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THE EFFECTS OF A 4-WEEK NEUROMUSCULAR TRAINING PROGRAM ON MOVEMENT COMPETENCY DURING THE BACK-SQUAT ASSESSMENT IN PRE- AND POST- PEAK HEIGHT VELOCITY MALE ATHLETES

AUTHORS:

IAN J. DOBBS[1]

JON L. OLIVER[1,2]

MEGAN A. WONG[1]

ISABEL S. MOORE[1]

GREG D. MYER[3,4,5,6]

RHODRI S. LLOYD[1,2,7]

AFFILIATIONS:

1. School of Sport and Health Sciences, Cardiff Metropolitan University, Cardiff, UK
2. Sport Performance Research Institute, New Zealand (SPRINZ), AUT University, Auckland, New Zealand
3. The SPORT Center, Division of Sports Medicine, Cincinnati Children's Hospital Medical Center, Cincinnati, Ohio, USA
4. Departments of Pediatrics and Orthopaedic Surgery, University of Cincinnati, College of Medicine, Cincinnati, OH, USA
5. The Micheli Center for Sports Injury Prevention, Waltham, MA, USA
6. Department of Orthopaedics, University of Pennsylvania, Philadelphia, PA, USA
7. Centre for Sport Science and Human Performance, Waikato Institute of Technology, Hamilton, New Zealand

CORRESPONDENCE:

Name: Rhodri S. Lloyd

Address: Cardiff Metropolitan University
Cardiff School of Sport and Health Sciences
Cyncoed Campus, Cyncoed, Cardiff, CF23 6XD, UK

e-mail: rlloyd@cardiffmet.ac.uk

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ABSTRACT

The back-squat assessment (BSA) is a novel movement screen to detect functional deficits; however, its sensitivity to detect meaningful changes in movement competency following exposure to short-term neuromuscular training remains unclear. Twenty-six pre- and 22 post-peak height velocity (PHV) males were divided into experimental (EXP) and control groups (CON) and performed the BSA before and after a twice-weekly, four-week neuromuscular training intervention. Intra-rater reliability was determined by rating both EXP group's baseline BSA on three separate sessions. ICC revealed very strong agreement for BSA total score in pre- (ICC $\geq$ 0.81) and post-PHV (ICC $\geq$ 0.97) groups across all sessions, but systematic bias was evident in the pre-PHV group for sessions 1 to 2. Analysis of kappa values for BSA individual criteria showed greater variability for pre-PHV ($\kappa \geq 0.31$) than post-PHV ($\kappa \geq 0.62$) across sessions. At baseline there were no differences in total score between the EXP and CON cohorts ($p > 0.05$). There were significant within-group improvements in total score for the EXP pre- (5.0 to 3.0, $ES = 0.68$) and post-PHV (2.0 to 1.0, $ES = 0.82$) cohorts, with no changes in total score for either CON groups ($p > 0.05$). Hip position was the criterion with the greatest improvement for both the EXP pre-PHV (12.0 to 7.0) and post-PHV (7.0 to 0.0) groups. The BSA appears to be a reliable screening tool for measuring movement competency in youth male athletes; and was sensitive to adaptations in movement competency following of neuromuscular training.

Key words: motor, skill, youth, strength, maturity

INTRODUCTION

Movement competency reflects the proficiency displayed by an individual during goal-directed human movement (37). Greater movement competency in children is associated with athletic (5, 16) and health related benefits (11, 21). Increased movement competency during childhood also increases the likelihood of individuals accruing greater quantity of physical activity during adult life (38). Additionally, the magnitude of associations between motor competency and other fitness qualities such as muscle strength (28), sprint speed (25, 29), and lower body power (15, 29) appear to increase from childhood into adolescence (37).

During childhood, the neuromuscular system is highly plastic as evidenced by the malleability and strengthening of neural pathways (2, 8), and offers the greatest opportunity for motor skill acquisition (17, 30, 31). Consequently, leading international consensus advocates the use of neuromuscular training to help children improve their fundamental movement competency early in life (16). Neuromuscular training utilizes a range of training modes including resistance training, plyometrics, dynamic stability, core strength development, and speed and agility training to enhance movement skill competence, physical fitness, and to target movement limitations or deficits (31). While neuromuscular training improves muscle strength, muscular endurance, lower body power and cardiorespiratory fitness in youth populations (5), research has yet to examine its effects on quality of movement.

Numerous assessment tools are available to rate movement competency (9) and assess injury-risk (7, 36); however, some of these screens are time-consuming and equipment intensive. Similarly, some athletic training programs may only choose to assess certain criteria within a given screening tool. Thus, practitioners often adopt abbreviated versions of movement screens, assessing proficiency in a smaller number of ‘key’ athletic movements (4). The squat movement is an example of a primal movement pattern in which youth athletes are required to display neuromuscular control, strength, stability and mobility throughout the body (17, 33). Literature also indicates that mastery of the squat and other fundamental movement skills may offer multiple long term physical and cognitive benefits (5, 10, 22, 34, 39).

The back squat assessment (BSA) is a novel screening tool that was developed to enable practitioners to assess competency in squatting (33). Consisting of a 10-point scoring criteria, the BSA serves as a practitioner tool to identify functional deficits in the squat pattern from which targeted training exercises can be introduced to enhance technique and movement quality (14). While the BSA can provide useful insights into movement competency of young athletes, to date no empirical data exists that has determined its validity as a screening tool or its sensitivity to detect meaningful changes in performance following neuromuscular training interventions. Therefore, the aim of this study was to 1) determine the intra-rater reliability of the BSA as a screening tool in pre- and post-peak height velocity (PHV) boys, and 2) determine the effects of a short-term, four-week neuromuscular training intervention on movement competency in the BSA.

METHODS

Experimental approach to the problem

Using a within-group approach, intra-rater reliability was determined by rating a pre-PHV and post-PHV group performing the BSA on separate occasions. The same videos were rated by the same rater on three separate occasions to assess reliability of total score and all individual rating criteria in both maturity groups. A between-groups design was used to determine the effects of a four-week neuromuscular training intervention on back squat movement competency. Participants were split into four groups; pre-PHV experimental group, pre-PHV control group, post-PHV experimental group, and post-PHV control group. The experimental groups completed four weeks of a twice-weekly neuromuscular training program. All participants were screened in the BSA before and after four weeks.

Subjects

A total of 48 elite male youth cricketers between the ages of 10-17 volunteered to take part in the study and were recruited from a professional county cricket academy in the United Kingdom. Participants were separated by maturity offset with 26 pre-PHV and 22 post-PHV athletes. Subsequently, the maturity groups were randomly sub-divided into an experimental (EXP) and control (CON) group for the integrative neuromuscular training intervention (Table 1). None of the players reported injuries at the time of testing and all participated regularly in cricket training sessions but no formal strength and conditioning activities. Parental consent and participant assent were collected before the commencement of testing. Ethical approval was granted by the institutional research ethics committee in accordance with the declaration of Helsinki.

Table 1 near here

Procedures

Anthropometrics

All participants were measured for standing height, sitting height, leg length, mass, and maturity offset during baseline testing. Standing and sitting height were measured using the nearest 0.1 cm with the use of a stadiometer (SECA, 321, Vogel & Halke, Hamburg, Germany). Participants sat on a 50 cm box with feet elevated off the ground when being measured for sitting height. Leg length was determined by subtracting sitting height from standing height. Body mass was measured to the nearest 0.1 kg on an electronic scale (SECA, 321, Vogel & Halke, Hamburg, Germany). These data were then entered into a sex-specific regression equation to calculate a maturity offset to estimate whether they were pre- or post-PHV (26). The cutoff for maturity status in the pre- PHV group was less than -1.00 years and greater than 1.00 years for the post-PHV group. Any participants with a maturity offset that fell between these cutoff ranges (i.e. -1.00 to +1.00)were removed from the final statistical analyses.

Back squat assessment

Prior to all testing sessions, participants performed a dynamic warm-up consisting of arm swings, bear crawls, high skips, high knees, side lunges, reverse lunges, single leg stick and land, and sprints. Each movement within the warm up was performed for a distance of 20 meters. Participants performed 5 sprints with increasing intensity at 50%, 75%, 90%, and twice at 100%, with 60 seconds rest between each run. During the BSA, participants were instructed to perform ten continuous squat repetitions in place with a wooden dowel on their back as per previously published guidelines (Myer et al., 2014). Participants were instructed to position their feet slightly wider than hip-width and to descend until thighs were parallel to the ground. Each participant completed the BSA twice, with one minute between each trial. Aside from the standardized script proposed by Myer and colleagues (33), no other verbal cues or advice were given to participants before or during the testing sessions. All ten repetitions were recorded at 30 f/s using two 2D high definition cameras (Apple iPad, California, USA) positioned at a height of 0.70 m and at a distance of 5 m from the center of the capture area in both frontal and sagittal planes. Scoring of BSA performance was conducted retrospectively using a 10-point criteria, with one point given for each technical fault (33). The 10-point criteria consisted of: head position, thoracic position, trunk position, hip position, frontal knee position, tibial progression angle, foot position, descent, depth, and ascent. During the scoring process, each of the 10 criteria were analyzed and a deficit was scored if present during two or more repetitions. Movement variation between repetitions indicates inefficient motor-unit coordination and is likely due to factors such as muscle weakness, strength asymmetry and joint instability (33, 40). Therefore, a deficit occurring twice or more highlights movement variability by the participant in the BSA (33). Deficits were tallied to provide a total score, with higher total scores indicative of poorer squat technique. The lowest total score for each participant was used for statistical analysis. To determine intra-rater reliability, the video footage taken at the start of the four-week intervention for both EXP training groups were viewed and scored on three separate occasions by the same rater. Scoring of the videos was separated by one month to reflect the length of time and potential associated noise of the subsequent short-term intervention. On each occasion, videos were viewed in a randomized sequence to avoid rater bias. The variables recorded for each participant were BSA total score and scoring of the individual criteria between scoring sessions 1-2 and sessions 2-3.

Neuromuscular training intervention

Following baseline testing, both EXP groups commenced the neuromuscular training intervention that required them to complete 1-hr training sessions, twice-weekly for four-weeks. All training sessions were led and supervised by a National Strength and Conditioning Association Certified Strength and Conditioning Specialist. The program consisted of a 10-minute dynamic warm up that incorporated multiplanar movement, mobility, coordination, balance, plyometrics and running with the goal of raising body temperature and was similar to the warm up completed for the BSA protocol. Following the dynamic warm up, participants performed primary exercises focusing on muscular power, lower body strength, upper body strength, and core strength. The participants were familiarized with every exercise within the neuromuscular training program and performed a warm up set prior to each exercise. Each training session aimed to develop the neuromuscular capabilities of multiple muscle groups through a combination of coordination, plyometrics, and resistance training. Volume increased incrementally as participants became more accustomed to the exercises. New exercises with similar movement patterns were introduced for both groups during week three to facilitate ongoing motor learning. Exercises included the use of body weight, barbells, dumbbells, resistance bands, and weighted plates (Table 2 and 3). Despite differences in exercise selection, both pre- and post-PHV EXP groups followed a similar training regimen outline. Participants performed between 3-4 sets of 10-15 repetitions for each primary exercise as per published recommendations (16, 17). Due to the low training age of all the participants, higher repetitions were prescribed for practice as well as to provide opportunities for feedback. When appropriate, relevant feedback on the movement quality of each exercise was given to participants to promote kinesthetic awareness and increase their understanding of correct technique. Instruction and technical correction of the squatting movement pattern were included in each session.

Participants were encouraged to increase loads on an individual basis where exercise technique could be performed adequately for 10-15 repetitions. External load was increased where competency was retained throughout the set; however, if a participant displayed poor technique then the load was reduced.

*** Table 2 near here ***

*** Table 3 near here ***

Statistical Analysis

To determine intra-rater reliability, baseline BSA data for both maturity groups were scored on three separate occasions, from which two-way mixed effects intraclass correlation coefficients (ICC) were determined to assess the rank order repeatability of BSA total score (assessment 1 vs 2 and 2 vs 3) (12). Thresholds for ICC values were classified as poor (< 0.50), moderate (0.50 to 0.75), good (0.75 to 0.90), and excellent (> 0.90). Cohen's kappa (κ) coefficient was used to determine the accuracy of scoring for each individual criterion within the BSA across all three assessments, with the strength of agreement classified as: >0.8, very good; 0.6-0.8, good; 0.4-0.6, moderate; 0.2-0.4, poor; <0.2, very poor (23). Descriptive statistics were calculated for all BSA variables for both pre- and post-training intervention data. The Shapiro-Wilk test was used to examine the distribution of BSA total score for each of the EXP and CON groups, which was determined to be non-parametric across all cohorts. As a result, median BSA total score was subsequently reported. Wilcoxon signed rank test was used to determine each group's training responsiveness and within-group differences for BSA total score. The Mann-Whitney U test was used to determine between-group differences for BSA total score. Effect size (*ES*) was calculated for post BSA total score between-groups using Microsoft Excel (v. 2016 Redmond, WA, USA) in order to interpret the magnitude of effects according to Cohen's *d* statistic, using the following threshold: <0.20 (trivial), 0.20-0.59 (small), 0.60-1.19 (moderate), and > 1.20 (large) (41). All descriptive data and statistical analyses were computed using SPSS (V.24 Chicago, IL, USA), with statistical significance for all tests set at an alpha level of $p < 0.05$.

RESULTS

Reliability

ICC for BSA total score revealed excellent agreement for both maturity groups across all sessions (Table 4). Cohen's kappa values showed greater variability in the pre-PHV group than the post-PHV group for the BSA individual criteria. Between sessions 1-2 in the pre-PHV group, trunk position had the lowest agreement (0.31). However, the three criteria with perfect agreement (1.00) were head position, foot position and depth. The remaining criterion had moderate to very good agreement in sessions 1-2. Between sessions 2-3, the lowest agreement for the pre-PHV group were in the foot position (0.42) and ascent (0.44) criteria, while all other criterion having good to perfect agreement. The post-PHV group displayed good to perfect agreement for all criteria across all sessions (Table 5).

*** Table 4 near here ***

*** Table 5 near here ***

Pre- to post-intervention total BSA score

No significant differences were observed in pre-testing BSA total score between the EXP and CON groups in either maturity cohorts (Table 6). The EXP post-PHV group had a large difference (*ES* = 0.69) in comparison to the CON group for BSA total score whereas the EXP pre-PHV group had a medium difference (*ES* = 0.43) compared to the CON group during post-testing. Wilcoxon signed rank test revealed large significant within-group differences ($p < 0.05$) in median BSA total score for the EXP pre-PHV cohort (5.0 to 3.0) and EXP post-PHV (2.0 to 1.0). No significant within-group differences ($p > 0.05$) were observed in the CON pre- or post-PHV cohort (Table 6). Data showed a significant reduction in post-testing BSA total score for the EXP groups but not the CON groups ($p < 0.05$). Following the intervention, 67% of the particpants in the EXP pre-PHV cohort decreased BSA total score, with only 13% recording a worse score. In comparison, 45% of the CON pre-PHV cohort reduced BSA total score with 36% recording a worse score. For the EXP post-PHV group, 91% of the participants reduced BSA total score, whereas, the CON post-PHV had only 9% reduce BSA total score and 73% recording no change, and 18% recording a worse total score.

*** Table 6 near here ***

Pre- to post-intervention individual BSA criterion scores

Descriptive statistics for the sum of individual criterion deficits indicate which criteria contribute to the decrease of BSA total score in both the pre-PHV (Figure 1) and post-PHV (Figure 2) EXP groups. The greatest improvements within the pre-PHV cohort were observed in hip position (12.0 to 7.0), trunk position (11.0 to 6.0), and thoracic position (9.0 to 5.0). However, the criterion that increased for sum of deficits were head position (0.0 to 4.0) and depth (9.0 to 10.0).

The greatest improvement in scores for the post-PHV group were hip position (7.0 to 0.0) and descent (6.0 to 1.0) with no increases in any criterion.

*** Figure 1 near here ***

*** Figure 2 near here ***

DISCUSSION

The current study has reported novel data on the intra-rater reliability of the BSA and the effects of a short-term neuromuscular training intervention on BSA competency in young male cricketers. Intra-rater reliability for BSA total score had very strong agreement across all testing sessions in both maturity groups; while ratings for the ten individual criteria were more reliable in the post-PHV group than the pre-PHV group. Additionally, BSA total score significantly improved within-group for both pre- and post-PHV experimental groups following the neuromuscular training intervention, which were significantly greater than any changes seen in the control groups. Hip position was the criteria with the greatest number of deficits at baseline, but also showed the greatest improvement in both maturity groups following training. Cumulatively, the findings of this study indicate that the BSA was a reliable screening tool for the individual rater when assessing movement competency in young male athletes and that improvements in movement competency can be achieved in four weeks.

Despite ICC levels for BSA total score being good and very good for both maturity groups, less agreement was observed for the individual criteria. Distinct differences in individual criteria were evident between the maturity groups, with kappa values ranging from poor to very good between sessions 1-2 and moderate to very good in sessions 2-3 for the pre-PHV group. This indicates that an additional familiarization session may be needed for raters when rating a pre-PHV cohort. Meanwhile, only one criterion from the post-PHV group had moderate agreement across all sessions, with all other criteria displaying good to very good agreement. The greater variance in kappa values indicate that there was more variability when rating the BSA performance in the pre-adolescent group. Previous research has noted that pre-adolescent children do not have fully mature sensorimotor function, which can affect neuromuscular and postural control during motor tasks (35). As a result, children show less stability during dynamic movements requiring posture and balance, which may explain why the pre-PHV group scored higher on the BSA than the post-PHV group. Despite the principal researcher rating the same trials on three occasions, having less stability during dynamic movements would contribute to more variability between repetitions, ultimately making the scoring process more challenging. It should also be noted that test-retest reliability of the BSA was not established prior to the intra-rater reliability for either maturity groups, and therefore typical fluctuation within the BSA screen is unknown. Previous literature has demonstrated that movement variability is greater in pre-adolescence when compared to more mature youth athletes (20, 35, 36). Greater variance in performance by pre-adolescent children arises even in static tests such as the isometric mid-thigh pull (27). This tendency to display heightened movement variability by pre-PHV children may explain the lower agreement between sessions for some individual criteria within the BSA, and underlines the potential need for a familiarization session by raters before scoring less mature young athletes.

Both EXP groups significantly improved BSA movement competency after the training intervention. A greater percentage of the EXP post-PHV group (91%) reduced BSA total score than the EXP pre-PHV group (67%) from baseline to post testing. However, the pre-PHV cohort had a greater reduction in BSA total score compared to the post-PHV group which may indicate a greater responsiveness to the training intervention. The greater reduction in BSA total score may also in part be due to the post-PHV group scoring lower at baseline and thus having less potential for improvement. It has been previously reported that exposing pre-PHV children to integrative neuromuscular training can have long lasting positive effects on movement competency due to the high ‘plasticity’ of their brains (5, 31, 32). Children that are regularly exposed to fundamental movements will likely enhance motor skill learning and the child is more likely to retain these skills throughout maturation (31). The findings of the current study would support the notion that neuromuscular training may be most effective with pre-adolescent children, which may help reduce the negative influence of the adolescent growth spurt.

A meta- analysis by Behringer et al. (2011) reported that pre-PHV athletes improved motor competency following resistance training significantly more when compared to post-PHV athletes (1). Yet, this gives no indication on the rate of motor skill development or the acute responsiveness to training in youth when exposed to neuromuscular training. Faigenbaum et al. (5) did report an improvement in movement competency in young children following an 8-week training intervention, however, there was no comparison with a post-PHV group. Similarly, there have been neuromuscular training interventions which have improved movement quality in solely post-PHV athletes after six-weeks (24, 34). While four-weeks was enough time to elicit an improvement in the current study, it appears that pre- and post-PHV athletes may differ in their responsiveness to neuromuscular training and the development of movement competency. Existing research has shown improvements in reactive strength index (RSI) and leg stiffness in youth athletes after four-weeks of training, albeit in plyometric performance (19). Cumulatively, it appears that four weeks may be the minimal amount of time to observe improvements in movement competency in youth athletes following a structured neuromuscular training program.

There may be specific individual criteria which caused the improvement in BSA total score for both EXP groups. Both EXP groups displayed greater reductions in the sum of deficits for thoracic, trunk, and hip position following the training intervention. Basic training principles dictate that untrained individuals will see the greatest rate of improvement (3, 13, 18). Given that these criteria were the most failed at baseline, they also had the greatest potential for improvement and contributed to the reduced BSA post-testing scores. Hip position deficit was the most common occurrence in both EXP groups for baseline testing, which corroborates with a recent systematic review that reported youth cricketers having poor lumbo-pelvic-hip movement control as a result of asymmetries formed during cricket-specific tasks such as bowling (6). Following the intervention, the pre-PHV group recorded no deficit for foot position criteria, indicating the group had altered movement mechanics during the descent of a squat. A common error in foot position during the squat is raising the heels due to a lack of ankle joint mobility during dorsiflexion (33). However, keeping the entire foot in contact with ground during descent may inherently effect the descent, depth, and ascent criteria if inadequate dorsiflexion mobility still exists. At post testing the pre-PHV group increased the number of deficits observed in ascent by two and only reduced descent criteria by one. However, the post-PHV group decreased the descent criteria by five and had no change in ascent. Similarly, different outcomes for squat depth criteria were observed during post-testing, with the pre-PHV group increasing in the number of deficits observed after the intervention and the post-PHV group decreasing the occurrence by three. There may be multiple reasons for this, such as lack of mobility, lack of lower body strength, and/or lack of kinesthetic awareness (14). The increase in the depth deficit occurring for the pre-PHV group during post testing may be due to natural movement variability and/or as per BSA guidelines, an absence of external load (33). This may inherently cause subjects to change their squat tempo by ascending and descending more quickly, which may have resulted in less kinesthetic awareness for reaching squat depth during post testing.

The current study provides a novel contribution to the literature that shows improvements in BSA movement competency can be realized in young athletes following an acute neuromuscular training program of just four weeks. A meta-analysis by Behringer et al. (1) did not report an optimal training dose-response for improving motor performance in youth, but did report the greatest results arrive from a combination of plyometric and resistance training (1). The results of the current study corroborate the Behringer (1) findings because both maturity groups improved motor competency when given neuromuscular training programs containing plyometric, resistance, and balance training. However, the pre-PHV group had a greater response to the training intervention due to a larger change in total score from 5.0 to 3.0, whereas the post-PHV group only had a change score of 2.0 to 1.0. While the post-PHV group also significantly improved squat competency following the intervention, their lower responsiveness to the training program indicates that maturity status and baseline may affect trainability and the rate of motor skill development in response to neuromuscular training.

One limitation of the current study is the short training period and the lack of information regarding the retention of back squat movement competency following training. While consistent neuromuscular training can have long lasting positive effects on movement competency (31), it is unclear how a longer and more chronic training dose would influence improvements in back squat competency for both maturity groups. Future studies could investigate the retention of movement competency in the BSA following a long-term neuromuscular training invervention. Another limitation of the current study was that intra-rater reliability was only established and that inter-rater reliability remains unknown. However, from a practical perspective it is suggested that any rater involved in using the BSA to assess movement competency in young athletes should establish their own reliability prior to administering the screen.

PRACTICAL APPLICATIONS

The BSA is a time-efficient test to administer in pre- and post-PHV male athletes as means for measuring movement competency and can detect changes in competency following short-term training interventions. However, reliability of the BSA total score indicates that rating is less robust when scoring pre-PHV athletes and an additional familiarization trial is recommended for practitioners before scoring BSA performance in this population. Practitioners should be cognizant that competency in the BSA in both pre- and post-PHV males can be improved in as little as four weeks when exposed to a neuromuscular training intervention. However, a greater improvement in movement competency was seen in the pre-PHV group when compared to the post-PHV group, which indicates a heightened training responsiveness in less mature athletes. Data from the current study showed that hip and thoracic positions were the greatest deficits at baseline in both maturity groups, while also having the greatest reduction following the training intervention. Therefore, coaches working with youth athletes should provide cues that stabilize the hip and thoracic positions during training which can improve overall movement competency. While the current study examined the acute effects neuromuscular training, practitioners should take advantage of the heightened neural plasticity in pre-PHV athletes by using a combination of resistance, plyometric, and balance training as part of a holistic, long-term athletic development program.

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FIGURE LEGENDS

Figure 1. Sum of deficits observed for each individual criterion in the BSA for the pre-PHV group from pre to post testing.

Figure 2. Sum of deficits observed for each individual criterion in the BSA for the post-PHV group from pre to post testing.

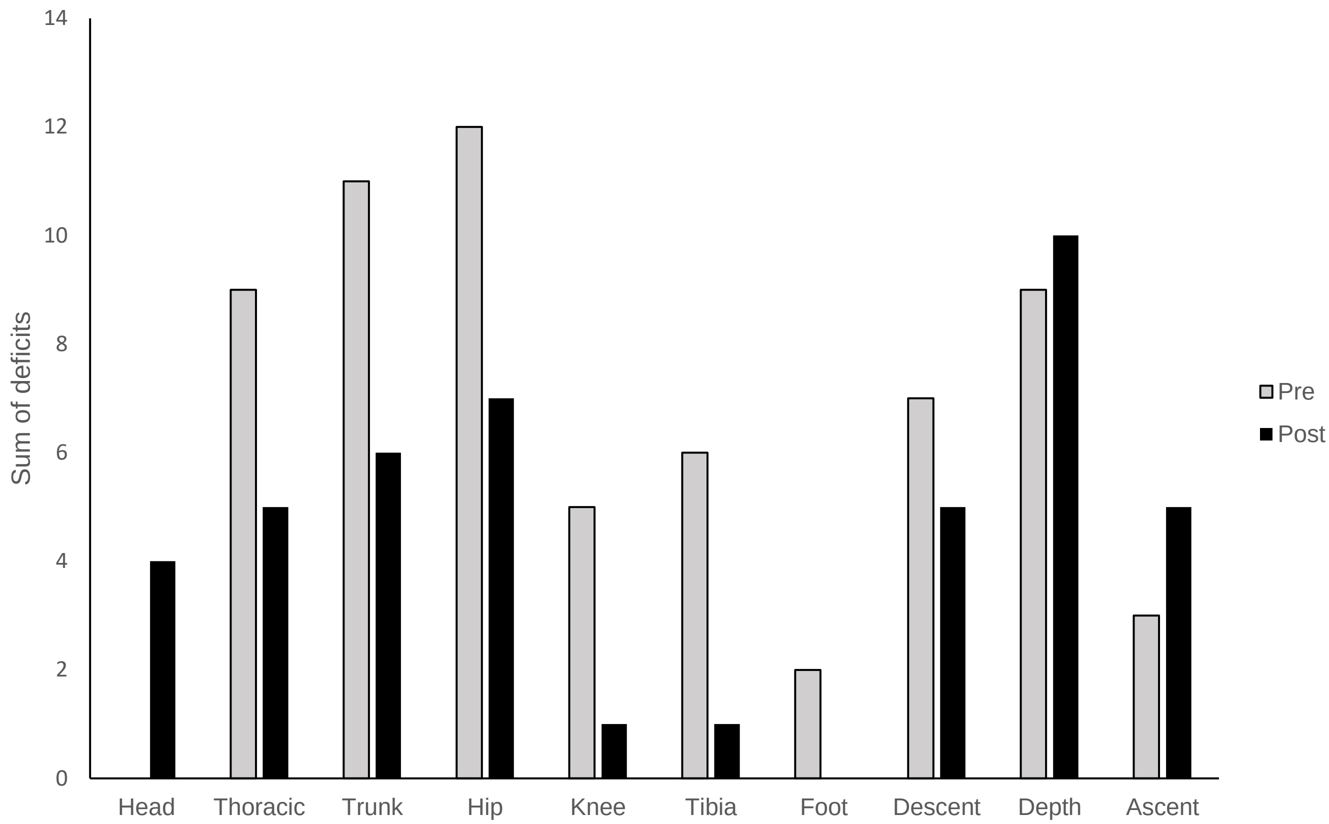

Figure 1. Sum of deficits observed for each individual criterion in the BSA for the pre-PHV group from pre to post testing.

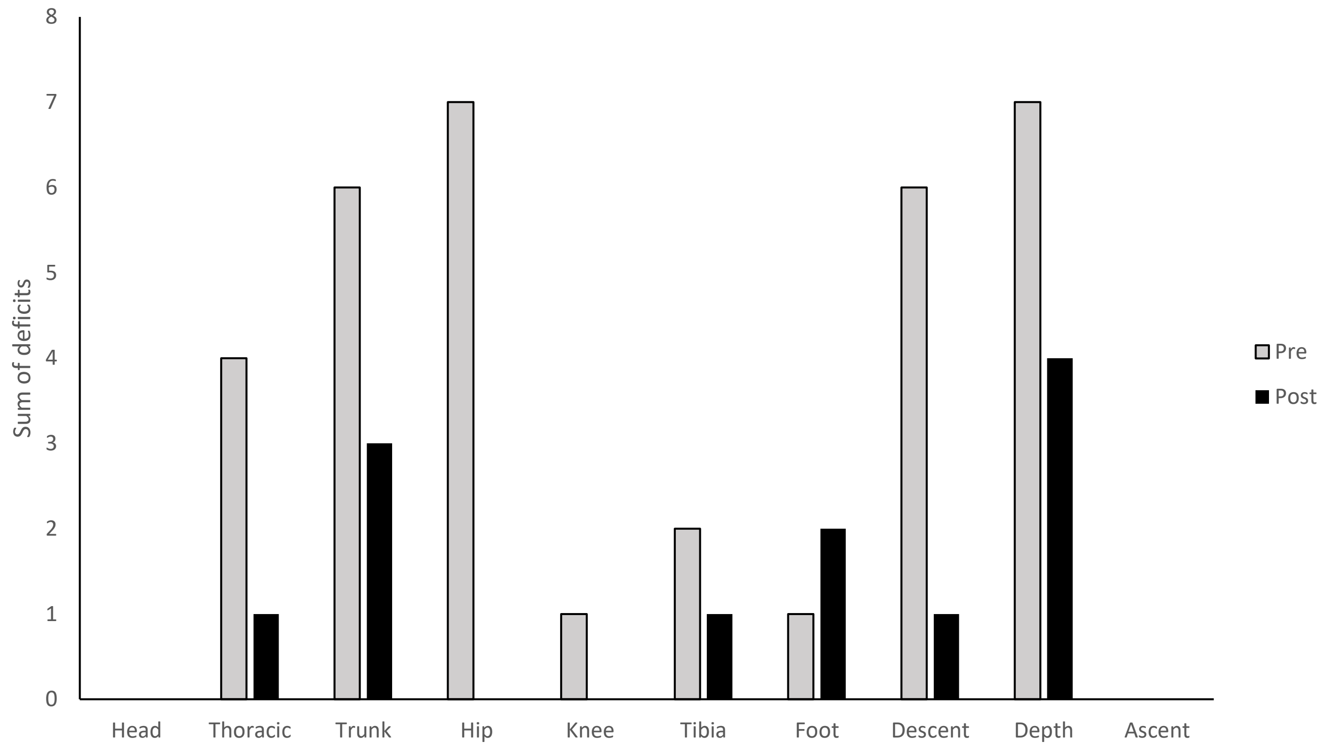

Figure 2. Sum of deficits observed for each individual criterion in the BSA for the post-PHV group from pre to post testing.

Table 1. Descriptive statistics (mean ± SD) for each group.

	Age (years)	Height (cm)	Mass (kg)	Maturity Offset (years)
Pre-PHV EXP (n=15)	11.2 ± 0.7	147.8 ± 5.6	39.8 ± 8.9	-2.2 ± 0.6
Pre-PHV CON (n=11)	11.6 ± 0.6	148.5 ± 6.8	42.2 ± 6.6	-2.0 ± 0.4
Post-PHV EXP (n=11)	15.4 ± 0.9	171.9 ± 8.4	64.4 ± 9.2	1.3 ± 1.3
Post-PHV CON (n=11)	14.5 ± 0.8	170.5 ± 11.9	61.6 ± 12.9	0.7 ± 1.1

Table 2. Neuromuscular training program for pre-PHV group week 1-4.

	Session 1				Session 2			
Week	Exercise	Sets	Repetitions	Rest	Exercise	Sets	Repetitions	Rest
1	Single Leg Hops	3	10 each	90s	Box Jumps	3	5	90s
	Push Ups	3	10	90s	Face pulls w/ band	3	10	90s
	Body weight squat	3	15	90s	DB Goblet Squat	3	10	90s
	Side planks	3	30s each	90s	Planks	3	30s	90s
2	Single Leg Hops	3	10 each	90s	Box Jumps	4	5	90s
	Push Ups	3	10	90s	Standing Band Rows	4	10	90s
	Body Weight Squat	3	15	90s	DB Goblet Squat	4	10	90s
	Side Planks	3	30s each	90s	Planks	4	30s	90s
3	Split Jumps	3	10 each	90s	Broad Jumps	3	5	60-90s
	DB suitcase carries	3	15m each	90s	Back Squat	3	12	60-90s
	Squat w/ band	3	12	90s	Inverted Rows	3	10	60-90s
	Shoulder Taps	3	10 each	90s	Deadbugs	3	10 each	90s
4	Split Jumps	4	10 each	90s	Broad Jumps	4	5	90s
	Squat w/ band	4	12	90s	Back Squat	4	12	90s
	DB suitcase carries	4	15 m each	90s	Inverted Rows	4	10	90s
	Shoulder Taps	4	10 each	90s	Deadbugs	4	10 each	90s

Table 3. Neuromuscular training program for post-PHV group week 1-4.

	Session 1				Session 2			
Week	Exercise	Sets	Repetitions	Rest	Exercise	Sets	Repetitions	Rest
1	Back Squat	3	10	90s	Bench Press	3	10	90s
	Standing Band Row	3	10	90s	DB Split Squats	3	10 each	90s
	Hurdle Jumps	3	10	90s	DB Rows	3	10 each	90s
	Shoulder Taps	3	10 each	90s	Paloff Press	3	15 each	90s
2	Back Squat	4	10	90s	Bench Press	4	10	90s
	Pull Ups	4	5 to 10	90s	DB Split Squats	4	10 each	90s
	Hurdle Jumps	4	10	90s	DB Rows	4	10 each	90s
	Shoulder Taps	4	10	90s	Paloff Press	4	15 each	90s
3	Back Squat	3	15	90s	Walking DB Lunges	3	10 each	90s
	Overhead Press	3	10	90s	Hip Thrusts	3	10	90s
	Split Jumps	3	10 each	90s	TRX Rows	3	12	90s
	Side Planks	3	30s each	90s	Weighted Bear Crawl Hold	3	30s	90s
4	Back Squat	4	12	90s	Walking DB Lunges	4	10 each	90s
	Overhead Press	4	10	90s	Hip Thrusts	4	10	90s
	Split Jumps	4	10 each	90s	TRX Rows	4	12	90s
	Side Planks	4	30s each	90s	Weighted Bear Crawl Hold	4	30s	90s

Table 4. Intra-class correlation (95% confidence intervals) for BSA total score across all sessions.

	Session 1-2	Session 2-3
Pre-PHV	0.81 (0.68 – 0.96)	0.98 (0.96 – 1.00)
Post-PHV	0.97 (0.94 – 1.00)	0.97 (0.95 – 1.00)

Table 5. Kappa values for all criteria in the BSA across all sessions.

	Session	Head	Thor.	Trunk	Hip	Knee	Tibia	Foot	Desc.	Depth	Asc.
Pre-PHV	1-2	1.00	0.87	0.31	0.76	0.67	0.72	1.00	0.60	1.00	0.58
	2-3	1.00	0.73	0.87	1.00	0.82	0.87	0.42	0.71	0.86	0.44
Post-PHV	1-2	1.00	0.79	0.81	0.81	0.62	1.00	1.00	1.00	1.00	1.00
	1-3	1.00	0.79	1.00	0.81	1.00	1.00	1.00	0.82	0.79	1.00

Table 6. Median BSA total scores after 4-week training intervention.

	Pre BSA total score	Post BSA total score	Between group difference at post testing (ES)	Within group change at post testing (ES)
Pre-PHV exp	5.0	$3.0^{* \beta}$	$d = 0.43$	$d = 0.68$
Pre-PHV control	5.0	4.0		
Post-PHV exp	2.0	$1.0^{* \beta \theta}$	$d = 0.69$	$d = 0.82$
Post-PHV control	4.0	4.0		

* significant difference from pre to post testing within group ($p < 0.05$)

$^{\beta}$ significant difference between experimental and control group total score ($p < 0.05$)

$^{\theta}$ significant difference in post BSA total score between experimental and pre-PHV group ($p < 0.05$)