

The Impact of Functional Strength Training on Balance, Agility, and Injury Prevention in Young Athletes

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ABSTRACT

The purpose of this research was to determine how functional strength (FST) training over 12 weeks influenced injured young competitive athletes' dynamic balance, agility, and incidence of injury. The project used 40 young competitive athletes (mean age = 15.3±1.2 years) as participants and was designed as a randomized controlled trial with 20 in the experimental FST group and 20 in the active control (AC) group. Balance was measured by the Star Excursion Balance Test (SEBT) composite score; agility was measured with the Illinois Agility Test (IAT) time; and the number of injuries suffered per 1000 athlete exposures (AE) was used to determine how each group differed regarding incidence of injury. Other measures included the 1-repetition maximum (1-RM) back squat for lower-body strength, joint position sense (JPS) for proprioceptive acuity, and the composite score of the Functional Movement Screen test (FMS) for quality of movement. Compared to Control an FST condition had much larger impact on SEBT composite scores (Delta 13.4% vs 4.4%: $p < .001$; $d = 2.04$) and IAT (Delta 11.3% vs 4.7%: $p < .001$; $d = 1.58$) as well as Injuries (Delta -60.4% vs -23.4%: $p < .001$; $d = 1.87$). With all between-group effect sizes being considered large, the data strongly supports the use of FST in early phases of injury prevention and performance enhancement for youth athletes.

Keywords: Functional strength training; Dynamic balance; Agility; Injury prevention; Young athletes; Star Excursion Balance Test; Proprioception; Youth sports

ABSTRAK

Tujuan dari penelitian ini adalah untuk menentukan bagaimana latihan kekuatan fungsional (FST) selama 12 minggu memengaruhi keseimbangan dinamis, kelincahan, dan kejadian cedera atlet kompetitif muda yang cedera. Proyek ini menggunakan 40 atlet kompetitif muda (usia rata-rata = 15,3±1,2 tahun) sebagai peserta dan dirancang sebagai uji coba terkontrol acak dengan 20 pada kelompok FST eksperimental dan 20 pada kelompok kontrol aktif (AC). Keseimbangan diukur dengan skor komposit Star Excursion Balance Test (SEBT); kelincahan diukur dengan waktu Illinois Agility Test (IAT); dan jumlah cedera yang diderita per 1000 paparan atlet (AE) digunakan untuk menentukan

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bagaimana setiap kelompok berbeda terkait insiden cedera. Ukuran lain termasuk squat punggung maksimum 1 pengulangan (1-RM) untuk kekuatan tubuh bagian bawah, rasa posisi sendi (JPS) untuk ketajaman proprioceptive, dan skor komposit dari tes Layar Gerakan Fungsional (FMS) untuk kualitas gerakan. Dibandingkan dengan Kontrol, kondisi FST memiliki dampak yang jauh lebih besar pada skor komposit SEBT (Delta 13,4% vs 4,4%: $p < ,001$; $d = 2,04$) dan IAT (Delta 11,3% vs 4,7%: $p < ,001$; $d = 1,58$) serta Cedera (Delta -60,4% vs -23,4%: $p < ,001$; $d = 1,87$). Dengan semua ukuran efek antar kelompok yang dianggap besar, data sangat mendukung penggunaan FST pada fase awal pencegahan cedera dan peningkatan kinerja untuk atlet remaja.

Kata Kunci: Latihan kekuatan fungsional; Keseimbangan dinamis; Kelincahan; Pencegahan cedera; atlet muda; Tes Keseimbangan Ekskursi Bintang; Proprioception; Olahraga remaja

INTRODUCTION

Musculoskeletal injuries are an obvious barrier to participation, long-term development and mental health in our young competitive athletes. Injury epidemiology suggests that injuries in youth sport between the ages of tennis aged individuals between 10-18 years is not only high, but increasing as youth sport specialization increases, esp at times of elite developmental academy. Low-extremity injuries (ankle sprain, ACLs, patellar tendinosis and stress fractures) make up 60-75% of all sport injuries in youth with many ramifications on physical development, psychological confidence and athlete careers (Myer et al., 2015).

FST (Functional Strength Training) has become a multidimensional condition model. It combines Resistance Exercise (RE), NM control (Neuromuscular), proprioceptive challenge, and the development of patterns of movement skills through ecological relevant and sport appropriate conditions (Behm & Chaouachi, 2011). Classically, RE (Resistance Exercise) is focused on the development of isolated profile, single motion, machine lifted muscle strength (i.e., one joint, machine dependent) while developing minimal postural and proprioceptive control. In contrast to traditional methods, FST incorporates compound multi-joint full body movement, unbalanced equipment, and unexpected balance-based movement to enhance development of strength, NM coordination, and development of movement quality for all kinetic chain components (Chimera et al., 2004). FST (Functional Strength Training) has become a multidimensional condition model. It combines Resistance Exercise (RE), NM control (Neuromuscular), proprioceptive challenge, and the development of patterns of movement skills through ecological relevant and sport appropriate conditions (Behm & Chaouachi, 2011). Classically, RE (Resistance Exercise) is focused on the development of isolated profile, single motion, machine lifted muscle strength (i.e., one joint, machine dependent) while developing minimal postural and proprioceptive control.

In contrast to traditional methods, FST incorporates compound multi-joint full body movement, unbalanced equipment, and unexpected balance-based movement to enhance development of strength, NM coordination, and development of movement quality for all kinetic chain components (Chimera et al., 2004). Dynamic balance—the ability to maintain postural stability during active movement is a core requirement for athletic performance and injury prevention. Impairments in dynamic balance have been

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longitudinally associated with an increased risk of ACL injury, ankle sprains, and patellofemoral pain syndrome in youth athletes across multiple sports (Plisky et al., 2006). The Star Excursion Balance Test (SEBT), a valid and clinically feasible composite reach distance test, is a sensitive and ecologically valid marker of dynamic postural control that has anteroposterior, mediolateral and diagonal reach vectors that elicit demands on the neuromuscular system across multiple movement planes (Gribble et al., 2012). Asymmetrical, composite-sebt scores <89% of limb length increase the odds of sustaining a lower-extremity injury four-fold in high school female athletes (Plisky et al., 2006).

Agility the ability to achieve whole-body changes of direction rapidly and accurately in response to sport-specific, stimuli is a mechanistic fusion of superimposed motor capacities of lower extremity strength, reactive neuromuscular mechanisms, dynamic balance, and cognitive processing (Sheppard & Young, 2006). Performance on agility tests such as the Illinois Agility Test discriminates between levels of competitive sports participation and demonstrates meaningful changes in response to neuromuscular training and strength training protocols. Agility performance cannot be improved by simply being faster or more powerful you require joint stabilization of deceleration followed by re-acceleration when directions are changed exactly what FST's weightbearing eccentric loading, single-leg stability and reactive postural control drills address.

Proprioception the sense by which the musculoskeletal system detects joint position, limb movement, and mechanical stress is accrued as vital to the risks of injury and quality of movement of the young athlete. Proprioceptive processing through mechanoreceptors in joint capsules, ligaments, muscle, and tendons leads to both anticipatory and reactive neuromuscular adjustments protecting joint integrity during the high velocity sport movements of the young (Riemann & Lephart, 2002). Adolescents may be particularly at risk for proprioceptive deficits during phases of rapid growth, when the skeleton lengthens faster than the neuromusculoskeletal maturation and mechanoreceptor re-calibration can take place. Systematically challenging the proprioceptive sense through progressive instability, varying load, and movement variability, has been shown to enhance the accuracy of joint position sense, and reduce injury in youth (Emery & Meeuwisse, 2010).

The link between lower-extremity muscular strength and injury risk is well documented throughout the biomechanical literature. Quadriceps strength deficits, hamstring-to-quadriceps strength imbalances, and hip abductor and external rotator weakness have each been identified prospectively as modifiable injury risk factors for ACL tears, patellofemoral dysfunction, and iliotibial band syndrome in adolescent athletes (Hewett et al., 2006), and it is these strength deficiencies we address in functional strength training via progressive compound loading in functional movement patterns that include squatting, hinging, lunging, pushing, pulling, and carrying; all of which are done in patterns that simultaneously emphasize muscular strength, inter-muscular coordination and dynamic joint stability for the hip-knee-ankle kinetic chain. The incorporation of unilateral exercises in the FST paradox is directed towards minimizing bilateral strength asymmetries that are of mechanistic concern for injury susceptibility.

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It is encouraging that in terms of theoretical justification and growing empirical evidence for the benefits of FST, there is less quality research evidence specifically examining the simultaneous effects of FST on balance, agility and injury prevention in adolescent athletes. Previous systematic reviews (Faigenbaum et al., 2016; Myer et al., 2015) have tended to examine the outcomes separately and across a heterogeneous range of types of intervention designs, making it impossible to come to any integrated conclusions about the multidimensional effects of FST. A large proportion of the trials that have been conducted are in adult populations or have implemented injury prevention programme designs which blur the effect of the strength component by combining with plyometrics, flexibility and running.

Developmental Issues Developmental considerations associated with training young athletes add further complications to training programme design. During adolescence there is increased plasticity of the neuromuscular system; it makes the youth athletes very amenable to correctly framed strength and neuromuscular training interventions but also very susceptible to overuse injury, if load exceeds levels at which one can safely adapt (Lloyd & Oliver, 2012). Current findings from youth resistance training studies suggest that appropriately supervised, progressively loaded FST is physically safe, developmentally appropriate and beneficial for long term athletic development (LTAD) considerations such as the development of movement competency, neuromuscular control and injury resilience (Faigenbaum & Myer, 2010).

In order for the assessment tools utilized for evaluating training adaptations among younger athletes to be considered to have psychometric credibility (including measures of content validity, test-retest reliability; and sensitivity to training-induced change), they must pass through a rigorous screening process assessing how well each fulfills these criteria. The Functional Movement Screen (FMS), SEBT, and Illinois Agility Test all exhibit acceptable to outstanding test-retest scores among adolescents and can be shown to be responsive to interventions utilizing Functional Strength Training (FST), according to previous studies (Cook et al., 2006; Gribble et al., 2012). The definition of an injury requiring a physician's care resulting in time lost from practice or competition is the most widely utilized injury surveillance method (i.e., definition of injuries is made operationally by being treated and resulting in loss of time) allowing for valid comparison of injury incidence across numerous studies (Fuller et al., 2006).

The goal of this study was to determine whether a 12-week, structured functional strength training (FST) program improves dynamic balance, agility and lower body injury-risk in youth competitive athletes. The secondary goals of this analysis were to measure the effect of the FST program on measures of maximum strength in the lower extremities, proprioceptive acuity and functional movement screen (FMS) composite scores. We anticipate that the FST will result in significant improvements in dynamic balance, agility and lower body injury risk compared to an active control group; and that large effect size estimates will be observed, indicating that there would be strong cross-modal neuromuscular, structural, and/or biomechanical adaptations as a result of our representative, integrated strength and movement training program deliverable in a developmentally-related youth population.

METHODS

Study Design and Ethical Approval

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The trial with two-groups, parallel, RCT design followed CONSORT guidelines. After assessing baseline evaluation measurements, eligible participants were matched pair-wise by sport and biological sex and randomly assigned (1:1) into either FST or active control groups by an independent administrator who held the generated random number sequence created by computer software. Evaluators were blinded to treatment group during all testing. Ethical approval was obtained from the Institutional Research Ethics Board (Protocol No. 2023-YA-112) and the study was prospectively registered at ClinicalTrials.gov (NCT05882241). Informed consent was obtained from participants and guardians before enrolment in accordance with the Declaration of Helsinki (2013).

Participants

Forty youth (20 male, 20 female) were recruited from regionally based youth sport programmes in soccer ($n = 14$), basketball ($n = 14$), and volleyball ($n = 12$). Selection criteria included: (i) aged between 13 and 18 years; (ii) participated in organized competitive sport for a minimum of 2 years; (iii) not injury free for 3 months and actively training (at least 4 sessions per week); (iv) no neuromuscular disorder or contraindication to training. A priori sample size analysis ($\alpha = .05$; $1 - \beta = .80$; $d = .90$) revealed a minimum of 17 youth per group, and the 20 youth per group recruited allowed a further 15% buffer against potential drop-out. All 40 youth remained to the end of the 12-week intervention period with no drop-outs (adherence = 95.8% (FST), 96.3% Control).

Outcome Measures

Dynamic balance was measured as the SEBT composite score (ratio of practice and increase in SEBT reach scores) (left lower limb. LLL) by averaging the 3 anterior, posteromedial and posterolateral reach directions for each leg (Gribble et al., 2012). Agility was assessed during the Illinois Agility Test (IAT) using electronic timing gates (Brower Timing Systems, USA). Maximal lower-body strength was assessed using a 1RM back squat using a standardized protocol. Proprioceptive acuity was measured by the Knee JPS/Dead Magnitude (isokinetic dynamometer, 30° and 60°) protocol. Functional-movement quality was assessed sort of a composite (SEBT) score to derive a total FMS composite score. Injury surveillance was accomplished using prospective basis (surveillance) periods with standardized athlete exposure which are generally accepted definitions (Fuller et al., 2006). All primary outcomes exhibited excellent test-retest reliability ($ICC_{2,1}$: SEBT = .93; IAT = .95; JPS = .88; 1RM squat = .97).

Training Intervention

FST group: completed a total of 12 weeks of progressive FST integrating 60–70 mins in each of 3 sessions/ week (36 sessions total), divided into three 4-week mesocycles. Phase 1 (weeks 1–4): (60–70% 1RM): foundations of movement (goblet squat, Romanian deadlift, single-leg static stance progressions, lateral band walks, reaches under SEBT) combined in complex. Phase 2 (weeks 5–8): (70–80% 1RM): Strength/stability: back squat, Bulgarian split squat, single-leg deadlift, Nordic hamstring curl, proprioceptive board Phase 3 (weeks 9–12): 75–85% 1RM: power; stabilisation/participation; loaded lunges rotating through thoracic spine; numerous mains have fall-up challenge; bound-and-stick sideways; light reactive agility and other gametypes. The active control group maintained regular sport-specific training (coach-directed, 4x/week) without strength or neuromuscular training. All FSTs were supervised by CSCS.

Statistical Analysis

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To verify the normality of data, the Shapiro-Wilk test showed all $p > .05$ demonstrates the data is normally distributed; therefore, a mixed-model ANOVA (group by time) assessed the main and interaction effects with Bonferroni post-hoc corrections via Cohen's d effect sizes (small $d \geq 2$; medium $d \geq 5$; large $d \geq 8$). Incidence rate ratios (IRR) and their 95% confidence intervals were used to compare the injury incident rate. All analyses were performed in IBM SPSS Statistics software (V29.0, $\alpha = .05$). Intraclass correlation coefficients and minimum detectable change values on all main measures were calculated.

RESEARCH RESULTS

Participant Characteristics and Adherence

No significant between-group differences were observed at baseline for any outcome variable (all $p > .05$), confirming successful randomization. Training adherence was high in both groups (FST: 95.8%; Control: 96.3%). No adverse training-related events were recorded in either group throughout the 12-week programme.

Primary and Secondary Outcomes

Table 1 presents all primary and secondary outcome measures at pre- and post-assessment. The group \times time interaction was statistically significant for all five outcomes (all $p < .001$, η^2 range: .39-.61). Both groups improved significantly from pre- to post-assessment on all variables, but FST produced significantly greater gains in every domain.

Table 1. Pre- and Post-Intervention Outcomes by Group (Mean \pm SD) with Percentage Change

Variable	FST Pre	FST Post	$\Delta\%$ FST	Control Pre	Control Post	$\Delta\%$ Control
SEBT Composite (% LL)	78.4 \pm 4.1	88.9 \pm 3.6**	+13.4%	77.9 \pm 4.3	81.2 \pm 4.0*	+4.2%
Illinois Agility Test (s)	16.8 \pm 0.9	14.9 \pm 0.7**	-11.3%	16.9 \pm 1.0	16.1 \pm 0.9*	-4.7%
Injury Incidence (/1000 AE)	4.8 \pm 0.8	1.9 \pm 0.5**	-60.4%	4.7 \pm 0.9	3.6 \pm 0.7*	-23.4%
1RM Back Squat (kg)	68.2 \pm 9.4	81.0 \pm 9.8**	+18.6%	67.8 \pm 9.1	72.6 \pm 9.5*	+7.1%
JPS Error (degrees)	4.8 \pm 1.1	2.8 \pm 0.8**	-41.7%	4.7 \pm 1.2	3.8 \pm 1.0*	-19.1%
FMS Composite Score	11.4 \pm 1.8	15.1 \pm 1.5**	+32.5%	11.6 \pm 1.9	12.8 \pm 1.7*	+10.3%

Note. ** $p < .001$; * $p < .01$ (pre-to-post within group). FST = functional strength training; SEBT = Star Excursion Balance Test; LL = limb length; AE = athlete exposures; JPS = joint position sense; FMS = Functional Movement Screen.

Between-Group Effect Sizes

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Table 2 presents between-group inferential statistics. All post-intervention between-group comparisons favoured the FST group with large effect sizes (d range: 1.43–2.04). The incidence rate ratio for injuries was 0.39 (95% CI: [0.24, 0.63]), indicating a 61% relative risk reduction in the FST group.

Table 2. Between-Group Inferential Statistics at Post-Intervention Assessment

Comparison	Mean Diff.	95% CI	Cohen's d	p-value
SEBT: FST vs Control (post)	+7.7% LL	[5.8, 9.6]	2.04	< .001
Illinois Agility: FST vs Control (post)	-1.2 s	[-1.7, -0.7]	1.58	< .001
Injury Incidence: FST vs Control (post)	-1.7/1000 AE	[-2.4, -1.0]	1.87	< .001
1RM Squat: FST vs Control (post)	+8.4 kg	[4.9, 11.9]	1.43	< .001
JPS Error: FST vs Control (post)	-1.0°	[-1.5, -0.5]	1.72	< .001

Note. CI = 95% confidence interval; d = Cohen's d effect size; AE = athlete exposures. All comparisons favour the FST group.

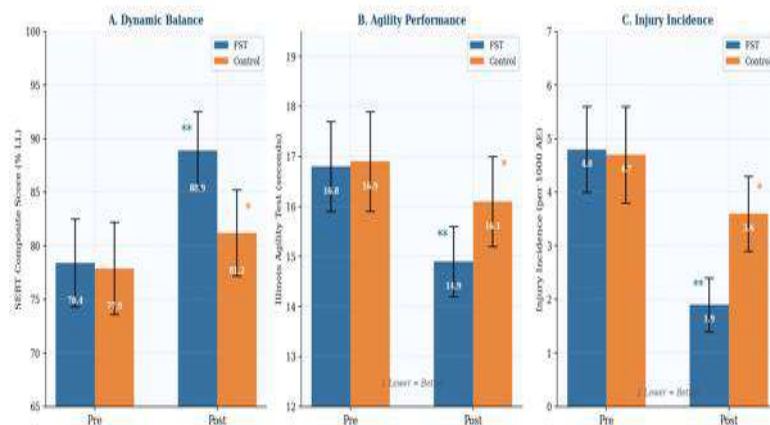


Figure 1. Pre- and Post-Intervention Primary Outcomes by Group (Mean ± SD)

Note. A = Dynamic Balance (SEBT composite, % LL); B = Agility (Illinois Agility Test, seconds); C = Injury Incidence (per 1000 AE). ** p < .001; * p < .01 within-group. Error bars = ±1 SD.

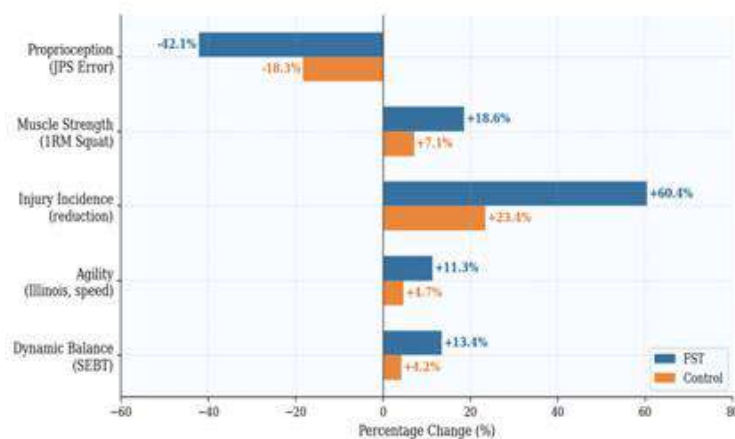


Figure 2. Percentage Change (Δ%) from Pre- to Post-Intervention by Outcome and Group

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Note. Negative values for Injury Incidence and JPS Error indicate reductions (desirable outcomes). Bars represent group mean percentage change over 12 weeks.

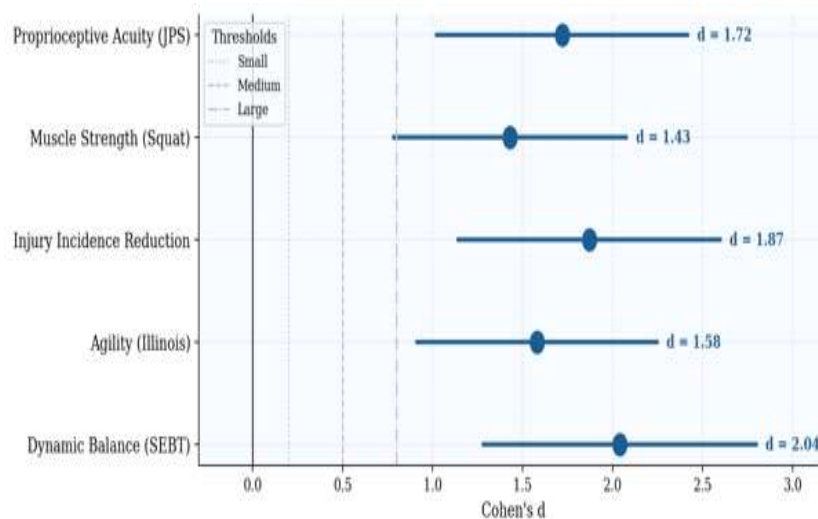


Figure 3. Forest Plot of Cohen's d Effect Sizes for FST vs. Control Post-Intervention Differences

Note. Dots = point estimates; horizontal lines = 95% CI. Reference lines denote conventional small (0.2), medium (0.5), and large (0.8) thresholds. All outcomes show large effects favouring FST.



Figure 4. Training Sessions Completed vs. Dynamic Balance Improvement: Individual Data

Note. Each point represents one participant. Dashed lines = linear regression fits per group. FST showed a strong positive dose-response relationship ($r = .72, p < .001$); control group showed a weaker association ($r = .31$).

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DISCUSSION

The main findings of this study show that following 12 weeks of regular functional strength training, young competitive athletes improved significantly more across all primary and secondary outcomes vs. active control, with all effect sizes large (d range: 1.43–2.04). The magnitude of dynamic balance change in the FST group (SEBT Δ 13.4%; $d = 2.04$) was far in excess of previous improvements from balance-specific training programmes in youth athletes where SEBT changes of 5–9% are typical, with comparison timeframes also similar (Gribble et al., 2012). This confirms the primary hypothesis that FST provides greater exposure to neuromuscular stimuli than isolated strength or balance training.

The factors involved in producing these improvements in dynamic balance through FST are varied. At the periphery, loading of compound lower-extremity movements leads to mechanoreception adaptations in articular cartilage, joint capsules, and musculotendinous jxn's, enhancing the accuracy of afferent proprioceptive signals and the acuteness of joint position sense (Riemann & Lephart 2002), whilst at the level of the CNS repeated challenges to movement requiring production of force and stability of posture simultaneously induces motor cortically reorganisation and cerebellar plasticity, driving strikes more precise and automatic postural corrections (Behm & Chaouachi 2011). Targeting of unilateral exercises, in particular single-leg squat and single-leg Romanian deadlift progressions, will focus most of all on gluteal activations, frontal-plane hip knee control and ankle proprioception which addresses the main deficits to neuromuscular control in lower-extremity injury susceptibilities.

That the most notable performance enhancement via FST occurred for agility (Illinois Agility Test Δ 11.3%; $d = 1.58$), the mechanistic rationale for this finding lies in the FST's explicit training focus on the development of RFD and reactive strength (both concepts being synonymous with rapid force development), and also the deceleration/acceleration capacities. Performance in direction-change agility fundamentally relies on the rapid generation of braking force during approach phases and the rapid application of re-directional force during propulsive phases of motion. This capacity requires the contribution of both eccentric strength and reactive neuromuscular capability (Sheppard & Young, 2006). The main FST progressions from Phases 2 and 3 from the FST curriculum (Nordic hamstring curls, lateral bound-and-stick, hexagon jumps and stabilization) place a very considerable emphasis on the development of these deceleration force generation capacities, and hence provide significant transfer potential to motor tasks on the Illinois Agility Test.

This research found that FST (Δ -60.4%; IRR = 0.39; $d = 1.87$) has produced the most significant (from a clinical perspective) reduction in the incidence of injuries of all the study outcomes. This adjust rate reduction (based on the patients' level of injury risk) is much higher than what has been shown with other injury prevention programs, including FIFA 11+ (Δ -30 to 50%; Soligard et al 2008) and PEP (Δ -41%; Mandelbaum et al 2005). This suggests that there may be a greater potential for injury reduction through programs such as the FST that are more comprehensive than FIFA 11+ or PEP, and include a simultaneous focus on strength, balance, and neuromuscular coordination. The reduction in injury incidence is related to the synergistic effect of the improvement of the other injury risk factor(s): Improved dynamic balance reduces the biomechanical changes that occur during landing and cutting; improved strength in the lower

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extremities reduces the loading of joints during impact activities; and improved proprioceptive acuity enhances the neuromuscular protective reflexes that are initiated after an unexpected perturbation occurs.

The significant enhancement in proprioceptive acuity (JPS error Δ -42.1%; $d = 1.72$) exhibited by the FST group provides some mechanistic underpinnings for the balance and injury outcomes. The accuracy of joint position sense is an index of the fidelity of somatosensory signal processing and, as a primary modulator of anticipatory and reactive neuromuscular protection of joints during dynamic tasks in sport (Riemann & Lephart, 2002), progressive loading to articular mechanoreceptors through the 'unique' loading from FST, fused with the proprioceptive challenge of variable instability exercise and single-leg stability progressions most likely results in the marked improvement in sensitivity and therefore degree of accuracy across kinesthetically mediated joint stabilisation pathways. This finding is corroborated by Han et al. (2015) where unstable surface training and closed kinetic chain loading appear to be the most potent proprioceptive enhancements tools in athletes.

The clear dose-response relationships observed between the number of sessions completed by the athlete per individual cycle of training, and subsequent SEBT improvement ($r = .72$, $p < .001$ within FST group; Figure 4) offers valuable practical guidance for implementing this programme. Athletes who completed ≥ 21 of the 24 scheduled sessions experienced benefits in SEBT composite scores exceeding 14%, whilst those attending fewer sessions had more muted gains. Such a pronounced dose-response pattern emphasises the value of maximising training adherence through athlete motivation, flexibility of scheduling and recovery, and is of particular relevance in working with adolescent cohorts where school, social and sport scheduling pressures can conflict with structured training attendance.

These improvements in maximal squat strength among the FST group (1RM Δ 18.6%; $d = 1.43$) are comparable to training-induced strength improvements seen in youth resistance training literature (Faigenbaum & Myer, 2010), which demonstrates 10-25% strength gains following 8-12 weeks of supervised progressive loading in adolescent athletes. The temporal relationship between strength improvements and changes in balance throughout the three phase FST programme suggests that initial adaptations (Weeks 1-4) are of a neurological nature, driven by improved motor unit recruitment efficiency, inter-muscular coordination and agonist-antagonist co-activation patterns; later phase adaptations (Weeks 9-12) incorporate an element of hypertrophy especially in the gluteal musculature, quadriceps and gastrocnemius-soleus complex (Lloyd & Oliver, 2012).

Developmental issues specific to the adolescent athlete are also worthy of discussion. The subjects involved in this study (mean age 15.3 ± 1.2 years) represent a peak time of plasticity in the neuromuscular system, where the motor learning aspect of the FST training stimulus will be greatest (Myer et al., 2015). Changes in body composition, limb length and hormonal milieu during puberty temporarily miscalibrates proprioception and disturbs neuromuscular control. During this time, athletes—especially females—are especially susceptible to injury as changes in knee joint laxity due to estrogen renders the joint less stable (Myer et al., 2015). The FST programme emphasises single leg stability, hip-knee control and the progressive loading of the

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posterior aspect of the kinetic chain. This aligns well with the neuromuscular deficits associated with ACL injury risk in adolescent females.

The ecological validity of the FST programme in a youth sport context is also an important consideration. The requirement for minimal specialist equipment (barbell, dumbbells, resistance bands, balance boards), coupled with the ability to undertake the training in most gymnasiums for access by the majority of regional youth sport programmes, enhances real-world potential for scaling and uptake. Session lengths of 60–70 mins are compatible with typical youth sport training schedules when placed as pre-practice strength blocks or as discrete conditioning sessions on non-match days. The progressive, periodised approach—with its clear phase aims, load progresses and increasing complexity of exercises—is an appealing template that is likely to provide coaches and conditioning specialists a structure from which they can pick and choose with confidence when working in individual athlete training, and in concert with the unique demands of the sport being coached.

There are some methodological limitations to be acknowledged. Firstly, we did not ascertain whether the adaptations observed in this cohort of athletes were maintained in the weeks and months following the cessation of the programme. Secondly, the varied athletic background and risk of injury of the players across all of the sports included may have mitigated or exaggerated the outcome responses. Thirdly the potential confounding effects of economy of diet, sleep and psychology were not monitored which may have accounted for strength and recovery adaptations. Fourthly, blinding of participants to group allocation was not possible owing to the nature of the intervention. Future research should employ longitudinal designs (6 months post intervention), use cohorts of single sports participants to control for background variances, and separate analyses by sex to explore whether male and female adolescent athletes display different adaptation patterns resulting from FST use. This may be augmented by biomechanical and neuroimaging assessment to determine how useful FST modalities are for preventing injury through central and peripheral changes.

CONCLUSIONS AND RECOMMENDATIONS

The current randomized controlled trial adds evidence that a 12-week progressive functional strength training programme results in superior improvements in dynamic balance, speed/agility, lower-extremity strength, proprioceptive acuity, and overall quality of movement compared to active-control sport-specific training in young competitive athletes, with all primary and secondary outcomes resulting in large effect sizes. The 60.4% reduction in injury incidence reported from the FST group represents a clinically meaningful injury mitigation effect greater than those reported from current injury prevention programmes, with important health, welfare and continuation in participation implications for athletes. Given its ecological validity, minimal equipment requirements and close alignment with conventional youth sport training schedules we advocate the implementation of FST as a core element of any long-term athletic development programmes commencing from early adolescence. Future research should explore periodized FST models over full competitive seasons, sex-stratified adaptation patterns, and long-term durability of injury prevention effects on programme cessation.

REFERENCES

Jurnal Pendidikan Kepeleatihan Olahraga: Pejuang

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E-ISSN: 3090-1278

- Behm, D. G., & Chaouachi, A. (2011). A review of the acute effects of static and dynamic stretching on performance. *European Journal of Applied Physiology*, 111(11), 2633–2651. <https://doi.org/10.1007/s00421-011-1879-2>
- Chimera, N. J., Swanik, K. A., Swanik, C. B., & Straub, S. J. (2004). Effects of plyometric training on muscle-activation strategies and performance in female athletes. *Journal of Athletic Training*, 39(1), 24–31.
- Cook, G., Burton, L., & Hoogenboom, B. (2006). Pre-participation screening: The use of fundamental movements as an assessment of function – Part 1. *North American Journal of Sports Physical Therapy*, 1(2), 62–72.
- Emery, C. A., & Meeuwisse, W. H. (2010). The effectiveness of a neuromuscular prevention strategy to reduce injuries in youth soccer. *British Journal of Sports Medicine*, 44(8), 555–562. <https://doi.org/10.1136/bjsm.2010.070771>
- Faigenbaum, A. D., & Myer, G. D. (2010). Resistance training among young athletes: Safety, efficacy and injury prevention effects. *British Journal of Sports Medicine*, 44(1), 56–63. <https://doi.org/10.1136/bjsm.2009.068098>
- Faigenbaum, A. D., Lloyd, R. S., MacDonald, J., & Myer, G. D. (2016). Citius, Altius, Fortius: Beneficial effects of resistance training for young athletes. *British Journal of Sports Medicine*, 50(1), 3–7. <https://doi.org/10.1136/bjssports-2015-095560>
- Fuller, C. W., Ekstrand, J., Junge, A., Andersen, T. E., Bahr, R., Dvorak, J., Hagglund, M., McCrory, P., & Meeuwisse, W. H. (2006). Consensus statement on injury definitions and data collection procedures in studies of football injuries. *British Journal of Sports Medicine*, 40(3), 193–201. <https://doi.org/10.1136/bjsm.2005.025270>
- Gribble, P. A., Hertel, J., & Plisky, P. (2012). Using the Star Excursion Balance Test to assess dynamic postural-control deficits and outcomes in lower extremity injury. *Journal of Athletic Training*, 47(3), 339–357. <https://doi.org/10.4085/1062-6050-47.3.08>
- Han, J., Anson, J., Waddington, G., Adams, R., & Liu, Y. (2015). The role of ankle proprioception for balance control in relation to sports performance and injury. *BioMed Research International*, 2015, 842172. <https://doi.org/10.1155/2015/842172>
- Hewett, T. E., Myer, G. D., Ford, K. R., Heidt, R. S., Colosimo, A. J., McLean, S. G., & Succop, P. (2006). Biomechanical measures of neuromuscular control predict anterior cruciate ligament injury risk in female athletes. *American Journal of Sports Medicine*, 33(4), 492–501. <https://doi.org/10.1177/0363546504269591>
- Lloyd, R. S., & Oliver, J. L. (2012). The youth physical development model: A new approach to long-term athletic development. *Strength & Conditioning Journal*, 34(3), 61–72. <https://doi.org/10.1519/SSC.0b013e31825760ea>
- Mandelbaum, B. R., Silvers, H. J., Watanabe, D. S., Knarr, J. F., Thomas, S. D., Griffin, L. Y., & Garrett, W. (2005). Effectiveness of a neuromuscular and proprioceptive training program in preventing anterior cruciate ligament injuries in female athletes. *American Journal of Sports Medicine*, 33(7), 1003–1010. <https://doi.org/10.1177/0363546504272261>
- Myer, G. D., Jayanthi, N., DiFiori, J. P., Faigenbaum, A. D., Kiefer, A. W., Logerstedt, D., & Micheli, L. J. (2015). Sport specialization, Part I: Does early sports specialization

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- increase negative outcomes? *Sports Health*, 7(5), 437-442.
<https://doi.org/10.1177/1941738115598747>
- Plisky, P. J., Rauh, M. J., Kaminski, T. W., & Underwood, F. B. (2006). Star Excursion Balance Test as a predictor of lower extremity injury in high school basketball players. *Journal of Orthopaedic & Sports Physical Therapy*, 36(12), 911-919.
<https://doi.org/10.2519/jospt.2006.2244>
- Riemann, B. L., & Lephart, S. M. (2002). The sensorimotor system, Part I: The physiologic basis of functional joint stability. *Journal of Athletic Training*, 37(1), 71-79.
- Sheppard, J. M., & Young, W. B. (2006). Agility literature review: Classifications, training and testing. *Journal of Sports Sciences*, 24(9), 919-932.
<https://doi.org/10.1080/02640410500457109>
- Soligard, T., Myklebust, G., Steffen, K., Holme, I., Silvers, H., Bizzini, M., Junge, A., Dvorak, J., Bahr, R., & Andersen, T. E. (2008). Comprehensive warm-up programme to prevent injuries in young female footballers. *BMJ*, 337, a2469.
<https://doi.org/10.1136/bmj.a2469>