The Effect of Core and Lower Limb Exercises on Trunk Strength and Lower Limb Stability on Australian Soldiers

Rolf Sellentin[1] and Dr Rhondda Jones[2]

Abstract

Study Design: A before and after design in the collection of data and using analyses of variance to examine the changes in each test score.

Objectives: The objectives and hypotheses of this study are: (1) Do specific core exercises, incorporating the lower limbs improve lower limb stability and trunk core muscle strength?; (2) Can the Star Excursion Balance Test be used as a measure of ankle and lower limb stability without a history of ankle instability?; (3) Can static core tests be used as a measure of core stability?; and (4) Is the Cumberland Ankle Instability Tool (CAIT) questionnaire sufficiently sensitive to show any changes to ankle instability following the outcomes of this study?

Background: An earlier study undertaken by Sellentin and Sanchez (2011) identified specific injuries sustained by Australian garrison soldiers of the 16 Air Defence Regiment. These injuries involved the neck, low back, knee and ankle. This current study was designed to address these injuries by providing exercises to specifically strengthen the core and lower limb muscles and to improve proprioception and muscle movement patterns, with the aim of reducing the number of injuries in Australian soldiers.

Methods and Measures: Eight young adult males volunteered for this study (mean age of 22 years). Female Australian soldiers did not participate in this study, as there were none available at the time and there were very few women in the Regiment. The eight male subjects undertook a twelve week supervised exercise programme loosely based on the validated FIFA 11+ programme. Subjects performed specific exercises over twelve weeks which were gradually increased in intensity, difficulty and resistance week by week. Each subject also completed a CAIT questionnaire before and after the 12 week exercise programme. In order to measure any effect from our exercise programme. Each subject was asked to perform a series of sustained flexion, extension, side holds and prone hold tests and the Star Excursion Balance Test (SEBT), which were recorded before and after the exercise programme as assessment tools. The SEBT was also used to assess if there were any sensorimotor deficits related to chronic ankle instability in any of the subjects. We chose to use the SEBT as it has strong intratester and intertester reliability, is sensitive in the detection of functional deficits associated with chronic ankle instability, and with the possibility that this instability might be related to performance deficits in the entire affected extremity (Hertel et al 2006). This is particularly relevant when one of the purposes of our study was to examine if our exercise programme could reduce the risk to the knee and ankle by improving lower limb stability.

Results: Even though the sample size was small, there were significant effects in the before and after tests following the 12 week exercise programme:

- The Sustained Flexion test showed significant improvement.
- The Prone Hold showed an increase but not a significant change.
- The Left and Right Side Bridge showed a levelling out.
- The SEBT showed significant effects on average reach scores in all of the posterior reach directions, improvements in the lateral and medial reach (left and right limb stance), and in anterior reach directions, subjects with low starting values tended to show larger improvements, while subjects with high starting values tended to increase less or to decrease.
- Averaging over all the scores of all the tests of the SEBT showed a significant improvement.

- If the SEBT composite score of anterior, posteromedial and posterolateral reach is taken as a predictor of lower extremity injury (Plisky et al. 2006), the results show a very strong improvement in post exercise scores. There was a shift in each subject's scores in our current study from below the critical 94% figure (identified by Plisky et al (2006) as a risk factor in lower extremity injury) to above 94% following the exercise programme.
- The CAIT showed a mixed result with one subject improving their ankle functional instability (FI) and two subjects showing a decreased score following the exercise programme.

Conclusions: The results from this study support the hypothesis that specific core and balance exercises improve core strength and lower limb balance. There is thus a very strong indication for its use in injury prevention.

Key Words: Core exercises, balance exercises, STAR test, SEBT, core assessment, CAIT questionnaire.

Introduction

This study sets out to determine if core exercises,that encompass lower limb movements and balance, improve core trunk strength and stability and lower limb balance. It also sets out to determine if the SEBT can be used as a measure of lower limb stability, and if static core tests can be an effective assessment tool.

Kibler et al. (2006) defines core stability as "the ability to control the position and motion of the trunk over the pelvis and to allow optimum production, transfer, and control of force and motion to the terminal segment in integrated athletic activities."

A previous study (Sellentin and Sanchez. 2011) identified that injuries to Australian garrison soldiers occurred in the neck, low back, knee, and ankle. The object of this current study was to find exercises that could improve a soldier's core strength with the aim of reducing neck and low back injuries, and to improve lower extremity strength, coordination and proprioception to reduce knee and ankle injuries. Our exercises have been identified as being effective in improving core strength and lower extremity balance. A future study could be undertaken to compare two regimens, one using our exercise programme and the other participating in standard PT exercises as the control, to determine if the incidence of injury is reduced using our programme.

Methods

Subjects

Australian soldiers from the 16th Air Defence Regiment volunteered for this study. The operational tempo of the regiment only allowed for twelve (male) soldiers identified by the Chain of Command who could be available for the duration of this study. From this, eight males volunteered for our 12 week exercise programme, with their age ranging from 19 to 26 with a mean age of 22 years and a body weight mean average of 83 kg. All subjects were right hand dominant. No female soldiers were available for this study.

Exclusion criteria included those potential subjects with an acute musculoskeletal injury, ankle sprain less than three months old, inner ear dysfunction/ tinnitus, flu, or habitual users of balance equipment such as wobble boards. Inclusion criteria of potential subjects required full pain-free joint range of movement for all extremities and trunk, physical fitness in order to cope with the exercise programme and a commitment to complete all phases of the 12 week programme. All eight volunteers met these criteria.

All subjects signed an informed consent form approved by the Australian Human Ethics Committee (ADHREC) to participate in this study. This study was approved by the ADHREC with the designated research protocol number 607-10. The soldier's rights and anonymity were protected throughout this study.

Age, weight, previous injury history, hand dominance and leg length were also recorded. Of the eight male subjects, three had a past history of ankle instability, one a knee ligament strain and two with shoulder strains. All subjects self-reported to be free of lower extremity injury, including an inversion ankle injury, within 3 months of this study. Each subject was asked if they were free of cerebral concussions, vestibular disorders, ear infections, upper respiratory infection, head cold, and if they had had prior balance training.

The first author, who is a physiotherapist, instructed the subjects in detail on performing the core assessment tests and SEBT, how to engage their core muscles, and supervised their 12 week exercise programme to ensure the exercises were performed correctly. Although data collection would be consistent using one person, this might also be a limitation, as it could be subject to possible bias.

Analysis

We used a repeated measures analyses of variance to examine the changes in each test score (and in composite measures recommended by Plisky et al (2006)) from the beginning to the end of the 12-week programme. We also examined correlations between starting values and changes in score to determine whether the changes were related to the physical capabilities of the subject at the start of the exercise programme. We used box plots rather than confidence intervals (which would have been imprecise) around each mean to show the whole distribution of values because the sample size was small.

Results

Core strength tests

There was evidence of improved core strength in three of the five tests (Table 1): flexion (a 68% increase), prone hold (30%), and right bridge (25%). Trunk extension scores were very similar before and after the programme, and left bridge scores tended to decline, though the average change does not achieve statistical significance.

Table 1: Effects of the exercise programme on core strength measures.

TEST	Mean before program	Mean after program	Mean change	ANOVA result
Flexion	112.8	189.7	76.9 (68%)	F1,7= 5.82, p = 0.047
Extension	91.6	90.0	-1.6 (-1.7%)	NS
Prone hold	173.4	226.6	53.2 (30%)	F1,7=2.02 P = 0.086
Right bridge	79.4	106.1	26.75 (25.2%)	F1,7=11.82, p = 0.0014
Left bridge	122.9	103.0	-19.9 (-16%)	NS

At the start of the trial, left bridge scores were, in most subjects, substantially higher than right bridge scores, with a highly variable left bridge: right bridge ratio averaging about 1.7. At the end of the trial, the left and right bridge scores were almost equal, with a left bridge: right bridge ratio close to 1 in all subjects (Figure 1a). The change in variance is significant (Levene's test, F1,14=16.8, p = 0.0011). The balancing-out between left and right occurs as a result of both increases in score (when starting scores were low), and decreases in score when starting scores were high (Figure 1b).

Figure 1a Variability of left bridge:right bridge ratios between subjects decreased during the exercise program. Boxplots show median, interquartile range, and total range.

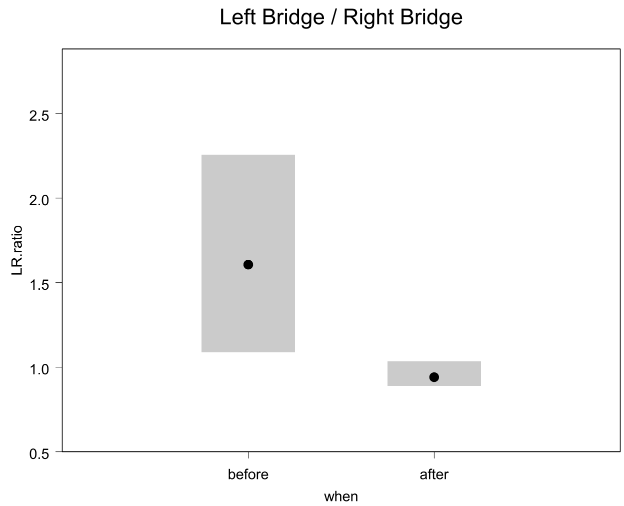
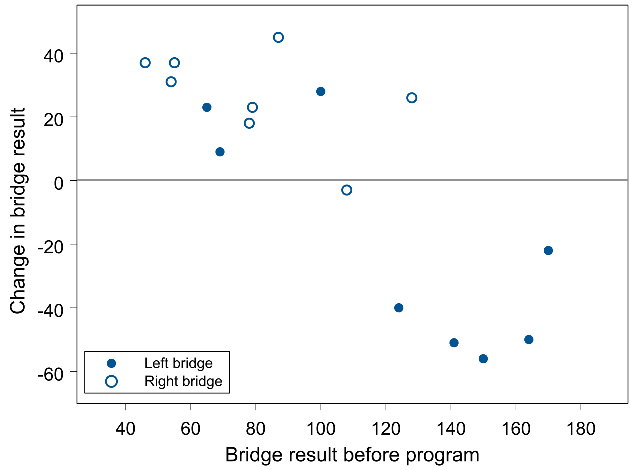


Figure 1b: Change in a bridge score during the exercise program is strongly correlated with its starting value.



Star Tests: individual test scores.

The effects of the exercise programme on individual test scores are shown in Table 2. Except for the anterior lateral reach direction, where right and left stances are shown separately in the table, there were no significant differences between right and left leg stances and average values for both stances combined are presented.

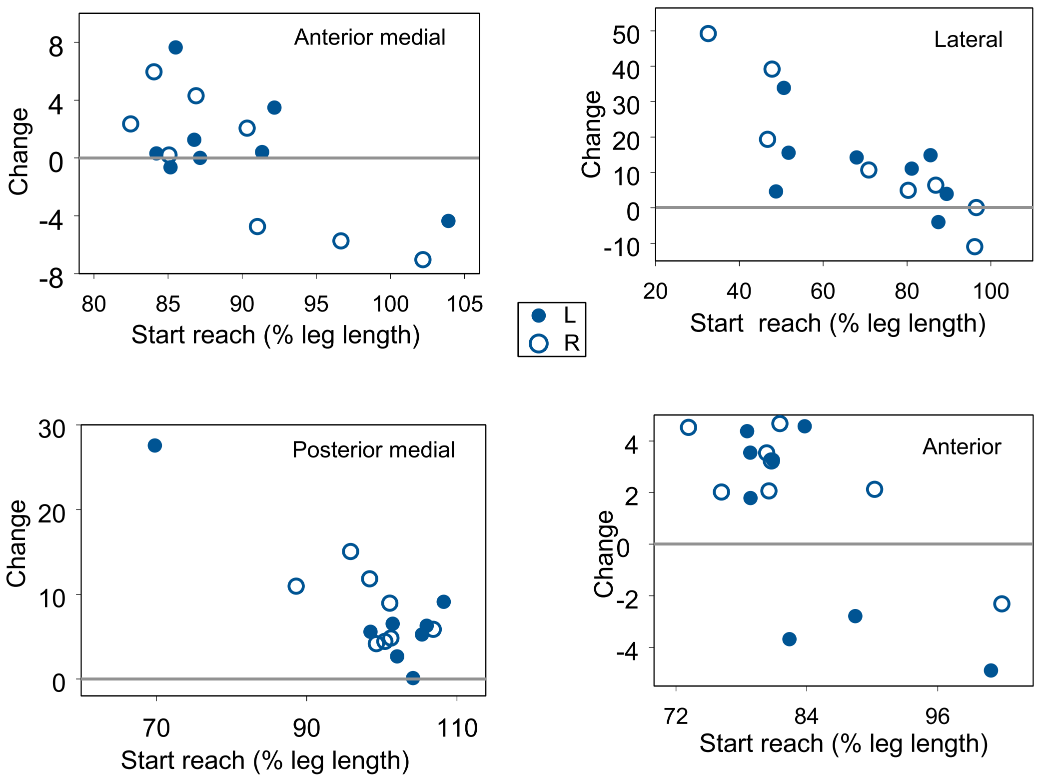
Table 2: Reach as % of leg length.

Reach direction		Mean before program	Mean after program	Mean change	ANOVA result	Change/start correlation
Anterior medial		89.7	90.0	0.3	NS	-0.71, p=0.002
Anterior lateral	Left	71.6	72.5	0.9	NS	-0.69, p=0.003
	Right	67.6	68.1	0.5	NS	
Anterior		83.6	85.2	1.6	NS	-0.71, p=0.002
Medial		95.3	98.6	3.3	$F_{1,23}$= 8.97, p = 0.0065	-0.52, p = 0.04
Posterior medial		99.2	107.3	8.1	$F_{1,23}$= 22.82, p = 0.0001	-0.84, p=0.0001
Posterior		104.7	110.3	5.7	$F_{1,23}$= 17.24, p = 0.0004	-0.70, p=0.003
Posterior lateral		95.9	101.0	5.1	$F_{1,23}$= 10.19, p = 0.0041	-0.41, p=0.11
Lateral		70.0	83.4	13.3	$F_{1,23}$= 15.28, p = 0.0007	-0.81, p=0.0001

The results in Table 2 indicate significant effects on average reach scores in all the posterior directions as well as the medial and lateral directions, but not in any of the anterior directions.

However, in every case, there is a moderate to strong negative correlation between the starting value and the change over the course of the programme. That is, even for anterior reach directions, subjects with low starting values tended to show larger improvements, while subjects with high starting values tended to a smaller increase or to a decrease. Four examples are shown in Figure 2.

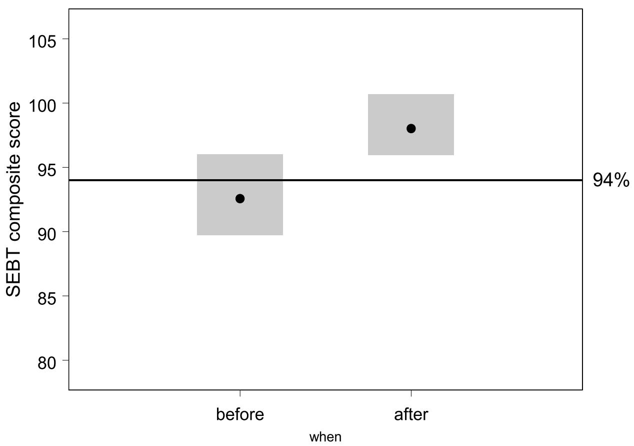
Figure 2: Relationship between starting value and change during the exercise programme for four of the SEBT reach measures.



Star Tests: composite scores

In a large study of basketballers, Plisky et al (2006) derived a composite score averaging anterior, posterior medial, and lateral reach. They demonstrated in that study that values below 94% in that composite score were a predictor of lower extremity injury in their study population. The average composite score for our sample improved significantly and similarly for both left and right stance over the period of the exercise programme, from 92.9 to 97.8 ($F_{1,23}$= 33.68, $p < 0.0001$), with most of the group moving out of the "at risk" category over the course of the study (Figure 2).

Figure 2: Change in the distribution of the SEBT composite score over the course of the 12-week exercise programme, averaged for right and left leg stances. The horizontal line represents the level below which Plisky et al (2006) identified a risk of lower extremity injury. Boxplots show median, interquartile range, and total range.



Left-right imbalances

An additional predictor of lower extremity injury identified by Plisky et al (2006) was an imbalance between left and right reach, with a difference of 40mm or more between left and right in posterior medial, posterior lateral or anterior reach identified as a risk factor. We earlier noted that the exercise programme corrected left-right imbalances in core strength measures: while there is some indication that there may also be reductions in posterior reach imbalance (Table 3), the gains are variable and do not achieve statistical significance in any of the reach measures in this small sample.

Table 3: Mean absolute differences in left and right reach.

Reach direction	Mean difference before program	Mean difference after program	Mean change	ANOVA result
Posterior medial	51.0	28.5	22.5	NS
Posterior lateral	54.0	42.6	11.4	NS
Anterior	36.9	37.2	-0.3	NS

The subjects also completed a CAIT questionnaire before and after the 12 week exercise programme. The CAIT is a measure of instability in subjects, and is a valid and reliable method for diagnosing and measuring the severity of FI using a graded scale between 0 and 30 (Coughlan and Caulfield. 2007). Scores greater than 27.5 represent highly stable ankles, and scores less than 24 represent ankles with increasingly severe instability. Tables 4 and 5 show a mixed result for the CAIT questionnaire. Before the exercise programme subject "d" indicated an FI of the left ankle and subject "g" indicated an FI to both ankles. Post exercise programme subject "g" indicated an improvement in functional stability and subject "d" indicated a small improvement to the left ankle but a reduction in the right ankle. There was also a reduction in the before and after scores for subject "h", indicating FI.

Table 4: CAIT BEFORE Exercise

subject	left ankle	right ankle
a	29	26
b	29	27
c	30	30
d	22	28
e	30	30
f	28	27
g	23	23
h	27	27

Table 5: CAIT AFTER Exercise

subject	left ankle	right ankle
a	29	29
b	29	29
c	30	30
d	23	23
e	30	30
f	25	25
g	26	26
h	22	22

Procedures

The eight subjects under took a 10 minute warm up consisting of a light jog, arm movements and leg and arm stretches prior to the commencement of the assessment tests and for each day of the programmed exercises.

The eight subjects performed the following sustained core tests as suggested by Brukner and Khan (2006); a prone hold, a side hold (left and right), sustained flexor hold and sustained extension, all of which were recorded in seconds before and then repeated again after the 12 week exercise programme. These tests assessed the subject's muscle strength and endurance and synergistic activation of the trunk muscles, and demonstrate how well the muscles functioned together. The prone hold test assesses primarily the anterior and posterior core muscles with the subject required to keep the pelvis and lumbar spine in a neutral position. Failure occurs if the subject loses this posture due to a loss in muscular strength and the lumbar spine falls into a lordotic position with an anterior rotation of the pelvis. The side hold assesses lateral core muscles, with the subject needing to maintain the body in a straight line. Failure occurs if the hips fall towards the floor. The static flexor hold assesses the torso flexors, with the subject asked to maintain a seated 60 degree trunk flexion (a metal frame set at 60 degrees was fabricated to ensure repeatability) with hips and knees flexed at 90 degrees (Figure 1). Failure occurred when the torso fell below 60 degrees.

The sustained extension test assesses the torso extensors as the subject overhangs over the end of a treatment table maintaining a horizontal posture. Failure occurs if the subject dipped below the horizontal (Figure 2).

These tests were used as a measurement of core strength before and after the exercise programme, and indirectly to determine if these tests were sensitive enough to detect any change.

Weir et al. (2010) state that "there are no widely accepted reliable tests for testing core stability in the clinic". However, core tests as described by Brukner and Khan (2006) were selected for our study as Weir et al. (2010) state that a "static test results in a better reliability when compared with dynamic tests". Bliss and Teeple (2005) advocate these same static core tests as they "yield significant information". Weir et al. (2010) further state that other so called Core Tests, such as Transverse, Frontal and Sagittal plane testing and the unilateral squat and lateral step down tests, as a means of measuring core stability, are questionable and have poor reliability. They conclude that there are "no other studies available on clinical core stability tests (and) no reliable clinical tests with which core stability can be assessed". Our study is significant since it demonstrates that static core tests are a sensitive measuring tool to detect changes to core strength following specific exercises.

The SEBT used in our study was the same as that described by Hertel et al. (2006). Four intersecting 3cm wide lines at 45 degree increments were painted onto a concrete floor, with the centre marked by "cross hairs" (Figure 3).

Each subject had the soles of their feet measured lengthways and widthways, the centre marked with intersecting "cross hair" lines. On testing, the subject's stance foot with its "cross hair" was meticulously placed upon the floor cross hair so that the test could be replicated after the 12 week exercise programme with minimal variation. Subjects were required to maintain a single leg stance whilst reaching with the contralateral leg, touching as lightly as possible and as far as possible with the most distal part of their foot along each line. The reach was disqualified and redone if the subject propped on the out-stretched foot, or if they lost their balance, or lifted their stance foot from the grid, or did not maintain the

Figure 1. The static flexor hold.

Figure 2. The sustained extension test

start and return position for a full second, or they failed to touch the black line. Each subject practised six trials in each of the eight directions on each leg followed by 5 minutes of rest before the recording began. Subjects then performed three trials in each direction on each limb, with the length of reach being marked by a pencil at the point where the most distal part of the foot touched the black line, with 10 seconds of rest between individual reach trials. The marks were measured and recorded in millimetres from the centre of the star to the point of contact and then were erased before the subject swapped legs. The average of the three reaches for each leg in each of the eight directions was calculated for analysis. It was atypical for the subjects to have their scores discarded, and none of the subjects reported fatigue during or after the SEBT.

The eight lines were labelled: anterolateral (AL), anterior (ANT), anteromedial (AM), medial (MD), posteromedial (PM), posterior (PO), posterolateral (PL), and lateral (LAT). The eight lines were named according to the direction of reach in relation to the stance leg. Half the subjects began by performing the right-leg stance tests first, and the other half began using the left-leg stance. The order of reach directions was assigned using a Latin square to avoid order effects from contaminating the data. The reach leg (right, left) order of excursions performed (clockwise, counterclockwise), and direction of the first excursion (A, M, L, P) were counterbalanced to control for any learning or order effect (Olmsted et al. 2002), and all trials were then performed in sequential order in either the clockwise or counterclockwise directions.

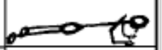
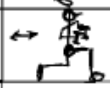
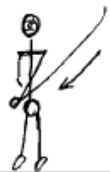
Figure 3. The SEBT

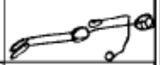
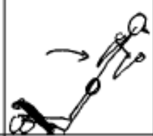
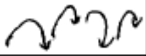
Our 12 week exercise programme consisted of exercises loosely based on the validated FIFA "The 11+" programme and from other research studies on neuromuscular training, such as Pasanen et al. (2008) study. The FIFA 11+ programme of strengthening and balance exercises had shown a 30-50 percent reduction in injured soccer players from a study with almost 2,000 female players. Our study was designed around the FIFA 11+ as it is a validated programme that has shown to reduce the incidence of lower limb injuries in soccer players. It was our need to design a similar but augmented programme with the view to reduce injury rates to Australian soldiers by improving their core strength and stability and lower limb stability for the manual tasks and sustained physical activity that is often required in their day-to-day duties. A strong core is necessary for a stable base from which the lower and upper extremities can work. Our design incorporated a high proportion of balance exercises with the view to improve lower limb proprioception, muscle co-ordination and reaction times in order to minimise the risk of injury to knees and ankles during physical activities.

Most rehabilitation studies for acute and chronic ankle instability involve a 6 week to 8 week training period, but changing a functional activity requires more intensive training (Coughlan and Caulfield, 2007) and a longer period of time. Thus our study was conducted over 12 weeks, as this allowed sufficient neuromuscular adaptation. Scutter et al. (1995) also state that before 5 weeks any change may be attributable to neural factors and it is not until after 5 weeks that muscle hypertrophy becomes the dominant factor and strength increases.

The eight subjects in our study undertook specifically designed exercises three times a week over 12 weeks (Figure 4). The exercises were divided into three blocks (weeks 1 – 4, 5 – 8, and 9 – 12), and the exercise hour was further divided into two 25 minute circuits, giving a 5 minute water break and equipment change-over between the circuits. Each piece of equipment was doubled to accommodate the number of subjects and each subject positioned themselves at a station to commence the circuit. The number of repetitions at each station before rotating to the next station was dictated by the pace setter which was the person doing the prone hold (in Blocks

Figure 4.

Circuit 1 Weeks 1 - 4			
Timings			
Week 1	30sec		
Week 2	45sec		
Week 3	60sec		
Week 4	45sec		
Exercise	**Action**	**Time/Reps**	**Picture**
Prone hold	participants required to hold the prone position	holding as per time for prescribed week	
Squat jump with dumbbell	participants holding onto a weight in each hand, start in the squat position then jump as high as they can in succession	Starting weight 1.75kg. Weight is increased to; 2.5kg week 2 5kg week 3 2.5 week 4	
One leg balance, medicine ball passing	standing on one leg and pass medicine ball around the body	Medicine ball is passed around the body five times each direction whilst balancing on one foot, then change feet. Week 1 = 3kg Week 2 = 4kg Week 3 = 5kg Week 4 = 4kg	
Single lunge with dumbell curl	alternate lunge with double DB curls	Reps	
High wood chop	participants required to have theraband anchored to a high point, standing side on to the band (feet double shoulder width apart), arm extended, from high shoulder hieght lowered to opposite hip.	starting band green/blue Five times each arm then change sides.	
Alternate lunge with medicine ball front raise	participants conduct a fwd lunge with a front raise with the medicine ball	Week 1 = 3kg Week 2 = 4kg Week 3 = 5kg Week 4 = 4kg	

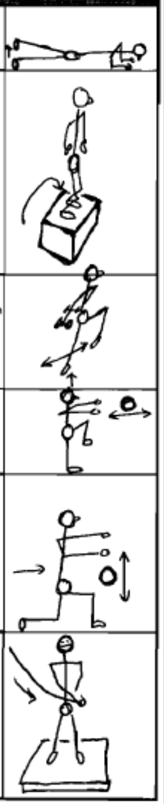
Circuit 2 Weeks 1 - 4			
Timings			
Week 1	30sec		
Week 2	45sec		
Week 3	60sec		
Week 4	45sec		
Exercise	**Action**	**Time/Reps**	**Picture**
Side hold	participants lie on side with hip elevated. Hips are to remain in line with ankles and shoulders	holding as per time for prescribed week	
Nordic hamstring exercise	participants required to have feet held under a weight (ash pole threaded through kettlebells), hips in line with knees and shoulders and lower themselves to the mat until the hamstrings can not support them.	3 - 5 Reps	
Back wood chop	participants required to have theraband anchored to a high point, standing side on to the band (feet shoulder width apart), using hand furtherest away from band, pulling down to hip, raising to opposite shoulder	band blue 5reps per side	
Bounding	participant required to concentrically load each leg whilst moving forward	moving forward, distance is rate of progression	
Alternate lunge with chest press	fwd lunge with a chest press theraband in each hand (anchored to the wall bars)	starting band green/blue	
Lunge with barbell held to front	with arms crossed infront holding a barbell, do alternating lunges. MAINTAIN CORE ACTIVATION.	Reps	

1 & 2) or Nordic (in Block 3). With each week the exercises became a little more demanding, and every four weeks the exercises were advanced in their level of difficulty. This type of exercise escalation was designed to both maintain the subject's interest and to challenge and strengthen the subject over the course of the study, since Coughlan and Caulfield (2007) claim that the progressive nature of a neuromuscular training programme is important to achieve neuromuscular outcomes. It is interesting to note that they also state that "dynamic training [such as that used in our programme] has been demonstrated to reduce sex-related differences in force absorption, active joint stabilisation, muscle imbalances, and functional biomechanics while increasing the strength of structural tissues". This is important should our exercise programme be used by female soldiers.

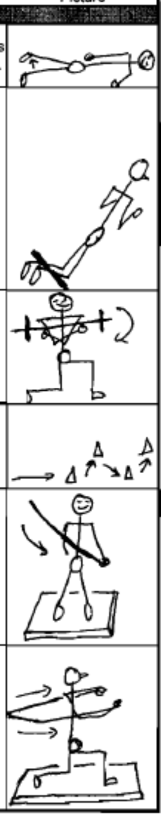
Our exercises were designed to incorporate both static and dynamic core strengthening. They also encompass neuromuscular facilitation, proprioception, lower limb strengthening, dynamic and multiplanar exercises, balance and plyometric running and jumping drills, as advocated by Bliss and Teeple (2005). O'Sullivan et al. (1997) point out in their study that Choleswicke and McGill (1996) reported lumbar stability is maintained in vivo by increasing the activity (stiffness) of the lumbar segmental muscles, and they highlighted the importance of motor control to co-ordinate muscle recruitment between large trunk muscles and small intrinsic muscles during functional activity to ensure stability is maintained. Our exercises were designed to provide a soldier with an all-encompassing comprehensive programme which engaged the neuromuscular system and targeted the main areas of the body that the previous study (Sellentin and Sanchez. 2011) had identified. Our exercises commenced with a neuro-developmental stage of bracing the core muscles until it became second nature, and ending at 12 weeks with engram motor programming becoming automatically

Figure 4.

	Circuit 1 Weeks 5 - 8		
	Timings		
	Week 5	30sec	
	Week 6	45sec	
	Week 7	60sec	
	Week 8	60sec	
Exercise	**Action**	**Time/Reps**	**Picture**
Prone hold leg lift	In prone position with one leg elevated approximately 15cm off the ground.	each limb half the time	
Box jumps	Starting in a squat position jumping onto a platform and landing in the squat position.		
Split lunge with DB hop	A weight held in each hand.The lunge is conducted on one leg with the rear leg brought forward into flexion & returning rearward and the stance leg hopping.	Elbow Extension on hop. Elbow Flex on return 5 reps per leg continuously	
Single leg balance with MB throw	Standing on one foot - a MB is chest passed to the wall and caught on the rebound.	5 throws each leg continuously - right and left leg	
Split lunge with MB bounce	Lunge conducted where on the 'down' phase of the lunge an MB is thrown to the ground and caght. The ball is thrown on the same side as the front knee.		
High wood chop on mat	participants required to have theraband anchored to a high point, standing side on to the band (feet double shoulder width apart), arm extended, from high shoulder hieght lowered to opposite hip whilst standing on a mat.	5 reps per arm continuously.	



	Circuit 2 Weeks 5 - 8		
	Timings		
	Week 1	30sec	
	Week 2	45sec	
	Week 3	60sec	
	Week 4	60sec	
Exercise	**Action**	**Time/Reps**	**Picture**
Side hold leg lift	In side hold position with leg on top lifted to horizontal	Timing for each side is half of the entire time.	
Nordic hamstring exercise	participants required to have feet held under a weight (ash pole threaded through kettlebells), hips in line with knees and shoulders and lower themselves to the mat until the hamstrings can not support them.	7-10reps	
FWD lunge with BB rotation	BB held to the front and each time a lunge is conducted the torso is rotated to the same side as the fwd knee.		
Running	running in a straight line with short changes in direction - zig zag.		
Back high wood chop	participants required to have theraband anchored to a high point, standing side on to the band (feet shoulder width apart), using hand furtherest away from band, pulling down to hip, raising to opposite shoulder whilst standing on a mat.		
Alternate lunge with chest press	fwd lunge with a chest press theraband in each hand (anchored to the wall bars) wilst on a mat.	5 reps pers side continuously.	



patterned in the motor cortex while performing demanding and complex exercises. Core strength in particular is important, since all motions are generated from the core and are translated to the extremities (Bliss and Teeple. 2005). Peate et al. (2007) also support this and state that there is "a clear relationship between trunk muscle activity and lower extremity movement". Hence the combination of core strengthening exercises and lower extremity exercises used in our study.

Each subject also filled out a CAIT questionnaire before and after the exercise programme to assess any perceived change in ankle stability. These were scored and analysed.

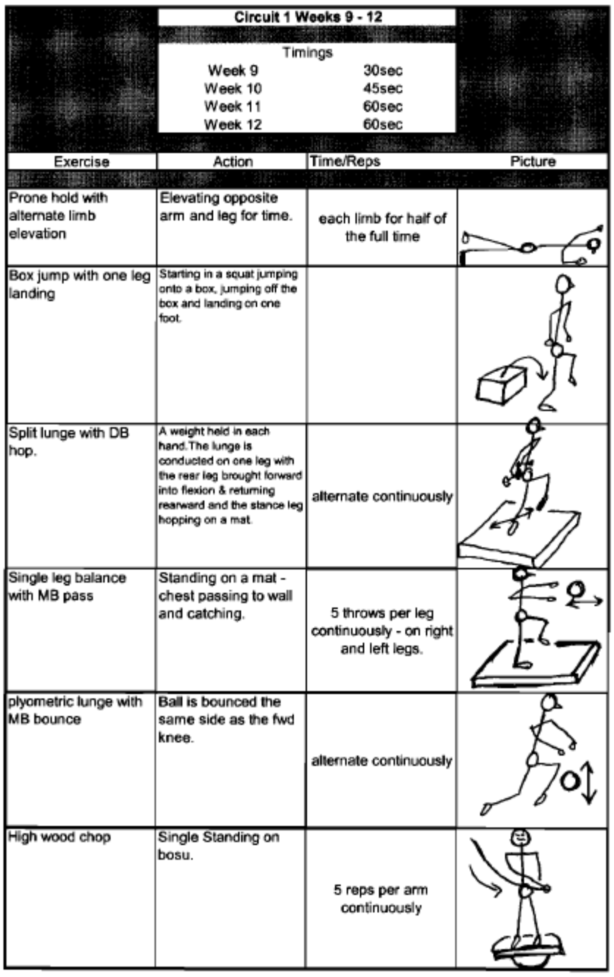
Discussion

The Australian Defence Force (ADF) has adopted a strategic focus in preventing occupational injury, illness and disease. Prevention is the primary objective of the ADF's approach to occupational health and safety. Injury can result in significant and long term personal disability and financial cost, and both a significant cost to the Australian Government in terms of compensation and a cost to the ADF in the reduction in operational capabilities.

The idea for a specific and concise exercise programme was developed by the need to reduce the number of injuries to soldiers. Australian garrison soldiers undertake daily physical training (PT), usually for cardiovascular fitness and general over-all body conditioning rather than regular core strengthening and lower limb balance exercises. The need for exercise specificity in regard to injury prevention and to address these short comings in unit PT sessions was the main focus for this study, and is paramount for force preservation. One reason for our study was the lack of evidence in the literature identifying specific exercise programmes that show a demonstrable change in core strength or lower limb stability in Australian soldiers.

Since lower limb and low back were the predominant injuries found to occur in Australian garrison soldiers (Sellentin and Sanchez. 2011), a specific 12 week exercise programme was designed to encompass both core strength and lower limb stability(Figure 4). The reader may note that many of the exercises combine dynamic core related strengthening with lower limb proprioception exercises, while others specifically target only the core muscles.

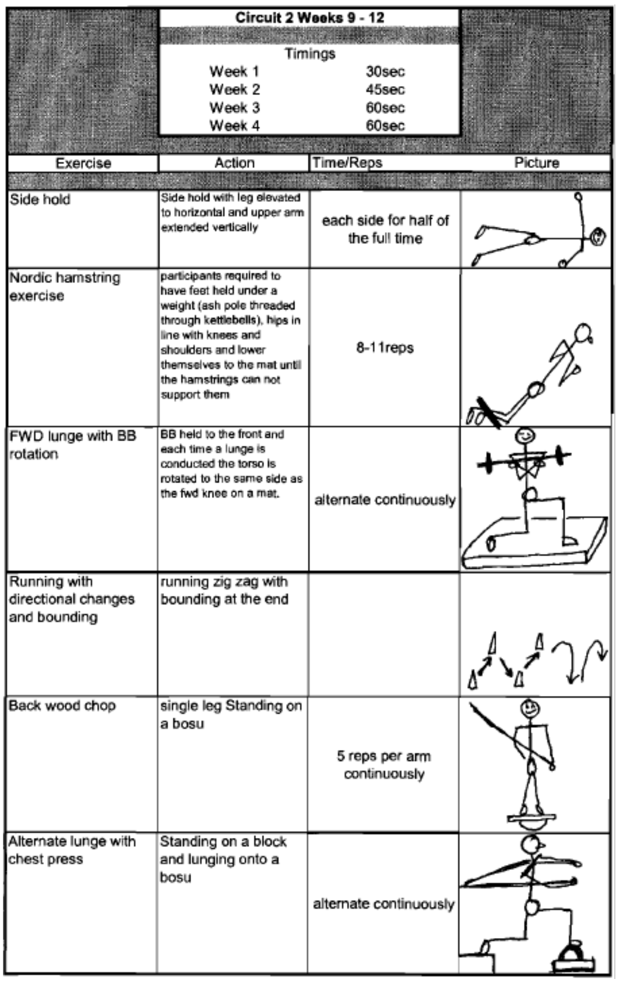
Figure 4.



Circuit 1 Weeks 9 - 12

Timings	
Week 9	30sec
Week 10	45sec
Week 11	60sec
Week 12	60sec

Exercise	Action	Time/Reps	Picture
Prone hold with alternate limb elevation	Elevating opposite arm and leg for time.	each limb for half of the full time	
Box jump with one leg landing	Starting in a squat jumping onto a box, jumping off the box and landing on one foot.		
Split lunge with DB hop.	A weight held in each hand. The lunge is conducted on one leg with the rear leg brought forward into flexion & returning rearward and the stance leg hopping on a mat.	alternate continuously	
Single leg balance with MB pass	Standing on a mat - chest passing to wall and catching.	5 throws per leg continuously - on right and left legs.	
plyometric lunge with MB bounce	Ball is bounced the same side as the fwd knee.	alternate continuously	
High wood chop	Single Standing on bosu.	5 reps per arm continuously	



Circuit 2 Weeks 9 - 12

Timings	
Week 1	30sec
Week 2	45sec
Week 3	60sec
Week 4	60sec

Exercise	Action	Time/Reps	Picture
Side hold	Side hold with leg elevated to horizontal and upper arm extended vertically	each side for half of the full time	
Nordic hamstring exercise	participants required to have feet held under a weight (ash pole threaded through kettlebells), hips in line with knees and shoulders and lower themselves to the mat until the hamstrings can not support them	8-11reps	
FWD lunge with BB rotation	BB held to the front and each time a lunge is conducted the torso is rotated to the same side as the fwd knee on a mat.	alternate continuously	
Running with directional changes and bounding	running zig zag with bounding at the end		
Back wood chop	single leg Standing on a bosu	5 reps per arm continuously	
Alternate lunge with chest press	Standing on a block and lunging onto a bosu	alternate continuously	

Our 12 week programme consisted of exercises that both strengthened and stabilised the spine through a graduated progression of resistance, effort and difficulty. There is an important distinction between strength and stability. To assess stability on its own is very difficult, so the assessment of strength was used in our study. Core strength refers to the ability of the muscle to generate force and power, whereas stability is the inherent result of strength acting on the spine. The greater the strength, together with neuromuscular facilitation, the greater the stability. Core strength was assessed using prone hold, a side hold (left and right), sustained flexor hold and sustained extension.

Bliss and Teeple (2005) explain that dynamic stabilisation refers to the ability to utilise strength and endurance in a functional manner through all planes of motion and action despite changes in the centre of gravity. The SEBT is a test that assesses both lower limb stability and indirectly the functional dynamic stability of the core muscles through the different directions and planes of movement. This will be discussed further.

Hodges and Richardson (1996) and Sharp et al. (2004) advocate that dynamic lumbopelvic stabilisation is achieved through training of both local and global systems. The local system consists of transverse abdominus and multifidi muscles that have direct attachment to the spine and control segmental motion and stability. While the global system consists of rectus abdominus, the internal & external obliques and the thoracic iliocostalis muscles which do not have direct attachment to the spine but through a larger torque, are the prime movers of the trunk. The theoretical basis of core training is to increase the recruitment efficiency and strength of the smaller, deeper ‘stabilising’ muscles of the spine and pelvis (transverse abdominus, multifidus and gluteus medius) and to improved movement patterns and body awareness.

Our 12 week exercise programme was designed to target both the local system using prone hold, side hold and wood chops, and the global system using weight loaded lunges (lunges are an excellent functional dynamic stability exercise, requiring a great deal of co-ordination of trunk and pelvic stabilising muscles). The findings in the Peate et al. (2007) study on core exercises performed on fire-fighters suggested that functional movement enhancement programmes, such as those found in our programme, prevent injuries in high risk workers.

Peripheral neural facilitation (PNF) was incorporated (such as the wood chops) to enhance neuromuscular function and learning, and balance exercises of varying levels of difficulty (such as on a BOSU ball, sponge mats, and single leg stance) were also incorporated to facilitate proprioception. Balance was a large part of our study since proprioceptive training is effective at developing better overall balance and reducing the chance of injury by increasing muscle reaction time and the contraction patterns that favour the correction of excessive inversion (Ross 2006). Furthermore, Zazulak et al.(2007) state “there is strong evidence that neuromuscular control of the trunk and lower extremity can improve with neuromuscular training”. Our study set about to strengthen the core muscles which also assisted lower limb stability, since the inability to transfer forces generated at the core to the extremities can result in decreased efficiency or even injury (Bliss and Teeple, 2005).

Even although the sample size was small, the results from our study show that there were significant effects on re-testing following the conclusion of our exercise programme. The sustained flexor hold test showed significant improvement and the left and right side hold showed a substantial levelling out (Table 1). This strongly supports the premise that the exercises had a direct strengthening effect on the local system. The greater the core strength, the greater the stability to the spine. Akuthota and Nadler (2004) cite Nadler et al. (2002) who found in their study a 47% reduction in the incidence of low back pain in male athletes (although it was not statistically significant) after a core strengthening programme using sit-ups, pelvic tilts, squats, lunges, leg press, dead lifts, hang cleans and roman chair exercises. The importance of a strong core is highlighted by Peate et al. (2007) who state that “current research suggests that decreased core strength may contribute to injuries of the back and extremities [and] that training may decrease muscular damage”. We therefore propose that with the greater trunk strength and stability developed by our subjects following the exercise programme, would produce a concurrent reduction in the risk to low back injury and would have a beneficial effect on lower extremity stability. Further research using a larger population and comparing injury rate between two groups - one group using our exercises and the other who undertake normal PT - would be informative.

Sustained extension showed no change, (mean of 102 seconds) ,in our study. This may possibly be due to the subjects having the maximum extensor strength already (although Brukner and Khan (2006) state that men can hold extension for a mean of 161 seconds) or the sample size was too small to detect a difference in this particular measurement. A study using our exercises on a much larger population might detect greater changes in sustained extension.

Not only does our study demonstrate significant improvements in core strength, but it also shows that static core tests can be a measure of core strength. This is an important finding, since a valid test for core stability is difficult, as indicated in the literature.

Our study also looked at the effect of the 12 week exercise programme on lower limb stability using the SEBT. There were indications that Australian garrison soldiers sustain knee and ankle injuries (Sellentin and Sanchez. 2011) through PT and sports. Enhancing lower limb stability through proprioception and lower limb strength may reduce this occurrence. A study by Pasanen et al. (2008) show that from the types of exercises not too dissimilar to the ones used in our study, showed “significantly fewer non-contact leg injuries (that) occurred in the intervention group than in the control group”. They go on to say that “a neuromuscular training programme was effective in preventing acute non-contact leg injuries in female floorball players…by 66%”. Similar exercise programmes in the literature have established that they can be effective in reducing the risk of lower limb injury “through improving the players’ motor skills and body control as well as preparing the neuromuscular system for sports specific manoeuvres” (Pasanen et al. 2008). Our exercises were similarly designed with the intention of reducing lower extremity injury to Australian soldiers. What has not been shown in the literature is: WHY the incidence of injury is reduced.Our study answers this by showing definitive improvement in areas of balance and lower limb control in our subjects performing the SEBT following our specific exercise programme.

Our study shows that there were improvements in the SEBT Lateral (left and right stance), Anterior (right stance), Medial (right and left stance) reach directions, and significant improvement in all of the Posterior reach directions (left and right stance). This suggests that our 12 week exercise programme had a direct influence on improving lower limb balance through proprioceptive facilitation at the ankle or entire lower limb and/or the improvement in core strength and stability. Zazulak et al. (2007) state that a “decreased core proprioception could alter dynamic knee stability and may explain the risk of knee injury during sports activity". They further state that there is an "association between decreased neuromuscular control of the body's core and increased knee injury risk". Performing our exercises could therefore have a significant reduction in lower extremity injury rates to Australian soldiers, since the SEBT showed significant improvement. The Anterior reach scores, however, made no change and may be attributed to the subject already achieving their maximum reach.

The SEBT was used in our study to reliably detect and measure any changes to the base line objective measures to lower limb stability by comparing before and after data following the 12 week exercise programme. Hertel et al. (2006) identify in their study that the SEBT was "sensitive in detecting functional performance differences related to chronic ankle instability (CAI) both within limbs of individuals with unilateral CAI and between subjects with and without CAI". Hertel et al. (2006) were "able to identify statistically significant differences between limbs with and without CAI". Olmsted et al. (2002) also state that SEBT is "the first non-instrumented, functional tests that have been shown to be both highly reliable and sensitive to deficits between subjects with and without CAI". Although Hertel et al (2006) recommend the use of AM, MD, and PM based on their data, all 8 directions of the SEBT were chosen in our study since we were assessing the whole lower limb, as they suggest, to "identify which reach directions are most appropriate for detecting functional deficits related to other lower extremity pathologies such as anterior knee pain". Furthermore, we were also interested in the effect, if any, of dynamic core strength on balance in all directions.

The use of the SEBT in our study was to identify any lower limb deficits in our subjects, to determine if our subjects fell into the "at risk of lower extremity injury" category, and it was an excellent test to assess the overall global muscle function of each subject. Plisky et al. (2006) state that the SEBT requires other neuromuscular characteristics such as lower extremity coordination, flexibility, and strength and each reach direction activates muscles to a different extent. They also suggest that injury risk is multifactorial and the SEBT requires multiple neuromuscular characteristics that may identify those who are at greater risk for lower extremity injury. The Plisky et al. (2006) study on basketball player injuries showed that the SEBT can predict lower extremity injury. Their results indicated that on the SEBT, a decreased normalised right composite reach distance of equal to or below 94%, and a greater anterior right/left reach difference of 4cm for boys predicted lower extremity injury. Our study shows that before our exercise programme, all eight subjects had an SEBT score below 94%, which may indicate that they were at risk of lower limb injury. After the exercise programme, most of the subjects were above 94% which indicates that the programme provided greater stability to the lower limb and therefore a reduction in the potential risk to lower limb injury. Plisky et al. (2006) suggest that the use of a neuromuscular training programme may improve deficits detected by a SEBT and decrease risk of lower extremity injuries, especially those using disc balance training. Zazulak et al. (2007) also state that "there is strong evidence that neuromuscular control of the trunk and lower extremity can be improved with neuromuscular training". Our current study answers the question expressed in Plisky et al.(2006) on whether the SEBT reach distance improves after completing a neuromuscular training programme.

Olmsted et al. (2002) state that a "dynamic postural stability has been defined as the extent to which a person can lean or reach without moving the feet and still maintain balance". They go on to say that they "believe that performance of the SEBT challenges the subjects limits of stability as he or she maximally reaches and is, thus, at least somewhat indicative of dynamic postural stability". The SEBT may then also measure functional core stability, and its use as a measure is further justified in this study. Olmsted et al. (2002) conclude in their study that SEBT is a "cost-effective tool for assessing functional deficits in a variety of lower extremity conditions…with future research to examine different injured populations" (e.g. anterior cruciate ligament strains and patella-femoral pain syndrome). They also suggested a SEBT study to determine if lower extremity reach improves with rehabilitation would be beneficial. The results from our study have shown this to be the case.

The use of the SEBT in predicting lower extremity injury was advocated by Plisky et al. (2006) in their study on basketball players. Equally, the SEBT could be used as a lower extremity injury predictor for Australian soldiers and recruits. This would save considerable money in injury compensation, rehabilitation, disability and suffering from lower limb injuries in Australian defence personnel by addressing those identified as having lower extremity issues and by providing our exercises to improve their lower limb stability.

A CAIT was used to determine if any of the subjects had functional instability (FI) and if their score improved following the 12 week exercise programme. Three of the eight subjects had a previous history of ankle sprain ("a", "d", and "g"). Subjects "d" and "g" in Table 4 show FI. After the exercise programme, subject "g" indicated greater stability, while "d" had a mixed result with the FI ankle marginally improving and his other ankle score deteriorating (Table 5). Perhaps this could be attributed to a general perception by the subject that both ankles were of equal stability post exercise compared with a much larger difference pre-exercise. Although subject "a" did not indicate FI, his scores also improved as indicated in Table 5. On the other hand, subject "h" decreased score (Table 5) implies that his ankles became more unstable! Looking back over his questionnaire suggests that he might have misinterpreted two of the questions in the follow up questionnaire to give this lower score.

What is significant is that when comparing Table 5 to Table 4 there is a levelling of the scores between the left and right ankles. This could be because of the subject's perception that both ankles had become equally stable instead of one being unstable or the other possibly having to over- compensate. This result has not been previously found in the literature. Interestingly, there was also a levelling a of left and right core imbalances (Table 1), a correlation which possibly adds further to the association between core strength and lower limb stability. Ross (2006) suggests that if there is a deficiency in any area of the synergistic function of muscle and nerve control of the ankle, then a perceived sense of instability may be noted and an altered sense of balance will heighten functional ankle instability because of increased movement at the body's periphery, away from the centre of gravity. This then might help to explain the evening of the CAIT scores in Table 5. He also states that studies have shown balance and coordination training has reduced the chance of recurrent ankle sprains by reducing muscle onset latency of the Anterior Tibialis, Peroneus Longus, Flexor Digitorum Longus, and Posterior Tibialis, but other studies indicate that proprioceptive exercise may not be effective in reducing the chance of ankle sprain. He suggested that more studies were needed to show the overall benefits of proprioceptive exercise for both the stable and unstable ankle. Zazulak et al. (2007) state that interventions that incorporate core neuromuscular training, including proprioceptive exercises, may significantly reduce knee injury risk, although this was supported in their study using female athletes who have a superior ability to control body sway on a single limb compared to men. In our study there appears to be on the whole a greater sense of equalised stability to both ankles, and this might further help to reduce lower limb injuries if the central nervous system has this perception of 'equal balance' where the control and effort is evenly divided to both lower extremities . An additional question added to the follow up CAIT questionnaire asked 'what benefit, if any, have you noticed from doing these exercises?' with all eight subjects answering that they felt that their core muscle strength and lower limb stability had greatly improved.

Should time be a factor regarding training, our exercise programme could possibly be reduced to once a week instead of three times a week and may still be effective. Scutter et al (1995) state that isometric training once per week had the same effect as dynamic training once per week or more often, and stated that Graves et al. (1989) showed that a frequency of training of once per week was as effective as two or three times per week. However, the FIFA 11+ programme upon which our programme is based supports a frequency of at least twice a week.

Possible limitations of our study might be: biases from a single person collecting the data, although an individual might possibly be consistent in the before and after collection of that data; the small sample size may not represent a given population or accurate results; however, even though our sample size was small, significant results were found which might suggest some credence; limited resources for equipment, although standard gym equipment was used consistently throughout our 12 week programme; and the lack of validated and standardised core assessment tests in the literature that we could utilise.

Conclusion

Our 12 week exercise programme using a combination of static core and 'dynamic stability' exercises has supported our hypothesis that it improves core strength and stability. The programme focused on the deep stabilising core muscles which are not recruited in isolation but in an efficient and co-ordinated manner to maintain correct alignment of the spine and pelvis when moving the extremities. Our study has also supported the hypothesis that static core tests are adequately sensitive to detect changes of strength in the core muscles.

Our exercise programme has also shown via the SEBT to enhance lower limb stability by improving core strength and lower limb muscle control (proprioception).

Our study supports our hypothesis that the SEBT can be a measure for ankle and lower limb stability without a history of ankle instability. It can be used as a predictor of lower extremity injury, and as an assessment tool for measuring proprioception based exercises.

The CAIT questionnaire showed a levelling of scores that may indicate a more balanced perception between left and right lower limb stability.

From our results, and on the balance of evidence from other studies regarding the reduction of injury rates using similar programmes, our exercises may be very beneficial in preventing or reducing the rate of low back and lower extremity injury to Australian soldiers.

Future directions for research could be the following: the same study performed on a much larger population of Australian soldiers to assess if similar results are obtained; to study the rate of injury between core exercises and non-core exercises in Australian soldiers; to assess the effect of detraining (i.e. a 12 week intervention followed by a 6-8 week rest from the programme ,which will occur when a unit deploys to a field environment, when the subjects will be retested to see if there has been any degradation of their results); the effect of this exercise programme on a more physically task-orientated population group such as infantry; to assess if performing core exercises just once a week would have the same outcomes since there are competing time interests for all soldiers; to conduct further research in static core tests to validate their use in future research; further investigation into the CAIT and how balance exercises act on perception of stability and how that might relate to injury prevention; and a longitudinal follow-up of the soldiers involved in our study to see if they had maintained their gains or to see if they regain them in a shorter time frame – the gold standard for the effectiveness of the programme.

Acknowledgements

The authors wish to give special thanks to LTCOL McLean, Commanding Officer of 16th Air Defence Regiment, for his support in this study; to the eight subjects who participated in the study; to the 16th Air Defence Regiment PTI, SGT Greg Probyn, for his expert guidance in exercise prescription and valuable assistance in this study; and to the reviewers for their constructive feedback and suggestions.

Authors' affiliations: Australian Defence Force[1] and Queensland University[2]
Corresponding author: Rolf Sellentin
Email: rolf.sellentin@defence.gov.au

References

1. Hertel J, Braham R, Hale S and Olmsted-Kramer L. Simplifying the Star Excursion Balance Test: Analyses of subjects with and without chronic ankle instability. J. Orthop Sports Phys Ther. 2006; vol 36;3:131-137.
2. Plisky P, Rauh M, Kaminski T, and Underwood F. Star Excursion Balance Test as a predictor of lower extremity injury in high school basketball player. J Orthop Sports Phys Ther. 2006; vol 36; number 12; 915.
3. Kibler W, Press J, and Sciascia A. The role of core stability in athletic function. Sports Med. 2006; 36:189-198.
4. Sellentin R and Sanchez P. Review of physiotherapy records to characterise musculoskeletal injury in Australian soldiers in the 16th Air Defence Regiment. J Military Veterans Health. 2011; Vol 19, Num 4.
5. Olmsted L, Carcia C, Hertel J, and Shultz S. Efficacy of the Star Excursion Balance Tests in detecting reach deficits in subjects with chronic ankle instability. J Athl Train. 2002; 37(4); 504, 506, 507).
6. Weir A, Darby J, Inklaar H, Koes B, Bakker E, and Tol J. Core stability: Inter- and intraobserver reliability of 6 clinical tests. Clin J Sport Med 2010; Vol 20; num 1: Jan.
7. Brukner P and Khan K. Clinical sports medicine. McGaw-Hill 3rd Ed. 2006; 162.
8. Bliss L and Teeple P. Core stability: The centrepiece of any training programme. Current Sports Medicine Reports. 2005; 4; 179–183.
9. Pasanen K, Parkkari J, Pasanen M, Hiilloskorpi H, Makinen T, Jarvinen M, and Kannus P. Neuromuscular training and the risk of leg injuries in female floorball players: cluster randomised controlled study. Brit. Med.J 2008;; 337: a295..
10. Coughlan G and Caulfield B. A 4-week neuromuscular training programme and gait patterns at the ankle joint. J Athl Train. 2007. V.42(1); Jan-Mar; 51-59.
11. Scutter S, Fulton I, Trott P, Parnianpour M, Grant R, and Brian C. Effects of various isoresistive training programmes on trunk muscle performance. Clin. Biomech. 1995. Vol. 10, No. 7, 379, 338.
12. O'Sullivan P, Twomey L and Allison G.Evaluation of specific stabilizing exercise in the treatment of chronic low back pain with radiologic diagnosis of spondylolysis or spondylolisthesis. Spine. 1997. Vol22, number 24: 2964.

13. Cholewicke J and McGill S. Mechanical stability of the in vivo lumbar spine: Implications for injury and chronic low back pain. Clin Biomech. 1996; 11: 1-15.
14. Peate W, Bates G, Lunda K, Francis S, Bellamy K. Core strength: A new model for prediction and prevention. J Occ Med and Tox. 2007; 2:3.
15. Hodges P and Richardson C. Inefficient muscular stabilisation of the lumbar spine in association with low back pain: a motor control evaluation of transverse abdominus. Spine. 1996; 21:2640-2650.
16. Sharp R, Olson K, and Maxeiner A. The effectiveness of the pressure biofeedback unit in the treatment of a patient with clinical lumbar spinal instability: a case report. Orthop Phys Ther Pract. 2004; 16;17-21.
17. Ross B. Proprioceptive exercises balance ankle stability and activity. Biomechanics. Oct 2006.
18. Zazulak B, Hewett T, Reeves P, Goldberg B, and Cholewicki J. The effects of core proprioception on knee injury: a prospective biomechanical-epidemiological study. Am J Sport Med. 2007. vol 35, No. 3; 370-372.
19. Akuthota V and Nadler S. Core strengthening. Arch Phys Med Rehabil 2004;85 (3 Suppl 1); S86-92.
20. Nadler SF, Malanga GA, Bartoli LA, Feinberg JH, Prybicien M and Deprince M. Hip muscle imbalance and low back pain in athletes: influence of core strengthening. Med Sci Sports Exerc. 2002; 34: 9-16.
21. Graves J, Pollack M, Foster D, Legget S, Carpenter D, Vuoso R, and Jones A. Effect of training frequency and specificity on isometric lumbar extension strength. Spine. 1989; 15(6) 504-9.