle (SSC) or non-reactive without using the SSC [7]. SSC-based jump exercises are characterized by short ground contact times (<250 ms) and high leg stiffness [8]. In contrast, non-SSC-based jump exercises (squat jumps) are typically characterized by long ground contact-times (>250 ms) and larger knee flexion angles [9].

Previously, it has been shown that performance-enhancing stretch-reflexes are elicited only during the eccentric phase of a SSC-based jump exercise program if ground contact times are below 250 ms [9]. A potentiating stretch reflex is not elicited if ground contact times are >250 ms during the eccentric to concentric transition phase [8, 9].To achieve short ground contact times, high leg stiffness is needed during the eccentric to concentric transition phase (i.e., reactive movement) [8]. Additionally, during SSC-based jump exercises, the muscles of the lower limb are pre-innervated prior to ground contact [10]. This preactivation mechanism is needed to stiffen the joints in preparation of touchdown and to enable a powerful push-off during the subsequent concentric phase [11]. Moreover, during the eccentric phase, energy is stored for a short time frame (<250 ms) in both the connective tissue and the tendons. When this eccentric phase is rapidly followed by a contraction (i.e., concentric) of the same muscle-tendon complex within a time period of 250 ms, the stored elastic energy can be used during the concentric phase inducing higher force output [12]. A typical non-SSC jump exercise is the squat jump. During the performance of squat jumps, athletes do not start the exercise with a prior countermovement which is a prerequisite for the SSC. In fact, squat jumps are characterized by a high movement speed of the leg extensors during the concentric phase of the vertical jump [7]. Therefore, based on the described characteristics, SSC-based jump exercises are different from non-SSC-based ones in terms of the underlying neuromuscular activation patterns [7].

In view of the different muscle activation mechanisms utilized during SSC-based and non-SSC-based jump exercises [9, 8], it is timely to contrast these training regimes and their effects on physical fitness and sport-specific performance in young athletes. Therefore, the objective of this study was to compare the effects of an 8-week jump training program that applied SSC-based exercises versus a program that did not use SSC-based exercises on components of physical fitness (i.e., jumping, sprint-time, and CoD) in prepubertal male soccer players. With reference to the relevant literature [9, 8, 7], we hypothesized that SSC-based jump exercises would generate larger physical fitness improvements than non-SSC-based jump exercises in prepubertal male soccer players.

METHODS

Participants

Twenty-six healthy young males from a regional soccer team were randomly assigned either to a SSC-based using countermovement-jump exercises (CMJ_G; n=13) or a non-SSC-based jump group using squat-jump exercises (SJ_G; n=13). The randomization sequence was conducted electronically (https://www.randomizer.org). Sample size was determined a priori using G*power software (Bonn FRG, Bonn University, Department of Psychology). Based on a similar study conducted by Ramirez-Campillo et al. [13] on the effects of plyometric training on countermovement-jump performance and assuming a type I error rate of 0.05 and 80% statistical power, 13 participants per group would be sufficient to observe a medium-sized main effect. All participants have a mean of 4.0 ± 1.5 years of continuous soccer training involving 3 to 5 training sessions per week. Subject characteristics and anthropometric data are presented in Table 1. Participants who missed more than 20% of the total number of training sessions and/or more than two consecutive sessions were excluded from the study. The maturation status of the participants was determined both before and after eight weeks of training, according to the maturity offset method [14]. All procedures were approved by the local Institutional Review Committee for the ethical use of human subjects in accordance with the latest version of the Declaration of Helsinki. Written informed parental consent and participant assent were obtained prior to the start of the study. All participants and their parents/legal guardians were informed about the experimental protocol and its potential risks and benefits before the start of the study.

--Table 1 near here--

Procedures

The two jump training programs (i.e., SSC- and non-SSC-based) were conducted during the in-season period of the regular soccer season. Two weeks before baseline testing, two sessions were undertaken to familiarize participants with the utilized physical fitness tests and plyometric drills. Before and after the intervention, tests were conducted for the assessment of proxies of muscle power (i.e., countermovement-jump, reactive-strength-index), speed (20-m sprint test with split sprint-time of 5-m and 20-m), CoD (Illinois CoD test), and sport-specific performance (maximal kicking distance). All tests were scheduled at least 48 hours after participants' most recent training session or competition, at the same time of day (7:30-9:30 a.m.), and under similar environmental conditions (22-24°C, no wind).

Measurements

The warm-up procedure for all tests consisted of 5 minutes of sub-maximal running with CoD exercises, 10 minutes of submaximal plyometrics (two jump exercises of 20 vertical [i.e., countermovement-jump] and 10 horizontal jumps), dynamic stretching exercises, and 5 minutes of a sprint-specific warm-up. All tests were separated by a 5 to 10 minutes break in-between. Each player participated in a familiarization trial and two test trials. Another rest period of 3 minutes was provided between trials. The best out of the two test trials was used for further analyses.

Countermovement jump test

Participants started from an upright erect standing position. They then performed a maximal vertical jump which was initiated by a fast downward flexion of the knees and hips, immediately followed by a rapid leg extension. Arms were positioned akimbo. The countermovement-jump techniques were visually inspected by the first author of this study. Jump height was recorded using an Optojump photoelectric system (Microgate, SRL, Bolzano, Italy). Participants were instructed to keep their legs fully extended during the flight phase.

Reactive strength index

Participants executed five repeated bilateral maximal vertical hops using an Optojump photoelectric system (Microgate, SRL, Bolzano, Italy). Subjects were instructed to maximize jump height and minimize ground contact time. The first jump was excluded with the four remaining trials being averaged for the calculation of reactive strength index using the following formula: reactive strength index *= jump height (mm) / ground contact time (ms)* [15].

Speed

Twenty-meter linear sprint performance was assessed at 5-m and 20-m intervals using a single-beam electronic timing system (Microgate, SARL, Bolzano, Italy). Participants started in a standing start position 0.3-m before the first infrared photoelectric gate, which was placed 0.75-m above the ground to ensure it captured trunk movement and avoided false signals via limb motion.

Change of direction test

The Illinois CoD test was conducted as previously outlined [16]. In brief, the Illinois CoD test involves placing 4 markers to indicate an area that is 10 m long and 5 m wide. In the center of the area, four markers were placed 3.3 m apart. The participant started in a prone position with the chin touching the surface of the starting line. The athlete accelerated for 10 m, turned around and returned to the starting line, swerving in and out of four markers, and completing two 10-m sprints to finish the course. Participants were instructed not to cut over the markers but run around them. The time needed to complete the test was used as a performance outcome and it was assessed with an electronic timing system (Microgate, SARL, Bolzano, Italy).

Maximal kicking distance test

Participants were asked to kick a new size 5 soccer ball (Nike Seitiro, FIFA certified) on a soccer field for maximal distance [6]. Two markers were placed on the ground side by side to locate the kicking line. After an approach of two strides, participants executed a maximal kick with their dominant leg. The maximal distance attained by the ball was measured using a metric tape. An evaluator was placed near the area where the ball landed to accurately locate the point of contact and measure the distance of the kick to the nearest 0.2 m. Wind velocity was <20 $km.h^{-1}$ during all testing sessions (local Meteorological Service).

Plyometric training

The two experimental groups participated in an 8-week in-season program consisting of two jump training sessions per week. These sessions were integrated into the regular training routine of the soccer team and were performed immediately after the warm-up, replacing some technical-tactical soccer drills. All sessions were performed on a grass field. The second jump training session was completed 72 h after the first so as to provide a sufficient between-session recovery period. Each soccer training session lasted between 80 and 90 minutes. The jump drills were conducted in a non-fatigued state and lasted between 9 and 25 minutes. The protocol was carried out in accordance with previously published recommendations for jump training intensities and volume [17]. To minimize stress on the musculotendinous unit, training volume and intensity were progressively increased (Table 2). Both jump training sessions consisted of a volume of 2-4 sets with 8-12 repetitions per set. Training volume was manipulated by progressively increasing the total number of ground contacts per session from 50 during the first week, to 120 during the last week of the intervention [17]. Each jump training session included horizontal (standing long jumps), vertical (countermovement-jumps), and unilateral jumps. To gradually increase training intensity, unilateral jumps were mainly performed horizontally during weeks 1 to 4, whereas during weeks 5 to 8, vertical unilateral jumps were introduced in addition to horizontal jumps. Athletes in the CMJ_G were advised to perform consecutive jumps with short ground contact-times and high leg stiffness (i.e., reactive jump in fast SSC). Athletes in the SJ_G performed consecutive jumps in a slower more controlled manner. They jumped by flexing the knees to a larger extent (i.e., non-reactive jump), pausing for around 3 seconds after each jump landing. From here they maintained their knee flexion angle before rapidly extending the knees for the next jump. Performance continued as such for the duration of the set. All jump exercises were performed with arms swing. A trainer to participant ratio of ▪ 1:6 was achieved during all training sessions with technical accuracy being highly prioritized during training. A 90-s rest was provided between each set of exercises.

--Table 2 near here—

STATISTICAL ANALYSES

Between-group baseline differences in anthropometric characteristics, maturity offset, and physical fitness were verified using the independent samples t-test. Data are presented as means and standard deviations (SD). Normality of data was tested using the Shapiro-Wilk's test. To establish the effect of the interventions on the dependent variables, a 2 (group: CMJ_G and SJ_G) × 2 (time: pre, post) ANOVA with repeated measures was determined for each parameter. When group × time interactions reached the level of significance (i.e., significant F value), group-specific post-hoc tests (i.e., paired t-tests) were used. The alpha level of significance was set at $p < 0.05$. A trend for statistical significance was accepted at $p < 0.10$. To determine the magnitude of the training effect, effect sizes (ES) were determined by converting partial eta-squared to Cohen's d using the following equation: ES = 2 × sqr(eta^2/(1 − eta^2)) [18]. According to Hopkins et al. [19] ES values are classified as trivial (<0.2), small (0.2-0.6), moderate (0.6-1.2), large (1.2-2.0), very large (2.0-4.0), and extremely large (>4.0). Test-retest reliability was assessed using the intraclass correlation coefficients (ICCs). All data analyses were performed using SPSS 25.0 (SPSS, Inc, Chicago, IL, USA).

RESULTS

All subjects received the treatment as allocated. The adherence rate was 100% in both groups. No training or test-related injuries were reported. All physical fitness and sport-specific performance measures at baseline and follow-up are displayed in Table 3. At baseline, no between-group differences were observed with respect to anthropometric characteristics and maturity offset (p>0.05). The maturation level of all participants was 'prepubertal' (Table 1). Similarly, no between-group differences were recorded at baseline for any measure of physical fitness (Table 3).

The ICCs for test-retest trials were high for all measures of physical fitness and sport-specific performance. Specifically, ICCs were 0.85 and 0.90 for 5-m and 20-m sprint, respectively, 0.92 for CoD, 0.91 for countermovement-jump, 0.90 for reactive strength index, and 0.85 for maximal kicking distance.

Sprint-time

Our analysis revealed no main effect of time for 5-m and 20-m ($F_{(1,52)}$= 0.88, ES=0.27 [small], p=0.35) and ($F_{(1,52)}$= 0.24, ES=0.14 [trivial], p=0.62), respectively. However, group × time interactions were observed for 5-m ($F_{(1,52)}$= 4.27, ES=0.60 [moderate], p=0.04) and 20-m ($F_{(1,52)}$= 5.00, ES= 0.64 [moderate], p=0.03) (Table 3). Post-hoc analyses showed pre-post performance improvements in the CMJ_G for 5-m (Δ1.6%; p=0.04; ES=0.54) and 20-m (Δ5.3%; p<0.01; ES=1.00). For SJ_G, the post-hoc analyses demonstrated 5-m (Δ-5.5%; p=0.01; ES=-1.12) and 20-m (Δ-3.7%; p=0.01; ES=-0.82) pre-post performance declines.

Change of direction test

For the CoD, results indicated a tendency toward a main effect of time ($F_{(1,52)}$= 3.19, ES= 0.51 [small], p=0.08). Similarly, a tendency toward a group × time interaction ($F_{(1,52)}$= 3.54, ES= 0.54 [small], p=0.06) was observed for the same test (Table 3). Post-hoc analyses demonstrated CoD performance decrements from pre- to post for SJ_G (Δ-6.0%; p<0.01; ES=-1.8). No pre-post changes were found for CMJ_G (Δ0.15%; p>0.05; ES=0.05).

Jump performance

For countermovement-jump, a main effect of time was observed ($F_{(1,52)}$= 6.07, ES=0.71 [moderate], p=0.01). However, the analysis revealed no group × time interaction ($F_{(1,52)}$= 0.00, ES=0.00 [trivial], p=0.99) (Table 3).

Reactive strength index

For reactive strength index performance, results showed a main effect of time ($F_{(1,52)}$= 3.72, ES=0.56 [small], p=0.05) and a group × time interaction ($F_{(1,52)}$= 4.21, ES=0.59 [small], p=0.04). Post-hoc analyses indicated pre-post improvement in reactive strength index for CMJ_G only (Δ-40.1%; p<0.01; ES=3.7).

Maximal kicking distance

For the maximal kicking distance test, a main effect of time ($F_{(1,52)}$=5.53, ES=0.68 [moderate], p=0.02) was found but no group × time interaction ($F_{(1,52)}$=0.02, ES=0.00 [trivial], p=0.88) (Table 3).

--Table 3 near here--

DISCUSSION

The main outcome of this study showed that SSC-based jump exercises, characterized by short ground contact-times, appear to be more effective than non-SSC-based ones in improving measures of sprint-time (5-m and 20-m) and muscle power performance assessed by the reactive strength index. Specifically, small-to-moderate sprint-time enhancements were noted in the CMJ_G while moderate performance decreases were observed in the SJ_G. Additionally, non-SSC-based jump exercises seem to negatively and largely affect CoD performance whilst SSC-based ones have no effect. Regarding jump performance (countermovement jump), both training interventions appear to be equally effective with moderate improvements. In terms of sport-specific performance, the two training interventions appear to be beneficial in improving maximal kicking distance performance in prepubertal male soccer players.

The results of this study indicated improvements in sprint time in the CMJ_G only (Table 3). More specifically, SSC-based jump exercises induced ‘small’ and ‘moderate’ improvements in acceleration (5-m) and sprint speed (20-m), respectively, after 8 weeks of training. This is in agreement with previous findings conducted in similar cohorts [6, 5]. Chaabene and Negra. [5] studied the effect of 8 weeks of high and low jump training volumes on measures of physical fitness in prepubertal male soccer players, revealing improvements in speed (20-m) after both training interventions (ES=0.8). Similarly, by comparing different jump training frequencies (one vs. two sessions per week) during a training period of 8 weeks in prepubertal male soccer players, Bouguezzi et al. [6] were able to demonstrate similarly meaningful improvements in acceleration (5-m; ES=0.5). Due to high neural plasticity in biologically immature children, the mechanisms that underpin the observed sprint-time improvement in the present study are most probably of neuromuscular origin [20]. This includes increases in the number and/or coding rates of active motor units as well as changes in the recruitment pattern of those motor units, particularly in fast-twitch muscle fibers [20]. Despite this assertion, further direct mechanistic evidence is required to support this stance.

Further to the above, the inclusion of horizontal jumping in the training program could have resulted in the enhancement of sprint performance due to the relative importance of horizontal force production and application in sprint actions [21, 22]. In contrast to the CMJ_G, moderate sprint time performance decrements were observed for the SJ_G. Considering the importance of the SSC during sprinting actions, this difference could be due to the lower contribution of the SSC mechanisms during non-SSC-based jumps [9]. This seems plausible given that concentric potentiation, muscle preactivation prior to landing, utilization of stored elastic energy, and the stretch reflex have all been shown to only occur during SSC-based jumping [8]. Given the key role of sprinting performance in soccer matches, the current findings should be taken into consideration by practitioners for the optimal development of sprinting abilities in prepubertal youth.

In terms of CoD performance, results showed a trivial pre-post change in the CMJ_G ($p>0.05$) and a large decrement in the SJ_G ($p<0.05$) after training (Table 3). Asadi et al. [23] conducted a meta-analysis dealing with the influence of maturation level on CoD performance gains after the jump training and reported a more pronounced improvement in mid and post-PHV youth when compared to pre-PHV youth. According to the same authors, the greater structural (e.g., muscle size) and neuronal (e.g., motor unit recruitment, firing frequency, inter-muscular coordination) plasticity could be responsible for the greater adaptive responses of older youths after jump training. In the current study, CMJ_G did not seem to be a sufficient stimulus to generate CoD performance improvements. This is in line with the findings of Sohnlein et al. [24] who reported no CoD performance (5×10 m shuttle run) improvements after a 16-week jump training program in 13 years male soccer players. Recently, Lupo et al. [25] investigated the effects of 12 weeks running technique training vs. soccer-specific training on CoD performance in prepubertal male soccer players. They reported that running technique training approach was more effective in improving CoD performance than soccer-specific training. Aside from the influence of neuromuscular factors and the training intervention *per se*, the lack of CoD improvement could, also, be explained by technical elements (e.g., low center of gravity, forward lean, stride length, rounded/sharp CoD) associated with CoD performance components [26, 27]. In fact, Condello et al. [27] argued that, in young athletes, the technical execution of CoD could provide more insight than simply recording performance time. Accordingly, the current study findings should be interpreted cautiously as we did not control for technical factors during CoD performance. The performance decrement in the SJ_G could partly be related to sprint performance alterations as discussed previously. Indeed, it has been recently demonstrated that CoD performance is associated (r=0.53 to 0.85) with sprint-time performance in prepubertal male athletes [16].

Our findings showed moderate performance improvements in the countermovement-jump test ($p<0.05$) with no difference between the two training interventions ($p>0.05$) (Table 3). This is in line with previous studies addressing the effects of jump training in prepubertal youth [6, 16, 28]. In a meta-analysis study, Moran et al. [28] revealed that jump training is moderately effective (ES=0.9) in stimulating increases in countermovement-jump in prepubertal youth. Jumping performance improvement can generally be attributed to neurological factors such as enhanced motor unit recruitment, greater inter-muscular coordination, enhanced neural drive to agonist muscles and better utilization of the SSC [29]. Given that no direct physiological measures were undertaken in this study, future investigations are needed to support these outcomes.

In line with our hypothesis, the study results demonstrated a very large reactive strength index performance gains after training in the CMJ_G ($p<0.05$), with no performance improvements in the SJ_G ($p>0.05$) (Table 3). It is noteworthy that the reactive strength index mirrors the ability of an individual to produce maximal strength within a minimal timeframe [30]. Thus, with training specificity in mind, reactive strength training, which incorporates extensive use of the SSC, should be a suitable way of stimulating significant improvements in that physical quality. Bouguezzi et al. [6] reported that 8 weeks of either one or two jump training sessions per week were similarly effective in improving reactive strength index performance in prepubertal male soccer players. Increased rate of force development, [31] higher leg stiffness [30] and greater motor unit recruitment [32] seem to be the main factors generating reactive strength index performance improvement following SSC-based jump training. In contrast to the CMJ_G, our findings indicated no reactive strength index performance increases in the SJ_G. This observation can be mainly attributed to the longer ground contact times between jumps and the resultant attenuation or even absence of the SSC activity in the SJ_G. With reference to our findings, SSC-based jump exercises should be recommended for prepubertal youth when it comes to improving reactive strength index performance.

Regarding maximal kicking distance, we observed a moderate performance improvement after both training interventions ($p<0.05$) (Table 3). This is in agreement with previous findings in prepubertal male soccer players which showed maximal kicking distance improvements after 8 weeks of either one or two jump training sessions per week [6]. The observed maximal kicking distance enhancement may be attributed to the aforementioned neuromuscular adaptations following jump training programs [17]. However, it is important to note that kicking distance is influenced by various external factors, such as ball trajectory and rotation, in addition to the technique used to perform the action (e.g., toe, dorsum or the inside part of the foot) [33]. These factors could affect kicking distance performance to a greater degree than a player's muscle strength and power levels.

The current study does have some limitations. First of all, we were unable to include an active control group. Nevertheless, in a study attempting to compare two different training methods, an active control group is not that required [5, 34]. Secondly, any overall training load differences were not controlled for. We are, nonetheless, confident that this was similar between the two groups since they both belong to the same club and all participants were exercising under the supervision of the same coaches with the same training program. Finally, the duration of the training intervention (i.e., 8 weeks) could constitute another limitation to this study. Accordingly, future studies considering longer training periods (e.g., 12 weeks or more) are recommended to confirm the present study's outcomes.

CONCLUSIONS

Twice-weekly SSC-based jump training, in place of some soccer-specific drills within a regular in-season practice, appears to be more beneficial than non-SSC-based in improving physical fitness in prepubertal male soccer players. Accordingly, coaches and strength and conditioning practitioners should devote more time to SSC-based compared to non-SSC-based jump exercises in the in-season training programs. Despite the apparent inferiority of non-SSC-based jump training, to improve technical competency in prepubertal male soccer players, such a programme can serve as a precursor to SSC-based training. Future studies are needed to support the present outcomes and to address sex- and maturity-specific effects of SSC-based vs. non-SSC-based jump training on components of physical fitness in young athletes.

ACKNOWLEDGEMENTS

Authors would like to express their gratitude to coaches, parents, and players for their adherence to this study. There is no conflict of interest related to the content of this research.

Conflict of interest statements

The authors declare no conflict of interest

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