THE EFFECTS OF CORE STRENGTH TRAINING ON CANOEISTS

BY

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DECLARATION

I, the undersigned, hereby declare that the work contained in this thesis is my own original work and that I have not previously in its entirety or in part submitted it at any university for a degree.

Signature:

Date: 29 November 2006

SUMMARY

The aim of this study was to determine the effect of a core strength training program on the core muscle strength and stability of canoeists, and to investigate whether a core strength training program could improve canoe performance.

Twelve canoeists, five men (mean age = 23 ± SD 3.24 years, range 18 - 28) and three women (mean age = 21.3 ± SD 3.23 years, range 18 - 24) formed the experimental group and three men (mean age = 23 ± SD 4.73 years, range 18 - 27) and one woman (21 years) formed the control group. Core stability was tested with five core stability tests and two balance tests. Canoe performance was tested with a six minute sub-maximal canoe test and four minute sprint test on a kayak ergometer. Subjects were tested under stable and unstable conditions for both canoe tests. Testing occurred before and after the intervention program. The experimental group performed two core stability training sessions per week for eight weeks, while the control group continued with their own training programs, which did not include core stability training.

The experimental group showed significant improvements in two of the core stability tests after the intervention program ($p < 0.05$). There were no other significant improvements with any of the other core stability and balance tests in either the experimental or control groups. There were no significant differences in the sprint tests for both the experimental and control group pre-and post-testing. In the sub-maximal test, the experimental group, under unstable conditions, showed a significant improvement in mean power output, with a concomitant non-significant decrease in oxygen consumption, heart rate and minute ventilation after the intervention program ($p < 0.05$).

It appears that a core strength training program may positively affect core stability and improve the paddling economy of a canoeist at a sub-maximal intensity. Choice of exercises in the core strength training program could be a reason for the lack of improvement in the unstable sprint test in the experimental group.

OPSOMMING

Die doel van hierdie studie was om die effek van 'n kernspieroefeningsprogram op die krag en stabiliteit van die kernspiere van roeiers te bepaal, en om te ondersoek of 'n kernspieroefeningsprogram die prestasie van roeiers kan verbeter.

Twaalf roeiers het aan die studie deelgeneem: vyf mans (gemiddelde ouderdom = 23 ± SD 3.24 jaar, reikwydte 18 - 28) en drie dames (gemiddelde ouderdom = 21.3 ± SD 3.23 jaar, reikwydte 18 - 24) die ekperimentele groep; en drie mans (gemiddelde ouderdom = 23 ± SD4.73 jaar, reikwydte 18 - 27) en een dame (21 jaar) in die kontrole groep. Kernstabiliteit is getoets deur die gebruik van vyf kernstabiliteit toetse en twee balanstoetse. Kano prestasie is getoets met 'n ses-minuut submaksimale kano toets, en 'n vier-minuut naellry toets op 'n kayakergometer. Die roeiers was getoets onder stabiele en onstabiele toestande vir albei toetse. Toetse het voor en na die oefenprogram plaasgevind. Die eksperimentele groep het twee kernstabiliteit oefensessies per week vir agt weke bygewoon, terwyl die kontrole groep hulle eie oefenprogram gevolg, het wat geen kernstabilteit oefenige ingesluit het nie.

Die eksperimentele groep het beduidende beter gevaar in twee van die kernstabiliteit toetse na die oefenprogram ($p < 0.05$). Daar was geen ander beduidende verbeterings in die kernstabiliteit en balanstoetse in die ekperimentele of kontrole groep nie. Daar was ook geen beduidende verbeterings in die naellry toetse vir albei die eksperimentele en kontrole groep vir voor-en-na oefenprogram nie. In die submaksimale toets, het die eksperimentele groep onder onstabiele omstandighede, 'n beduidende verbetering vertoon in gemiddelde krag uitset, met 'n afname in suurstofverbruik, hartspoed en minuutventilasie na die oefenprogram ($p < 0.05$).

Dit wil voorkom asof 'n kernspieroefeningsprogram 'n positiewe effek op kernstabiliteit het, wat ook die roei ekonomie van 'n roeier gedurende submaksimale oefenig verbeter. Dit is moontlik die keuse van oefening in die kernspieroefeningsprogram wat die rede is vir die verhoed van verbetering in the onstabiele naellry in die eksperimentele groep.

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LIST OF ABBREVIATIONS

b.min^{-1} : beats per minute
cm : centimeters
EMG : electromyography
EO : *external oblique*
ES : *erector spinae*
et al : and others
Exp : experimental
Fig : figure
HR : heart rate (b.min^{-1})
IAP : intra abdominal pressure
JCA : Japanese canoe association
kg : kilogram(s)
km.h^{-1} : kilometers per hour
LBP : low back pain
L.min^{-1} : litres per minute
m : metre(s)
m/s : metre(s) per seconds
min : minute(s)
mmHG : millimeters mercury
n : number
NCAA : National Colleges of American Athletes
p : probability value
PBU : pressure biofeedback unit
post : post-test
PO : power output (W)
pre : pre-test
RA : *rectus abdominus*
s : second(s)
SBPSCST : Swiss ball prone stabilization core stability test

SD	:	standard deviation
SEM	:	standard error of the mean
TrA	:	*transverse abdominus*
USA	:	United States of America
VCO_2	:	volume of carbon dioxide production
V_E	:	minute ventilation ($L.min^{-1}$)
VO_2	:	oxygen consumption ($L.min^{-1}$)
VO_{2max}	:	maximal oxygen consumption ($mL.kg^{-1}.min^{-1}$)
W	:	Watt

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CHAPTER ONE

Introduction

The strengthening of the core muscles has become a very important aspect of training in all sportsmen. This is evident through the increasing use of swiss balls and unstable training equipment, like foam rollers and wobble boards, to help improve core muscle strength and stability. However, there is much debate about what core stability really is and how to effectively train it.

Core stability has been linked to clinical rehabilitation, training of elite athletes and the improvement of health and physical fitness of individuals (Liemohn et al, 2005). Most coaches and trainers incorporate core training exercises into their training regime, and though the effectiveness of such training programs has been researched (Nadler et al, 2002; Stanton et al, 2004; Liemohn et al, 2005; Tse et al, 2005), results have shown to be inconclusive.

Boyle (2005), a specialist in functional sports training, stated that core stability entails the ability to create extremity movement without compensatory movement at the spine or pelvis. The benefits of preventing compensatory movement are that the athlete can produce or transmit force without energy leaks at the hips, spine or scapula-humeral joints (Boyle, 2005). In light of this, it can be argued that if canoeists improved their core stability, they could optimize their performance during training, since balance on an unstable surface is the main characteristic of the sport.

The nature of effective core training programs and proper testing procedures are also unanswered issues, as there is limited scientific information and research on the topic. It is not known, for instance, how much core training is necessary to cause an improvement in core stability and strength and whether these improvements will translate into better athletic performance. The lack of standardised core stability testing procedures also means that the effects of core training programs have not been quantified yet. Coaches, trainers and athletes can be better served if we know exactly how to train and test core stability and strength.

The aim of this study was not to establish whether core stability training could improve performance, but rather whether it could contribute to developing more stable core muscles in canoeists. If core stability does in fact improve canoe performance, it warrants the inclusion of such training programs in the training regime of canoeists.

Definition of terms:

1. Core stability: A term given to describe the ability of the torso muscles to help stabilise the body during movement.

2. Sub-maximal test: A test that is performed at a set workload for a given time period. The purpose of this test is usually to obtain a measure of the economy of movement.

3. Sprint test: A test in which the subject paddles on a kayak ergometer as fast as possible for a given period of time.

CHAPTER TWO

Literature Review

With the recent increase in awareness about core stability in sports training and the potential to improve performance, several aspects surrounding core stability need to be discussed in greater detail. These aspects include: (A) the definition of core stability; (B) the importance of core stability, especially for canoeists; (C) the testing and evaluation of core stability; (D) the effect of core stability on sport performance and (E) the relationship between core stability and low back pain.

A. Defining core stability

Firstly, the core needs to be defined. The core is usually referred to as the midsection of the body, namely the *abdominals* and the *lower back*. However, Akuthota and Nadler (2004) defined the core as a box with the *abdominals* in the front, *paraspinals* and *gluteals* in the back, the *diaphragm* as the roof, and the *pelvic floor* and *hip musculature* as the bottom.

According to Panjabi (1992), spinal stabilisation is maintained through three subsystems, namely, the passive, active and control subsystems. The passive subsystem is comprised of the osseous and articular structures and the spinal ligaments and their control over the segmental movement. The active subsystem refers to the force-generating capacity of the muscles themselves, which provides mechanical ability to stabilise the spinal segment. The control of these muscles for the requirement of spinal support is described as the neural control subsystem. These three subsystems work interdependently for spinal stabilisation with one capable of compensating for deficits in another.

Due to the fact that the body usually moves in all three planes during physical activity, namely sagital, frontal and transverse, it is important to stabilize the body in all directions. However, many athletes continue to train the more superficial muscles thinking that it will provide the necessary stabilization. Sahrmann (2002) stated that the primary disadvantage of improving the *rectus abdominus* only, is that it can not produce, nor prevent, rotation. Sahrmann (2002) continued to explain that the primary role of the *abdominal* muscles is to provide isometric support and limit the degree of rotation of the trunk. By controlling the range of motion around the trunk, the athlete is more stable in a movement, which conserves energy, as well as limits any potential injuries. The fact that athletes rarely maintain the flexion / extension position of the body during a sport activity / movement, and that one makes full use of rotation, the muscles that rotate the torso need to be trained to provide sufficient support. It is evident that the stabilization of the core is not only necessary, but essential to help improve performance and possibly also to reduce the risk of injury.

Another trunk muscle which serves to stabilise the trunk is the *internal oblique*. In a study by Thorstensson and Daggfeldt (1997), tests were conducted to evaluate intra-abdominal pressure during spinal unloading. The reason for this research was that previous studies on how an increase in intra abdominal pressure (IAP) affects the loading of the lumbar spine during back extension showed contradicting results. The researchers recorded electromyographic activity in subjects performing isolated back extensions and lifting tasks. Their results showed that the *external oblique* and *rectus abdominus* were silent during most tasks, while the *internal oblique* and the *transverse abdominus* (TrA) were most active. This is important to note as most sportsmen persist on exercising the "six-pack" muscles, namely the *rectus abdominus*, through curl-ups and sit-ups. Seeing as very few sports or daily activities remain in the sagital plane, rotational training is important, and therefore should be a part of most training programs.

B. The importance of core stability, especially for canoeists

The core of the body has been dubbed the "powerhouse" from where we generate most of our energy (Handzel, 2003). The core is the centre of the functional kinetic chain, and as such, it seems necessary to ensure that it is stable and strong so that no energy leaks occur. It is for this reason that core stability training is incorporated into athletic training programs.

In a recent review, Warpeha (2004) stated that subjecting the body to unstable surfaces requires additional work from the core region. For example, sitting on a stability ball while raising one foot might prove difficult for a beginner, as the core of the body must now stabilize itself to overcome the instability created by the ball. However, an athlete with advanced core stability can perform an alternating dumbbell shoulder press, while sitting on a Swiss ball with one foot raised off the ground.

Keeping this in mind, the strain placed on canoeists to stabilize themselves before they even begin to paddle is therefore quite apparent. Furthermore, canoeists also need to paddle long distances while maintaining a competitive tempo to ensure a good performance. In addition, there are various obstacles in the water, such as rocks and sand banks, which can impede the canoeist and in turn challenge the canoeist's stability. Changes in the current of a river can also disrupt a canoeist's stability, as the surface now becomes more dynamic and unstable, causing the canoeist to concentrate more on balancing in the canoe. This causes a change in the canoeist's paddling stroke, as more energy is placed on balance and staying in the canoe, and less on maintaining a proper technique and competitive tempo. This can be compared to a rugby player, running more slowly and cautiously on a wet playing field.

In open water canoeing, wind and waves may also affect the canoeist ability to stabilize themselves on the water. Thus, a canoeist with superior core stability will be able to adapt better to these changing conditions and in some cases use it to their advantage to outperform their opponents. Having a weak core region would result in the canoeist tiring more rapidly, and ultimately affecting his/her performance. Stephenson and Swank (2004) explained that functionally, the core muscles are designed to resist fatigue, and that it is therefore necessary to design a program which incorporates core training, such that it is specific to the athlete's demands.

The core further serves as a muscular corset that works as a unit to stabilize the body and spine, with or without limb movement (Akuthota and Nadler, 2004). This is important to note because canoeing is predominately an upper body sport and the legs assist only to rotate the torso during paddling. Because little assistance comes from the legs, it is important that the torso is strong and stable enough to provide sufficient stability so that the canoeist can execute the paddling movement with greatest efficacy. Allen et al (2002) stated that the torso is used actively or as a stabilizer in just about any athletic movement An example of the torso being used actively during a stable environment is golf, where the power is generated from the hips during the rotation in the swing, particularly during the down swing and contact of the golf ball.

The role of the trunk muscles during seated sport positions needs to be addressed to fully understand how important core stability training is for canoeists. A canoeist's base of support while paddling is his/her backside, posterior thighs with the toes giving added support. Thus, the lumbopelvic muscles are under constant strain to ensure stability while paddling. In a study by O'Sullivan et al (2002), the differences in electromyography (EMG) of the lumbopelvic muscles were compared during common standing and sitting postures. 20 healthy and pain-free subjects were tested with surface EMG to measure muscle activity in the *multifidus, internal oblique, rectus abdominus, external oblique* and *thoracic erector spinae* during erect standing and sitting postures and sway standing and slump sitting. The results showed that the *internal oblique, multifidus* and *erector spinae* muscles showed a significant decrease in activity during sway standing ($p = 0.007$, $p = 0.002$, $p = 0.003$, respectively) and slump sitting ($p = 0.007$, $p = 0.012$, $p = 0.003$, respectively) compared to erect sitting. However, the *rectus abdominus* activity increased significantly in sway standing compared to erect standing ($p = 0.005$). Therefore the stabilising muscles of the canoeist need to be trained, especially in the seated position, in order to ensure that they remain active during long periods of training and/or competitions. It is these long hours in the canoe which cause the canoeist to slump in their seat which then ultimately inhibits the stabilising muscles of the lumbopelvic region. If this happens, the canoeist's balance could become jeopardised, resulting in a weaker paddling stroke and consequently a poorer performance.

Additionally, when stabilising the trunk during paddling, certain core muscles assist in the action of the paddle stroke. The rectus *abdominus, erector spinae* and the lateral fibres of the *external oblique* are categorised as mobilizers or "task muscles" which assist in muscle movement (Norris, 1999). The *internal oblique*, medial fibres of the *external oblique* and *quadratus lumborum* also have force producing abilities, however, their primary function is still stability. Lastly, the *transverse abdominus* and the *multifidus* muscles are the primary stabilising muscles of the body. Thus, the importance of training these muscles becomes paramount in developing a stronger core to help stabilize as well as assist in movement for the canoeist. Interestingly, during paddling, the canoeist's stability in the frontal plane is maintained by shifting body mass toward the water contact side at paddle entry and away from it at exit (Mann and Keanrey, 1980). Thus, as the centre of gravity shifts to the side of water contact so does the body. This lateral flexion of the trunk is achieved by the action of the *quadratus lumborum, rectus abdominus* and the *internal* and *external obliques*. This shows the mobilising abilities as well as the stabilising abilities of these trunk muscles and the importance to train them to help improve performance.

Although much is known about how muscles maintain static equilibrium, little is known how they maintain dynamic balance when exerting an external force e.g. paddle stroke of canoeist (Anderson and Behm, 2005). Functional joint stability and its effect on balance are dependent on an integrated local and global muscle function. Comerford and Mottram (2001), have proposed a classification system for muscle function. They defined vertebral muscles as local stabilisers, global stabilisers and global mobilisers. The role of the local stabilisers is to maintain low continuous activity in all positions of joint range and in all directions of joint motion. Global stabilisers generate torque and provide control over some motions. Finally, global mobilisers provide full range of motion around a joint without causing overstrain elsewhere in the movement system. Despite their main function being as movers, global mobilisers do provide support under high load or strain. The normal function of the local muscle system is to provide sufficient segmental stability to the spine while the global muscle system provides the necessary trunk stabilisation and enables the static and dynamic work necessary for daily living and sport activities. Kiefer et al (1997), defines global muscles as acting on the spinal column via the rib cage and the local muscles that are attached directly to the lumbar spine. Seeing as these muscle systems are necessary for normal functioning as well as sporting activities, training these muscles according to their function becomes quite obvious.

The essence of core stability for canoeists is to stabilize the torso sufficiently in order to prevent any excess energy from being wasted and on keeping good posture and position in the canoe. This reserve energy could rather be used to direct all energy into the paddling stroke, which may then improve and enhance overall performance.

C. The testing and evaluation of core stability

To date there are no standardised testing procedures to evaluate core stability. There are only tests which target certain muscles associated with core stability, but nothing that tests the core of the body as a whole. There is thus a need for tests that target more than one muscle, at one time, as the core is considered a group of muscles working together as a unit to stabilize the body.

Tse et al (2005) used four tests to measure core stability. The back extensor test (#1) used was the Biering-Sorensen test which measured low back extensor endurance. The upper body was cantilevered out over a test bench with the lower legs secured. Only the lower body was secured to the test bench while the upper body was unsupported over the edge of the bed. The arms were folded across the chest with the hands held on opposite shoulders. The subject had to maintain this horizontal position for as long as possible. The test ended when the subject fell below the horizontal position. The time taken to successfully maintain this position before the subject fell below the horizontal, was taken as the subject's score.

The abdominal fatigue test (#2) was performed by having the subject sit on a bench with the back support that was at an angle of 60°. Both the knees and hips were flexed at 90° and the feet were fixed securely to the bench with a canvas strap. The arms were folded across the chest with hands placed on opposite shoulders. Subjects leaned against a 4-inch thick rubber pad that was wedged between their back and the 60° back rest. Once the wedge was removed the subjects had to maintain their body position. The test ended when the subject could no longer maintain the 60° angle. The time taken to successfully maintain this position before the subject could no longer maintain the 60° angle was taken as the subject's score.

The third and fourth test was the side bridge test for both sides of the body. The subjects lay on their side with their legs extended. The top foot was placed in front of the lower foot for added support. The subject had to support himself on his elbow, forearm and feet with his hips raised off the ground. The subject had to maintain a straight body position in the frontal plane. The unsupported arm was placed across the chest on the opposite shoulder. The test ended when the subject's hips started to sag and the body position could not be maintained. This test was performed on both sides of the body. The time taken to successfully maintain this position before the subject could no longer keep the desired body position was taken as the subject's score.

In a study done by Liemohn et al (2005), a four-item battery of core stability tests, modelled on typically core stabilization activities used in training and rehabilitation, was developed. 16 university students, free of any orthopaedic disability, volunteered for the study. The researchers used a stability platform to measure core stability. The stability platform is a sensitive instrument that is designed for the measurement of standing balance with the feet placed parallel to the tilt axis. The four tests were administered on four separate days with five trials per test. The testing days were not on consecutive days but rather over a period of two weeks.

The researchers used a quadrupled (subject on hands and knees) arm raise to test the balance and coordination needed for core stability. They tested the subjects parallel and perpendicular to the tilt axis. The arm raise was done to the beat of a metronome set at 40 beats per minute in which the subjects' alternated left and right arm raises from side to side. The subjects were also tested while kneeling on the platform and raising their arms alternatively in time with the metronome which was set at 60 beats per minute. The fourth test was a bridging test, which saw the subjects lying supine on the stability platform with their bodies being supported by their feet and upper back positioned parallel to the tilt axis of the platform. The subjects' hips were raised off the ground and positioned in line with the knees and shoulders. The subjects' arms were placed alongside the body for extra support.

All the above balance tests were of 30 second duration and the tilt limit was set at 5° to either side. Additionally, the clock counter counted the number of seconds within the 10° arc. Additional data that was collected was the number of times the subject was outside the 10° arc during the 30 seconds and ratings of perceived exertion for each test.

The main purpose of the above study (Liemohn et al, 2005) was to develop a measurement regime that would enable us to quantify core stability and maximise internal consistency reliability and stability reliability. The researchers hypothesised that the first day of the four test days and the first trial of each day would show the highest (worst) result. The results showed that repeated test trials on each of the four days produced intraclass correlation coefficients that in most instances exceeded 0.90 and stability reliability coefficients on the third and fourth days of testing exceeded 0.90 for two of the tests (kneeling arm raise and quadrupled arm raise, parallel) and 0.80 for the other two tests (quadrupled arm raise, perpendicular and bridging). This means that to accurately assess core stability, repeated testing must be carried out over several days to improve the reliability of the test results.

Stanton et al (2004) used the Sahrmann core stability tests to evaluate the core stability of runners in their research study. The researchers also used the Swiss ball prone stabilisation core stability test (SBPSCT) to evaluate the subject's core stability.

The Sahrmann core stability test uses five levels to test core stability. The subject lies in the supine position with an inflatable pad of a stabiliser pressure biofeedback unit (PBU) placed under the natural lordotic curve of the subject's back. The pressure is then inflated to 40 mm Hg.

Level one starts with the subject in the crooked lying (supine bridge) position. The subject then raises one leg to a position of 100° of hip flexion with a comfortable knee flexion. Once the desired leg position is attained, the other leg is then raised to the same position without a change of more than 10 mmHg on the PBU. This position of the legs is the starting position for the following levels. The pressure on the PBU is noted and any pressure drop or increase of greater than 10 mmHg, from the 40 mmHg baseline, is an indication of lumbopelvic instability. If a subject maintains control throughout the initial movement, but not during the final movement, a subject receives a score of 0.5 for that test level. For level two, the subject slowly lowers one leg so that the heel contacts the ground and then extends the leg until it is straight. The subject then returns the leg to the starting position. For level three, the subject lowers one leg until about 12 cm above the ground. The leg is then extended until it is straight and then is returned to the starting position. For level four, the test follows the same procedure as level two, except that the subject lowers both legs at the same time. Level five follows the same procedure as level three, except that the subject lowers both legs at the same time. In order for a subject to reach the next level, the lumbar spine has to be maintained, which is indicated by a change of no more than 10 mmHg during each level.

For the SBPCST, the subject positions him/herself in a push-up position with the subject's toes on the vertical apex of a swiss ball. The subject's arms must be locked, with the hands positioned under the shoulders, and is instructed to maintain a neutral spinal curvature as best possible. The subject has to maintain this position for as long as possible. To assist the researchers in calculating the time to failure during the test, subjects were marked with self-adhesive reflective markers. The landmarks on the body were positioned on the right side of the body on: (a) the most lateral border of acromion, (b) the most lateral border of the iliac crest , and (c) the lateral epicondyle of the femur. These markers were used to identify hip flexion angle during video analysis. Failure of this test was when the subject's hip flexion angle was greater than 10°.

During SBPSCST, surface electromyographic data was collected from the *rectus abdominus* (RA), *external oblique* (OE) and the *erector spinae* (ES) on the right side of each subject. The researchers used electomyographic data to investigate whether a six week training program could elicit a greater response to the trunk muscles while a subject performed the core stability exercise. Purton et al (2001) reported that the crunch exercise performed on the swiss ball elicited a greater response in the external oblique when compared to the Ab-roller crunch. Stanton et al (2004), therefore hypothesized that swiss ball training could improve the recruitment of the core muscles. However, the results of this study showed no significant improvement in the RA, EO and ES muscles. Despite these findings, the experimental group showed a significant improvement in time to failure for the SBPSCST.

Cosio-Lima et al (2003) studied the effects of five weeks of physioball core stability and balance exercises compared with conventional floor exercises in women. 30 women were selected according to no prior experience with the physioball exercises or any routine exercise programs. The subjects were then randomly assigned into two groups (control and experimental).

The control group performed the modified curl-up and back extension exercises on the floor. The experimental group performed the same exercises as the control but used a physioball while they performed the exercises. The two groups performed these two exercises, from Monday to Saturday for five weeks under the supervision of a researcher. The volume of the program increased at week one, two and five.

The researchers used the CYBEX Norm machine to test core muscle strength. The subjects were tested before and after the five weeks of abdominal and back training. Abdominal and lower back strength were determined with a five maximal repetition test at 60 degrees per second.

Electromyogram recordings of the RA and ES muscle were taken before beginning and on completion of the training program while performing trunk flexion and extension exercises. The readings were recorded when the experimental group were on the swiss ball and the control group on the floor.

A unilateral leg balance test was also administered to the subjects. In this test, the subject closed both eyes, balanced on one leg and flexed the other knee to 60 degrees. In this study, the subjects all used there right leg to balance on as they all reported right leg dominance. The total time the subject maintained this balance position, was recorded as the test score. This balance test was tested before and after the training program.

The mean positive changes for EMG trunk flexion ($p= 0.04$) and extension ($p= 0.01$) were significantly higher for the experimental group than the control group. The mean changes in leg balance after training was significantly higher in the experimental group than in the control group ($p = 0.0001$) There were no significant differences in mean changes in the CYBEX trunk flexion and extension for either group ($p > 0.05$).

The results of this study showed that unstable training, such as that on a swiss ball, showed a significant improvement in core stability, as tested in this study, compared to training performed on the floor. The results of this study thus validate the use of certain swiss ball exercises to improve an athlete's core muscles.

Tse et al (2005) used four tests to assess core stability of rowers. The back extension and 60° abdominal fatigue tests were performed in the sagital plane, which is the plane that rowing is performed in. Thus these two tests specifically targeted the main core muscles needed during rowing, namely the *erector spinae* and the *rectus abdominus*. However, if the stability platform was used, as in Liemohn et al (2005), the principle of specificity would not be adhered to, when testing core stability for canoeist and rowers. Despite the researchers finding high reliability and validity in their results, the type of exercises they used to evaluate core stability was limited in its function. Very few sports are performed in the quadrupled position, thus the carryover effect the tests have to everyday sport is very small. If for example, the subject was to stand or sit on the stability platform, testing would be more specific. However, in the study by Liemohn et al (2005), the stability platform wasn't tested to see if it was an appropriate apparatus to test core stability, rather the study was to determine which could be the best possible procedure to effectively measure core stability.

The principle of specificity is probably the most important factor that must be taken into consideration when testing core stability. Core stability tests need to challenge the core muscles that are most recruited during that sport/activity. The tests must also challenge the subject in the position most similar to that sport/activity. For example, it is no good testing a golfer's core stability using exercises performed on the ground, when the sport itself is played standing upright.

If we look at the Sahrmann core stability tests, the muscles that were tested were mainly the *abdominals*. These are not the only core muscles used while running, which include the *hip musculature* and *back extensor* muscles. The balance test that Stanton et al (2004) used, was more specific in testing of core stability of runners as it targeted muscles used during running that are needed to maintain balance and stability during a single leg stance, more specially the *gluteus medius* and the *quadratus lumborum*. Possible future tests of a runner's core stability would be to combine the balance test on the stability platform.

The use of electromyography (EMG) looks to be an effective tool to be used in conjunction when testing core stability. The use of biofeedback, like the EMG and PBU, allows the researcher the benefit of assessing the muscle while it functions. Other testing procedures rely on repetitions and time to exhaustion to evaluate performance, which is effective in gauging a subject's performance, but ineffective in seeing whether your exercise or test is actually eliciting a response from the core muscles being targeted. For example, a subject might have strong *hip flexor* muscles which will allow him/her to perform better during the 60° abdominal fatigue test. The subject could therefore maintain the 60° position for longer because he/she has strong *hip flexors* and not because of strong *abdominals*. Thus this test could prove to be ineffective in assessing the core muscles.

A disadvantage with using EMG and stability equipment is the cost involved. Not every researcher has these facilities at hand to effectively test core stability. With this in mind, researchers resort to self-developed test batteries instead.

The importance of the type of tests used when testing core stability is paramount. With every sport using different muscles at different times, as well as being performed in various positions and in dynamic environments, choosing exercises and tests for core stability is a hard task. The fact that there is no standardised testing procedure for core stability leaves the testing field wide open. Ultimately core stability tests need to test the core in the best manner possible, with regards to that sport/activity. With ongoing studies, we are hopefully moving towards the development of standardised core stability tests, to accurately and effectively assess core stability and strength.

D. Core stability and sport performance

Tse et al (2005) studied the effectiveness of an eight week core endurance intervention program in college-age rowers. 45 rowers took part in the study, where 25 rowers were assigned to the experimental group and the other 20 to the control group. The reason that the subjects were assigned to the groups, was because the subjects were busy training for an interuniversity rowing competition and therefore preferred to remain with their own teams in the testing and training program. The experimental group underwent a trunk training program where the subjects trained two days per week for eight weeks, under supervision of a researcher. The control group did not receive any trunk training, however, due to their existing rowing program, they performed trunk exercises like: bent-knee sit-ups and back extension, two times a week. Before and after the training program, the subjects performed four trunk endurance tests (see description on page 7 and 8) and a variety of functional performance measures were also assessed. One of these performance tests was a 2000m maximal rowing ergometer test which is the standard performance test for rowing.

For the abdominal fatigue test, there was no significant difference ($p > 0.05$) between the core training group and the control group. Both the left and right side bridge results showed no significant difference between the core group and control group. There was no main effect of group for the back extensor tests ($p > 0.05$). There was no significant between-group or within-group differences ($p > 0.05$) for any of the performance parameters, nor were there any interactions for any of the measures. The results of this research showed that although training of the core muscles have improved the core muscle strength and stability of the rowers, this improvement did not translate to improved athletic performance.

In a similar study, Stanton et al (2004) evaluated the effectiveness of a short-term Swiss ball training program on the core stability and running economy of 18 young male athletes. After initial testing, the subjects were assigned to experimental and control groups. Nine subjects formed the intervention group who underwent a six week Swiss ball training program. The training program consisted of two sessions of core stability training per week, which was supervised by one of the researchers. During the intervention program both groups continued with their normal physical training, which included skills training and run-based conditioning. The athletes were assessed before and after the training program for core stability, electromyography activity of the abdominals and back muscles (see description on page 8 and 9), running posture, treadmill VO_{2max} and running economy.

Electromyography activity data was collected from the *rectus abdominus, external oblique* and the *erector spinae* on the right side of each participant. The data was collected while the subjects performed the SBPSCST. The purpose of the EMG was to assess whether there would be an increase in core muscle activity after the swiss ball training program. The results showed a significant change for the experimental group after training ($p < 0.05$). Furthermore, there was a significant difference in EMG activity between the experimental and control group following training ($p < 0.05$).

Running economy was calculated using linear regression analysis. A graph of VO_2 versus running speed was plotted and the regression equation for the line of best fit was used to calculate running economy at 60, 70, 80 and 90% of maximal treadmill velocity as determined with a standardised VO_{2max} test. The results showed a significant improvement in core stability, as measured by the Sahrmann test, between the pre and post test for the experimental group ($p < 0.05$). There was also a significant difference between the groups following the training program ($p < 0.05$). There was a significant improvement in time to failure for the SBPSCST, between the pre- and post-tests for the experimental group ($p < 0.05$). Furthermore, there was a significant between-group difference following the training program ($p < 0.05$). However, despite the significant improvements in core stability, there was no significant change in the running economy in either the experimental or control group.

That fact that the performance parameters in both of these studies (Tse et al, 2005 and Stanton et al, 2004) did not improve after the training program is unfortunate, but nevertheless fine, as the aim of core training programs is to primarily improve core stability. Any carryover effect it has on performance is an added bonus. If core training doesn't improve athletic performance, a possible benefit of a stronger core could be to prevent or reduce low back pain (LBP) or any other injuries. If this was the case, the inclusion of a core stability training program should be essential to all athletes' training programs.

One could, however, argue that the core stability of all the subjects in the previous studies, were not challenged adequately, or perhaps not at all. Both of these studies included tests that were performed under "stable" conditions. The 2000m maximal rowing ergometer test and the running economy test are performed in a laboratory under a stable/constant environment. If the 2000m maximal rowing test was also performed in the field, then there might have been a difference in results as the testing environment is now more dynamic, which would require a greater demand of the core muscles to help stabilise. By doing this, the effects of a core training program could be properly assessed against field performance tests.

Running economy was also assessed by linear regression from a VO_{2max} test. The fact that the subjects never ran at steady workloads throughout the test, means that the subjects never attained true homeostasis or sub-maximal consistency. In the VO_{2max} test, the subject had a five minute warm-up at 7 $km.h^{-1}$ from which the running speed commenced at 8 $km.h^{-1}$. The workload was then increased by one $km.h^{-1}$, every minute, until volitional fatigue. Thus as soon as the subjects adjusted to the current workload, it was increased, which caused a greater physiological demand on the subjects. If the running economy was tested properly (i.e. longer workload intervals), the effects of core stability might have had a different outcome on the results. The closer a test simulates the movement/activity of that sport, the more credible the results. This will also allow the effects of the training program to be more closely observed on the performance tests. This is important to note for future research on core stability.

Although it is widely believed that superior core strength and stability enhances sports performance, this relationship has not yet been scientifically investigated in canoeing. In the current study, a novel test battery was constructed to evaluate the effectiveness of a core strength training program. The aim was to demonstrate whether an eight week core training program can significantly improve core stability and perhaps canoe performance.

E. Core stability and low back pain

Experts agree that core stability plays a significant role, not only in the athlete's movements, but also during everyday activities (Handzel, 2003). McGill (2001) advises that stability and flexibility training should take precedence over strength training for the core muscles for both athletes of all sports and those in need of back rehabilitation. During daily activities as well as during strenuous exercise, the spine can buckle or rotate at a segmental level. McGill (2001) also contends that stability and flexibility training be incorporated so that the muscles controlling spinal stability adapt to the stress associated with spinal stability. Furthermore, he also stated that flexibility training of the core musculature is necessary to ensure strengthening of the spine. The stability of the spine depends on the flexibility of the spinal muscles; therefore there is no use in training the core muscles, unless there is sufficient range of motion of the spine which will benefit from core stability training.

There is a debate about whether core training can help those that have low back pain (LBP). People with LBP are primarily those that are inactive, and/or sit at a desk all day resulting in poor posture and positioning. Hodges and Richardson (1996) discovered that over time, poor posture may result in the inactivation of the TrA, which is one of the more important core muscles. The purpose of their study was to evaluate the temporal sequence of the trunk muscle activity associated with arm movement and to observe whether the dysfunction of this parameter was present in LBP patients. 15 patients with LBP and 15 matched control subjects performed rapid shoulder flexion, abduction and extension in response to visual cues. Electromyographic activity of the *abdominal* muscles, *lumbar mutifidus* and contra lateral *deltoid* muscle was measured using fine-wire and surface electrodes. The results showed that the trunk muscles contracted before or shortly after the deltoid in the control group, when the arm was moved in every direction. The TrA was the first muscle that was active and it was not influenced by direction of the arm movement. The results also showed that the contraction of the TrA was significantly delayed in patients with LBP in all directions.

From this research study it can be stated that the TrA has an important role in the stabilization of the torso during rapid upper body movements, such as in canoeing. So to ensure that the canoeists are more stable in their canoes, the TrA must be trained to stay active at all times while they are paddling. Essentially a TrA with a high endurance will benefit a canoeist as it will maintain stabilisation of the trunk for a longer period of time. Moreover, an active TrA may help prevent or reduce any back pain that is experienced during paddling.

An important aspect of a canoeist's performance is the duration of the race, and as most races can last up to several hours, back pain can occur. There are several contributing factors which can cause back pain during the race; one of these includes the position in which a canoeist sits, as was also observed during the testing of the subjects in the current study. The subjects exhibited a hunched over position, resulting in a shortened anterior trunk and a stretched posterior trunk. The subject's pelvis was also tilted in a posterior position. McGill (2001) believes that adopting a posterior tilt when performing many types of low back exercises, actually increases the risk of injury by flexing the lumbar joints and loading passive tissues.

Kameyama et al (1999) researched the frequency and type of injuries that competitive canoeists sustain during canoeing. A sports injury questionnaire was sent out to the members of the Japanese canoe association (JCA). They also performed a medical check on the top 63 canoeists of the JCA, including laboratory and physical tests and radiographic examinations of the spine, chest, shoulder, elbow and wrist joints. Of the

417 questionnaires that were completed 94 (22.5%) reported that they experienced lumbago (sciatica), while 20.9% experienced shoulder problems. On medical examination, lumbago was found to be mainly of myofascial origin or due to spondylolysis. Impingement syndrome was found in four of the canoeists with shoulder problems. From this study it may be concluded that low back pain is a prevalent medical condition in competitive canoeists.

Schoen and Stano (2002) did a survey on equipment used, paddling style and injury rates and patterns of injuries sustained during canoeing and kayaking. The survey was handed out to all the canoe and kayak clubs in the USA. The survey included questions on demographics, paddling style and equipment, acute injuries, and chronic injures. From a total of 319 respondents, 388 acute and 286 chronic injuries were reported. This amounted to 2.1 injuries per person. The shoulder and arm was the most common site of injuries. Interestingly, men reported more acute back injuries than women (80.5% vs 19.5%) whereas women reported more chronic back, chest and hip injuries (37% vs 64%). With back injuries sustained through paddling, 2.4% were acute and 16.5% were chronic. Both these values were reported as the least amount of injuries compared to other injuries. However, both the acute and chronic back injuries featured the longest in the time to recover over 24 month period. 9.5% of the acute back injuries and 40.5% of the chronic back injuries took more than 24 months to recover. These figures show that if a canoeist sustains an injury to his/her back, the recovery time can take up to two years before he/she can resume normal paddling.

Nadler et al (1998) noted that athletes with lower extremity overuse or acquired ligamentous injuries were significantly more likely to require treatment for LBP. Therefore in 2002, Nadler et al investigated the occurrence of LBP before and after incorporating a core-strengthening program in NCAA Division I Collegiate athletes. 236 athletes received the core strengthening program. All athletes performed a 30 to 45 minute program, four to five times a week in preseason and two to three times per week during the inseason. The program included sit-ups, pelvic tilts, squats, lunges, leg presses, dead lifts, hang cleans, and Roman chair exercises.

Although there was a reduction in LBP occurrence in males after incorporating the core strengthening program, this was not a statistically significant decrease. Specifically, LBP decreased from 8% in the 1998-1999 season, to 4.3% in the 1999-2000 season, in males. There was, however, an increase in occurrence of LBP in female athletes from 7.9% to 9%. The reason for the negative effect of the program in the women could be as a result of the choice of exercises in the training program or that the exercises needed to be modified to accommodate females. Unsafe exercises, such as the Roman chair were used, while no rotational exercises were included in the core training program. The other exercises that were used, which were also performed only in the frontal and sagital plane, could have included rotational movements. For example, a lunge with a twist would be a good example.

The results of the core strengthening program showed no advantage in using the program to reduce occurrence of LBP, but this could be contributed to the small numbers of subjects with LBP that were treated. Larger numbers of subjects with LBP need to be treated in order to validate the results of this study and the overall effects of core training on LBP.

Research on core stability and the effects on sports performance are very limited. There are only a few studies advocating the use of core training to help an athlete's performance, otherwise most information comes from anecdotes from coaches and trainers. Furthermore, no studies guarantee that core stability will improve sports performance, however, there are studies showing improved core stability after various core training programs (Stanton et al, 2004). More research needs to be conducted on core stability and the effects it has on sports performance. Due to the fact that previous research have indicated that certain stabilizing muscles have a role in stabilising the torso which may improve or prevent LBP, and that there are other core muscles responsible for stabilisation, the importance of core training on athletic performance needs to be investigated more intensively.

CHAPTER THREE

Statement of the problem

When training to improve canoe performance, many athletes and trainers prescribe cardiovascular training such as running and cycling. In conjunction with this type of training, canoeists generally paddle to improve canoe performance. Whether this is high-intensity sprint training or low-intensity endurance training, canoe training programs are limited to time on the water. Thus the need to explore other areas of training to improve canoe performance is warranted. Seeing as the paddling stroke requires strong balance from the torso as well as rotational movement, training the core to be more stable and more powerful could be essential to attain excellence.

The primary aim of this research study was to evaluate the effect of a core strength training program on the core muscle strength and stability of canoeists. The secondary aim of the study was to determine if the effects of core stability training translates to improved sub-maximal and maximal canoe performance. This study is motivated by the increasing use of core stability programs to help improve sports conditioning in athletes and for rehabilitation purposes.

If core training can improve canoe performance, there is a great need to develop training programs that will benefit the canoeist's performance. Even if core stability does not directly result in improved canoe performance, it may promote a healthy spine and thus reduce the risk of acute and/or chronic injuries.

CHAPTER FOUR

Methodology

A. Study design

This study involves a pre-and post-test experimental research design with the aim to determine the effectiveness of a core strength training program to improve the core muscle strength and stability as well as the athletic performance, of club level canoeists.

B. Subjects

The Matie Canoe club of Stellenbosch University was approached to assist in recruiting volunteers. All procedures as stated in the consent form (Appendix A) were explained and the opportunity for questions was given. Only those that signed the consent form were illegible for the study. The following in-and exclusion criteria were applied to finalise the group of volunteers:

1. Inclusion criteria

1.1. A minimum participation in competitive canoeing locally and/or internationally for at least two years.

1.2. Training frequency of at least twice per week.

1.3. No chronic back pain or other sporting injuries, at the time of baseline testing.

2. Exclusion criteria

2.1. Development of back pain during the training program.

2.2. Subjects who could not perform tests or exercises in the required time period due to illness, injury or other responsibilities.

Twelve canoeists qualified for the study. Of those, five men (mean age = 23.0 ± SD 3.24 years, range 18 - 28) and three women (mean age = 21.3 ± SD 3.23 years, range 18 - 24) formed the experimental group and three men (mean age = 23.1 ± SD 4.73 years, range 18 - 27) and one woman (21 years) formed the control group. Due to logistical reasons, groups were not randomly assigned.

3. Ethical aspects

Only canoeists, who gave their voluntary, oral and written consent, were included in the study. All results were handled confidentially and were only available to the individual concerned. Each subject also completed a general health questionnaire to exclude any disorders or conditions that might affect the outcomes of the study.

C. Testing procedure

Each of the twelve test subjects visited the Sport Physiology laboratory on separate days to perform the test exercises. There were four test dates in total that the subjects had to attend. Each subject set a time and date for each testing day with the researcher; the test dates had to be separated by at least 24 hours. Each subject performed the canoe test session first, and then on another day performed the balance and core stability tests. All the subjects followed this testing schedule.

No invasive procedures were performed in any of the tests in the study. All measurements were tests which form part of a standardised fitness evaluation of athletes.

1. Testing requirements

1.1 All tests on different days were conducted more or less at similar times of the day.

1.2 Subjects adhered to their normal diet throughout the duration of the study.

1.3 Subjects were requested not to engage in strenuous activity on the day of the testing.

1.4 Subjects were requested that they limited their training intensity to moderate levels on the days prior to testing and if they had exercised the day before, that they had completed exercising at least 15 hours before the onset of the test to ensure sufficient rest.

1.6. There was a familiarisation session for the stability testing. The researcher ensured that all subjects were able to execute the tests correctly on all apparatus.

D. Measurements and tests

1. Kinanthropometric tests

1.1 Standing height

Standing height was measured with an anthropometer placed vertically against the wall and perpendicular to the floor. The subject stood with his/her back and heels against the wall/anthropometer. The midline of the body was in-line with the anthropometer behind the subject. The measurement was taken at the point where the calliper was placed firmly on the vertex of the head, while the head was in the Frankfort plane and the subject was instructed to take a deep breath. The measurement was taken to the nearest 0.1 cm.

1.2 Body weight

Body weight was measured with a BW-150 freeweight electronic scale to the nearest 0.1 kg. Subjects were dressed in their appropriate exercise clothes for testing on the K1 Ergo and without shoes.

1.3 Body fat percentage

Bio-electrical impedance analysis using the Bodystat meter was used to measure body fat percentage. To ensure an accurate reading from the Bodystat meter the subjects had to adhere to certain requirements: refrain from any exercise 24 hours in advance, no caffeine intake on the day of testing, limited fluid intake an hour before testing and an empty bladder. These requirements were only for the Bodystat testing and did not influence the requirements for the kayak testing (as described on page 21). After body weight and height was measured the subjects were instructed to lie on their back on an examination bed. The subjects were instructed to remove all jewellery and position themselves so that no body part was touching another. An alcohol-based cleaning fluid was used to sanitise the surface of the skin where the electrodes were placed. The four sites at which the electrodes were placed are: proximal to the middle knuckle on the right hand; proximal to the second toe on the right foot; centre of the two epicondyles on the right wrist and centre of the two epicondyles on the right ankle. During the testing, the subjects remained still as any movement could lead to incorrect readings.

Outcome variables: Standing height (cm), body weight (kg) and body fat percentage (%) was used for analysis.

E. Exercise tests

There were two pre-tests performed on a kayak ergometer, followed by an eight week intervention program and then another two post-tests on the kayak ergometer. One test was performed under so-called “stable” conditions and the other under “unstable” conditions. The order of the “stable” and “unstable” tests was randomly allocated for each subject.

The unstable test was performed on the kayak ergometer while sitting on an inflatable cushion. The instability caused by the cushion simulated the unstable surface of the water when paddling. The aim of the unstable test was to subject the canoeist to a more stressful environment, which we hypothesise, would cause a difference in the test results between the stable and unstable testing. The stable condition was the normal seating position of the kayak ergometer.

The exercise test consisted of a six minute sub-maximal test, followed by a four minute sprint test on an air-braked kayak ergometer (K1 Ergo, Australian Sports Commision). There was a two minute rest period between the sub-maximal and sprint test.

Each subject was individually positioned on the kayak ergometer. The foot rest was adjusted to a suitable distance and this position was recorded for future testing. The subject then had a practise period to accustom himself/herself to the ergo. During this practise period, the subject paddled until they reached a power output of 150 W for men and 80 W for women, so as to feel how fast to paddle to reach the set value, prescribed for the sub-maximal test. Besides this practise paddle no warm-up was prescribed to any subject at the start of the testing. Once the subject had finished their practise paddle, the researcher fixed a heart rate monitor around the subject's trunk. The heart rate monitor was tight enough so as not to slip down when the subject breathed deeply.

The main aim of the six minute sub-maximal test was to test the paddling economy of the canoeist while they paddled at their given sub-maximal worload. Economy was defined as the oxygen consumption, heart rate and minute ventilation at the given sub-maximal workload. After the subjects had positioned themselves on the kayak, they were connected to the Cosmed Quark b^2 cardiopulmonary system via a mask which was firmly attached to their head. Through the mask the canoeist's minute ventilation (V_E), oxygen consumption (VO_2) and carbon dioxide production (VCO_2) were measured while the heart rate was measured by telemetry (Polar HR monitor) throughout the sub-maximal test. The K1 ergo was also interfaced with a PC monitor system through which the power output were recorded. There was no verbal motivation during the sub-maximal tests. The mean temperature and humidity in the laboratory was 20.2 SD ± 3.57 °C and 53.9 ± SD 10.46 % for all testing days (range: 15 - 27 °C and 37 - 77 %)

Once the subjects had completed the six minute sub-maximal test, the mask was removed and they were given a two minute rest period to walk around, catch their breath, and drink some fluid if they wished.

For the four minute sprint test, the subject positioned himself/herself on the kayak ergometer before the two minute rest period was finished. Once the rest period was completed the subject started to paddle as fast as possible and attempted to maintain that tempo as best possible. The aim of the sprint test was to generate as much power as possible for the four minutes. During each sprint test, verbal motivation was given to each subject.

Once the subject had completed their four minute sprint test, they were given a 30 minute rest period, after which they would perform the other stable or unstable sub-maximal and sprint test. The 30 minutes rest period was sufficient rest for the subjects to return to baseline levels. During this period the subjects rested, read, drank fluid and were taught how to activate the TrA muscle.

Outcome variables:

Sub-maximal: Heart rate ($b.min^{-1}$), Minute Ventilation ($L.min^{-1}$) and Oxygen Consumption ($mL.kg^{-1}.min^{-1}$)
Sprint: Average Power output (Watts)

During the 30 minute rest period, each subject was taught how to correctly activate their TrA. The aim of teaching the subjects to activate the TrA was to familiarise them with core stability techniques for use during the training programme. (Boyle, 2005) stated that the TrA needs to be activated to help train the deep abdominal muscles which stabilize the trunk of the body. Hodges and Richardson (1996) concluded that the TrA contracts before or concomitantly to any other muscle during a movement / action. Therefore under these findings, the subject's TrA would instinctively activate to help stabilise them without outside assistance. However, teaching the subjects to consciously activate their TrA would encourage them to keep their abdominal section contracted which would help them during testing.

Three exercise techniques were used to activate their TrA. Firstly, the subject would lie supine on a massage bed, with his/her knees and hips flexed but with his/her feet flat on the bed. The subject's arms were placed at his/her side. The subject was instructed to relax his/her body and take a deep breath, as he/she breathed out he/she had to pull his/her belly button inwards, towards the spine. The subject would continue to hold this contraction while continuing normal breathing. The emphasis of the contraction was on endurance and not on strength, as the TrA muscle is a stabilising muscle of which its primary purpose is to maintain posture. Therefore the subjects were instructed not to pull the belly button in as strongly as possible, but rather as firm and long as possible. This action would correctly activate the TrA. The subject performed this five times in row. The subject then placed his/her index finger proximal to his/her *iliac crest* bone, and performed the technique again. When the TrA was activated, the subject could palpitate the TrA with his/her finger. This biofeedback helped the subject to activate the muscle correctly and understand its function better. Secondly, the subject was instructed to position himself/herself in the quadrupled prone position, on all fours. The subject was instructed to maintain a neutral spine and to completely relax his/her stomach, and to let his/her stomach contents weigh down on the stomach muscles. The researcher then placed his palm under the stomach of the subject. The subject then inhaled a deep breath and as he/she exhaled, pulled his/her stomach off the researcher's hand. During this technique there was to be no spinal movement at all. Any spinal movement showed that the subject was using other muscles to pull in the stomach and not the TrA. The subject performed 10 repetitions in a row.

The last exercise technique to activate the TrA, saw the subject positioned on his/her knees on the examination bed with his/her hips and arms extended, and his/her hands clasped together above their head. The subject then performed the same breathing technique as described above, to activate the TrA. The subject performed 10 repetitions.

There was no set rest period between the three exercise techniques or repetitions. Subjects performed them in their own time while under supervision of researcher.

F. Test battery for balance and core stability

Due to the lack of core stability tests, especially for canoeists, a self-developed test battery was designed to evaluate the core stability of the canoeists. The test battery consisted of two balance tests and five core stability tests (Appendix C).

There were two reasons for the inclusion of balance tests in the test battery. Firstly, to see if a core strength training program could improve balance, and secondly, to see if the balance exhibited by a canoeist on water, could be translated to other areas of balance. Both the balance tests were performed under unstable conditions, the reason being that canoeists paddle under unstable conditions, which should hypothetically make their balance more advanced. Therefore the balance tests needed to be more complex to challenge the canoeists.

The exercises for the core stability tests were developed to best test the core stability of canoeists, in the same manner the muscles function when paddling. The exercises targeted the specific *rectus abdominus, internal and external obliques, transverse abdominus, multifidus, quadratus lumburum, erector spinae* and *shoulder stabilizers (supraspinatus, infraspinatus, teres minor and subscapularis)* muscles needed to stabilise the torso while paddling. The walk out and lateral sway tests also made use of unstable equipment, like the swiss ball, to increase the demands placed on the canoeists to maintain balance and control. The use of a myometer in the one minute modified lying leg lifts, allowed for biofeedback during the test, allowing the researcher to observe whether the subjects were effectively using their trunk muscles whilst executing the exercise.

Two factors need to be taken into consideration when developing core stability tests for canoeists: it is a water based sport and it is performed in a seated position. The use of unstable apparatus can be used to simulate the instability of water but there are very few methods currently available to test athletes in the seated position. It is therefore difficult to develop exercises that will effectively test canoeists' core stability when taking these two factors into consideration. Hopefully, further research will find answers to these two problems.

1. Balance tests

Each subject performed two balance tests. These balance tests were performed before and after the intervention.

1.1. Swiss ball balance test

In the first test the subject had to balance on his/her knees on a 65 cm swiss ball, holding a wooden bar above his/her head, for a maximum of 60 seconds. The subject knelt on the ball so that there was a 90 degree angle at his/her knee joint. The subject had to maintain a neutral spine with the wooden bar above his/her head. Once he/she attained this position the time started. Each individual was given two attempts and the best time of the two attempts was taken.

1.2. Wobble board balance test

The second test was performed on a wobble board. The subject had to position his/her feet evenly on the board and maintain a standing position without allowing the board to tip and touch the floor. The subject had to balance for a minute and every touch was counted. Each subject had two attempts and the score with the least amount of contacts was taken as the final result.

Before the subject attempted either exercise they were given a practise session to familiarise themselves with the exercise. These practise sessions were 30 seconds each. A rest period of one minute was given between each exercise attempt and a two minute rest period between the wobble board and swiss ball test.

2. Stability tests

The purpose of the stability tests was to assess the strength and endurance of the core musculature responsible for total body stability. A self-developed test battery was used to assess the strength and endurance of the core musculature. The tests included in the test battery were designed to target the core muscles needed while paddling in a canoe. Exercises were developed according to the position of the canoeist in his/her canoe; the movement of the canoeist during the paddling stroke; and the primary muscles involved to help stabilize the canoeist while paddling.

2.1 Stability test battery

All tests were performed with the subjects clothed in tight-fitted clothes so that body posture and positioning could be observed at all times. Exercises performed on the floor were done on gymnastic mats. Other equipment used: 35 cm bench, stopwatch, blood pressure cuff, masking tape, 65 cm swiss ball, one-and-a-half metre wooden bar and 15 cm ball.

Each of the stability exercises were performed twice. There were no practise attempts in any of the exercises. There was a one minute rest period between each attempt and a two minute interval between each test.

2.1.1 One minute walk out

The purpose of this test was to test the endurance and strength of the *spinal erectors, gluteal maximus ,rectus abdominus, internal and external obliques* and shoulder stabilizers*(supraspinatus, infraspinatus, teres minor and subscapularis), transverse* *abdominus and erector spinae* in the sagital plane. The subject was to move with the swiss ball in the sagital plane. Markers (stickers) were placed on the lateral shoulder, hip and ankle joints on the side of observation. The subject was instructed to: kneel behind the ball, lie trunk over ball and place hands on the floor under the shoulders. The subject then walked out on his/her hands letting the ball roll down the body until the pelvis was on the ball (starting position). The subject then walked out on his/her hands letting the ball roll down the body until his/her shins were on the middle part of the ball (end position). The subject then returned to the starting position.

A line was drawn at the third fingertips on the floor at the starting position and the end position with masking tape. The subject performed as many repetitions possible in one minute. Repetitions were counted for exactly one minute with the help of a stopwatch. A repetition was not counted if: (1) the subject did not touch the line with their third fingertips at the end position, (2) the elbows were not in line under the shoulder joints at the end position, (3) the whole body with arms perpendicular to the floor were not behind the line at the starting position before continuing with the next repetition, (4) the hips, shoulder and knee joints were out of line (hips sagging). The subject received one warning for incorrect technique. If the subject fell off the ball at any time during the test, the subject was instructed to continue with the test as the time would not be stopped.

2.1.2 <u>One minute modified lying leg lifts</u>

The purpose of this test was to test the endurance of the *transverse abdominus* and *rectus abdominus and iliopsoas* muscles. The subject was instructed to: Lie supine with a myometer placed under the hollow part of the back. The subject lifted up his/her legs with hips and knees at a 90 degree angle with trunk (starting position). The subject pushed his/her lower back into the floor while lowering one leg at a time, keeping the bent knee position, straight down to the floor until the heel of the foot touched the floor. Once the heel touched the floor the subject returned the leg to the starting position. The subject then proceeded to lower the other leg to the floor. The subject would perform as many repetitions possible in one minute.

In the starting position, 80 mmHg of air was pumped into the airbag of the myometer cuff; this was the same pressure value for all subjects. The pressure had to stay above 40 mmHg, otherwise a repetition would not be counted. Repetitions were counted for exactly one minute. A repetition was not counted if: (1) the subject's foot did not touch the floor, (2) the pressure on the myometer dropped to a value lower than the prescribed threshold pressure and (3) the other leg moved from its position. The subjects received one warning for incorrect technique throughout the test.

2.1.3. Prone isometric extension

The purpose of this test was to test the endurance of the *multifidus*, *erector spinae*, *shoulder stabilizers* (*supraspinatus, infraspinatus, teres minor and subscapularis*) and *transverse abdominus* muscles. The subject was instructed to kneel behind the 35 cm bench and place the 15 cm ball between his/her thighs above the knees. The subject then positioned his/her hip bones in the middle of the bench, lay prone, and extended the legs and arms straight out. The subject had to maintain this position for one minute. Once the subject attained the extended position, a one-and-a-half metre wooden bar was placed along the length of the subject's spine. The bar showed any movement of the spinal column, which would deter from the neutral position.

Time started when the bar was in position. The time stopped when (1) the subject could no longer maintain the desired position, (2) the subject could not continue to maintain the neutral spine curvature or (3) if the subject voluntarily quitted. The subjects received one warning for incorrect technique throughout the test.

2.1.4. Lateral ball sway

This exercise tested the subject's ability to move laterally in a horizontal position. The muscles targeted in this exercise were the *internal and external obliques, transverse abdominus, quadratus lumborum*. The subject was instructed to: position himself/herself in a bridge position with his/her knees 90 degrees and perpendicular to the floor with his/her shoulders and neck supported by the 65 cm swiss ball. The subject's arms were abducted to the side, parallel to the floor, with palms facing upwards. The subject's knee, hip and shoulder joint were in one line. Once this position was attained the wooden bar was positioned across the subject's hip bones. This was the starting position.

From this position he/she had to move laterally without dropping his/her hips or shoulders. The subject would move sideways until his/her shoulder was off the ball. This was the end position and counted as a repetition. The subject then had to return to the starting position. The subject had to perform as many repetitions as possible in one minute. A one minute rest period was given between the left and right sides. The total amount of repetitions performed in one minute was his/her score. A repetition was not counted if: (1) the wooden bar dropped while performing the test, (2) the bar did not remain horizontal during the repetition or (3) if the subject's shoulder didn't lift off the ball. The subject received one warning for incorrect technique throughout the test.

2.1.5. Rotational oblique bridge

The purpose of this exercise was to test the strength and endurance of the *internal and external obliques, quadratus lumborum, erector spinae, rectus abdominus* and *multifidus.*

The subject was instructed to: position himself/herself in the push-up position (starting position) and maintain a neutral spine. The subject then pushed off and rotated to the one side into a bridge position. The free arm was abducted and perpendicular to the body. The subject's pelvis was not sagging but in a neutral position in relation to the body (end position). The subject then returned to the starting position.

This exercise was performed as many times possible to one side in one minute. Once the minute was completed, the subject rested for a minute and then proceeded to test the other side. The number of repetitions performed on each side was taken as his/her score. A repetition was not counted if the subject failed to attain the correct end position. The subject received one warning for incorrect technique throughout the test.

G. Intervention

13 subjects took part in the intervention program (Appendix B) while four subjects formed the control group. During the eight week intervention program, the control group and experimental group continued with their own training programs. The intervention lasted approximately eight weeks or until the subjects completed 16 sessions. Each subject attended a minimum of two training sessions per week. If a subject missed more than two (2) sessions in a row or a total of more than three (3) sessions throughout the program, he/she was excluded from the intervention program. Originally, 13 paddlers were included in the experimental group, however, five subjects were excluded from the experimental group during the course of the intervention. Three subjects withdrew due to personal responsibilities, one broke his arm at the beginning of the intervention and the other completed the intervention program but failed to complete the post testing sessions due to sickness.

Each session lasted between 45 and 60 minutes and all training sessions took place at the Department of Sport Science, Stellenbosch University. Each subject was trained individually. If the subjects trained on the days preceding the sessions, it had to be of moderate intensity and completed 15 hours prior to the session, to allow for sufficient rest. There was also a 24 hour rest period between each core stability training session. Training was completed more or less the same time on separate days. As with the stability tests the subjects wore tight-fitting clothing, so that the researcher could observe their posture and positioning during the sessions. The subjects only needed to bring a towel and liquid refreshment if needed. There were no invasive procedures throughout the duration of the training program.

H. Statistical Analysis

Descriptive statistics were presented as mean ± SD, unless otherwise stated. 2 X 2 analysis of variance (pre vs post and stable vs unstable) for repeated measure was used to evaluate the effect of the core stability program on the balance and core stability of the experimental and control groups, separately. Student's paired t-tests were used to test for significant differences in the changed scores (pre-minus post-testing) for the experimental and control groups. Student's unpaired t-tests were used to compare the changed scores of the experimental and control groups. 2 X 2 analysis of variance (pre vs post and stable vs unstable) for repeated measures was used to test for differences in performance measures (i.e. power output) and physiological variables (i.e. VO_2, HR and V_E) between the pre-and post-intervention responses and between stable and unstable conditions for each group (experimental and control group) separately. The SPSS statistical package (version 13.0, SPSS, Inc, Chicago, Illinois, USA) was used. The level of significance was set at ($p < 0.05$).

CHAPTER FIVE

Results

A. Subject characteristics

The canoeists who took part in this study were between 18 and 28 years old. They were of average built and their percentage body fat was within expected ranges for male and female athletes. There was no statistically significant between-group or within-group differences either before, or after the intervention program (p > 0.05).

Table 1. Descriptive statistics (mean ± SD) of the subjects before and after the intervention program.

	Experimental (n = 8)		**Control (n = 4)**	
	Pre	**Post**	**Pre**	**Post**
Age (years)	22.3 ± 3.01	22.6 ± 3.38	22.8 ± 4.03	23.0 ± 4.25
Height (cm)	175.1 ± 10.74	175.4 ± 3.84	176.3 ± 6.29	176.8 ± 3.48
Weight (kg)	72.6 ± 11.21	73.1 ± 10.99	75.4 ± 7.76	75.4 ± 8.06
Body Fat %	14.9 ± 7.72	16.3 ± 7.29	12.9 ± 6.52	13.8 ± 5.86

B. Balance and Core Stability

1. Balance tests (Fig. 1A and B)

The results of the balance tests are presented in Fig. 1A and B. Although the experimental group showed an improvement in the Swiss ball balance test: 44 ± SEM 8.0 s vs 53 ± SEM 4.73 s; this change was not statistically significant ($p > 0.05$). There was no improvement in the Wobble board balance test: 29 ± SEM 2.69 s vs 29 ± SEM 3.14 s. The control group slightly improved their performance on the Swiss ball balance test during the post measurements, but performed worse in the Wobble board balance test. None of these changes, however, were statistically significant ($p > 0.05$). Overall, there were no statistically significant differences in the test scores between the experimental and control group for either pre-intervention or post-intervention measurements.

2. Core Stability tests (Fig. 1C - G)

Core stability was evaluated with 5 different tests, namely, Prone isometric extension (Fig. 1C), One minute walk out (Fig. 1D), One minute modified lying one leg lift (Fig. 1E), Lateral ball sway (Fig. 1F) and Rotational oblique bridge (Fig. 1G). The Prone isometric extension test showed no change in test scores for the experimental group. There were statistically significant improvements in the test scores for the One minute walk out test (Fig. 1D) and the Rotational oblique bridge (left side) test (Fig. 1G) ($p < 0.05$). The results for the Rotational bridge on the right side improved from 19 ± SEM 2.16 repetitions to 24 ± SEM 1.89 repetitions and this change bordered on statistical significance ($p = 0.09$). In all remaining tests, there were small but non-significant improvements after the intervention program.

There were only slight changes in the test scores of the control group in all the tests, but none of these changes were statistically significant.

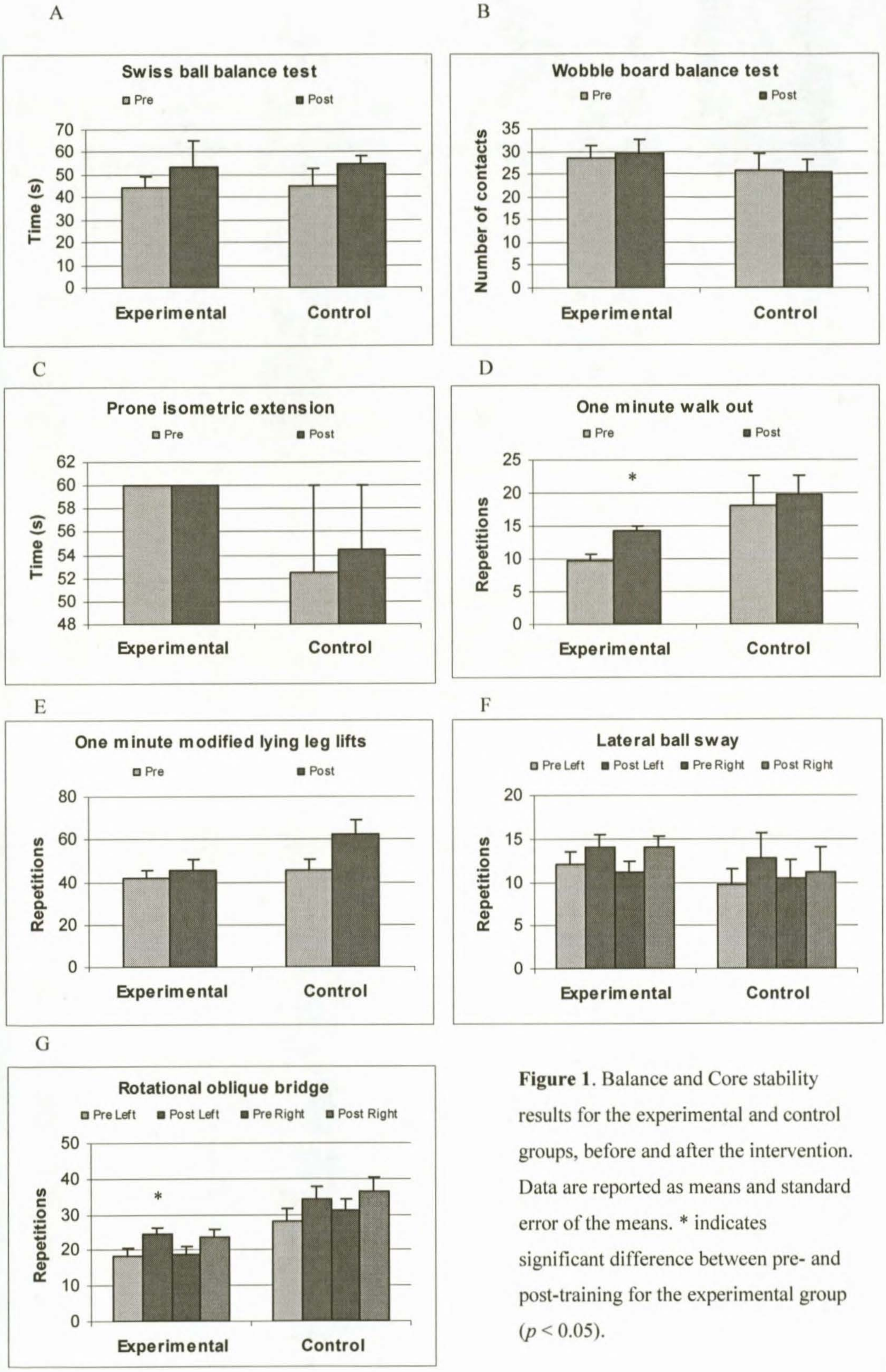

Figure 1. Balance and Core stability results for the experimental and control groups, before and after the intervention. Data are reported as means and standard error of the means. * indicates significant difference between pre- and post-training for the experimental group ($p < 0.05$).

C. The four minute sprint test

1. Power Output

In all the sprint tests (Fig. 2), the experimental group started the sprint with a very high power output, which decreased significantly towards the end of the four minutes ($p < 0.001$). Similarly, during the stable sprint tests (Fig. 2), the control group also started with a high power output, which decreased towards the end of the four minutes, However, Figure 2C and D showed that the control group weren't able to produce as high a power output values during the unstable testing, compared to the stable sprints. Thus the graphs show that the control group seemed to pace themselves over the four minute sprint. This resulted in no significant decreases over time during the test ($p > 0.05$).

Overall, there were no significant differences in mean power output between the stable and unstable conditions for both the experimental and control group, either before or after the intervention (Table 2). However, for the experimental group, the difference in mean power output over four minutes between the stable and unstable conditions were greater after the intervention than before the intervention (25.2 ± SEM 27.26 W vs 9.1 ± SEM 8.20 W). The difference in the changed scores was not statistically different ($p > 0.05$). The difference in mean power output for the control group between stable and unstable conditions was smaller and not statistically significantly different (pre: 22.8 ± SEM 25.45 W vs post: 17.6 ± SEM 7.55 W).

Table 2. The mean (± SEM) power output (W) for stable and unstable sprint tests, before and after the intervention program.

	Experimental		Control	
	Pre	**Post**	**Pre**	**Post**
Stable (W)	175.2 ± 25.12	188.2 ± 25.23	210.1 ± 40.44	217.4 ± 40.03
Unstable (W)	166.2 ± 23.16	163.2 ± 22.18	187.3 ± 33.91	199.8 ± 35.57

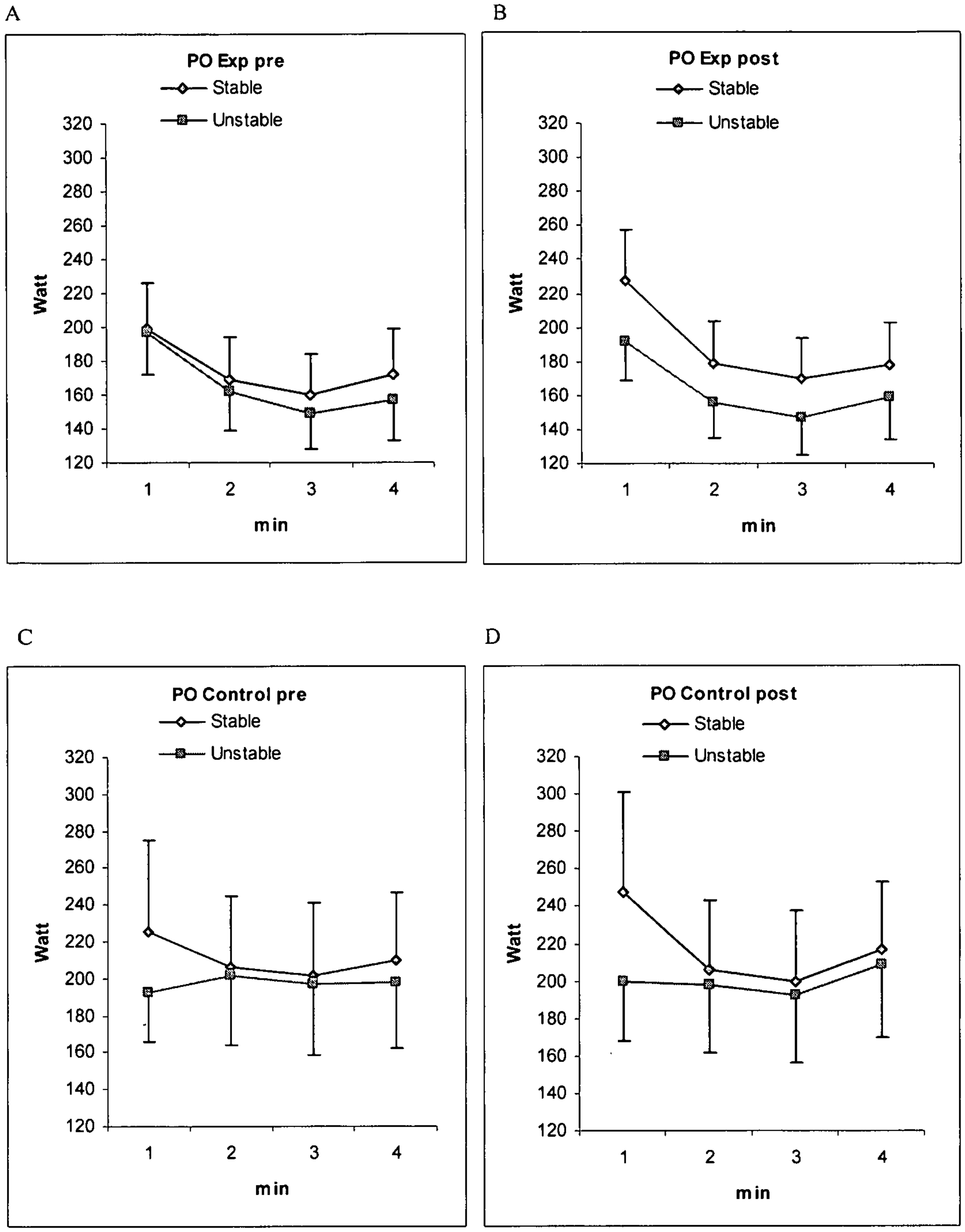

Figure 2. The power output (PO) responses of the subjects for the stable and unstable sprint tests, before and after the intervention program. Values are presented as means and standard errors of the means. * indicates statistically significant difference between stable and unstable conditions ($p < 0.05$).

D. The six minute sub-maximal test

1. Power Output

In the experimental group, there was no significant change in power output over the six minutes in either the pre- or post-intervention testing ($p > 0.05$). However, Figures 3C and D show that there were statistically significant changes in power output in the control group over the six minutes ($p < 0.01$), mainly due to low power output values at the beginning of the test during the unstable condition tests.

For the experimental group, the difference in mean power output before the intervention between the stable and unstable conditions was 4.7 ± SEM 0.64 W, while the difference after the intervention was only 1.8 ± SEM 0.18 W. This difference was statistically significant ($p = 0.02$) and can primarily be attributed to the improved performances of the subjects in the unstable tests (Table 3). There was a statistically significant improvement in the sub-maximal power output response for the experimental group ($p = 0.03$) in the unstable condition tests during the post-intervention tests (Table 3).

There was no statistically significant difference in the mean power output during the stable tests for the control group (Table 3). However, the control group managed to significantly improve their performance during the unstable tests ($p = 0.006$). The difference in mean power output between the stable and unstable conditions during pre-testing was 11.4 ± SEM 2.4 W, while the difference was only 3.2 ± SEM 3.9 W for the post-testing. This change was also statistically significant ($p = 0.02$).

More importantly, however, was that the differences in mean power output between the stable and unstable conditions was statistically significantly less for the experimental group (1.8 ± SEM 0.18 W) compared to the control group (3.2 ± SEM 3.9 W) ($p = 0.001$).

Table 3. The mean (± SEM) power output (W) for the stable and unstable sub-maximal tests, before and after the intervention program.

	Experimental		**Control**	
	Pre	**Post**	**Pre**	**Post**
Stable (W)	* 123.6 ± 13.36	*† 122.7 ± 13.28	* 133.4 ± 19.66	133.5 ± 19.12
Unstable (W)	118.9 ± 13.60	† 120.9 ± 13.11	121.9 ± 16.15	† 130.3 ± 17.86

† indicates statistically significant differences between pre and post testing ($p < 0.05$).

* indicates statistically significant difference between stable and unstable conditions ($p < 0.05$).

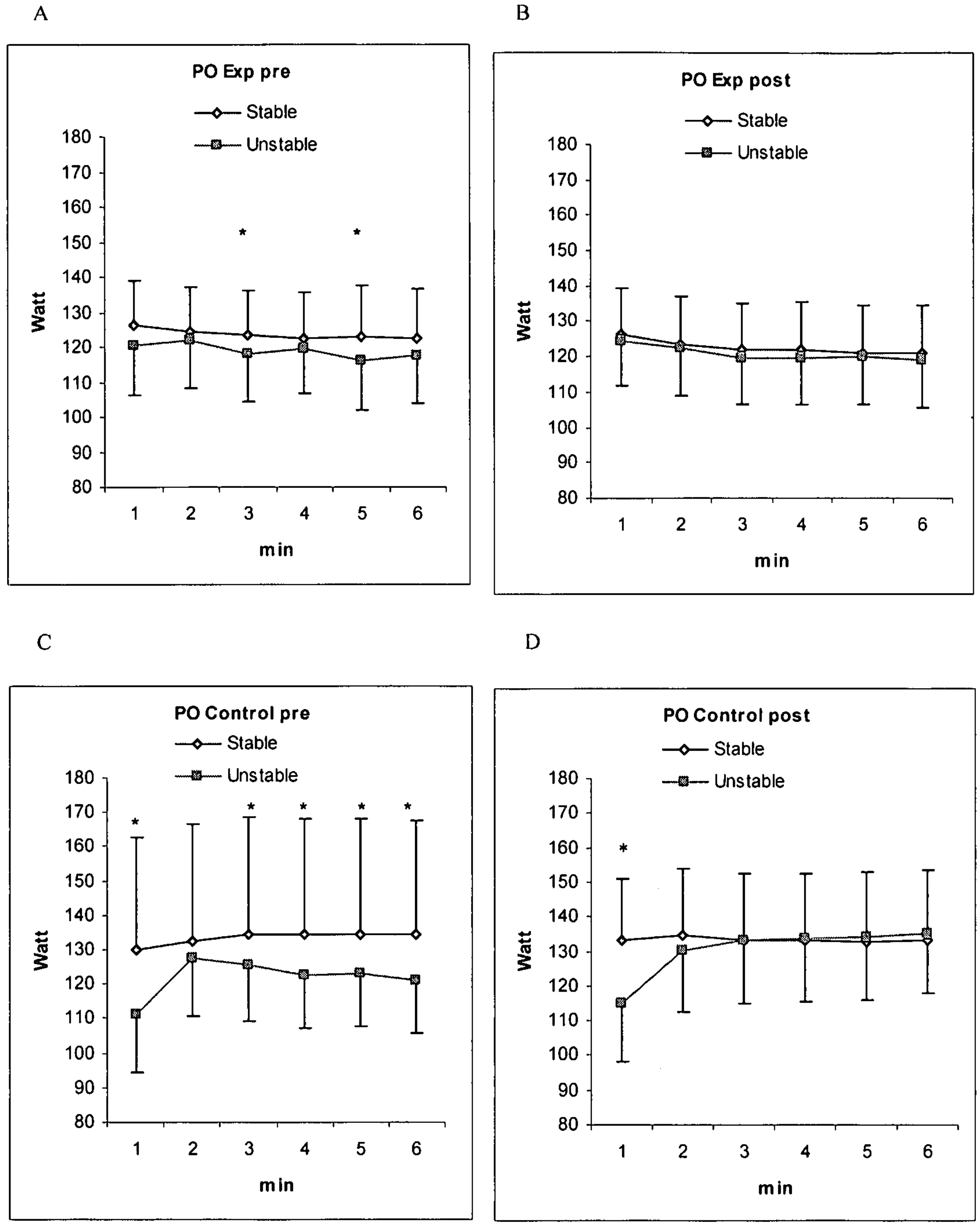

Figure 3. The power output (PO) responses of the subjects for the stable and unstable sub-maximal tests, before and after the intervention program. Values are presented as means and standard errors of the means. * indicates statistically significant difference between stable and unstable conditions ($p < 0.05$).

2. Oxygen Consumption

There was a statistically significant increase in VO_2 over time for both groups and for both the pre- and post-tests (p = 0.0001), which was mainly due to the low VO_2 values at the beginning of the exercise. Importantly, the VO_2 responses for all the unstable tests, but in particular for the pre-tests, were higher compared to the stable tests.

Overall, there were no significant changes in mean VO_2 values for either the experimental or control group after the intervention period (Table 4). Although there was no significant change in the difference between the stable and unstable values after the intervention for the experimental group ($p > 0.05$), it is evident from Fig. 4B that the difference was less during the post-tests (pre: 1.8 ± SEM 3.32 $mL.kg^{-1}.min^{-1}$ vs post: 0.2 ± SEM 0.84 $mL.kg^{-1}.min^{-1}$; $p > 0.05$).

In contrast to the experimental group, the control group was not able to maintain stable VO_2 values towards the end of the test (Fig. 4D), leading to statistically significantly higher VO_2 values at minutes 5 and 6 (p = 0.03). Similarly to the experimental group, the difference between the stable and unstable values for the control group during the post-test was also less than during the pre-test (pre: 1.4 ± SEM 2.35 $mL.kg^{-1}.min^{-1}$ vs post: 0.6 ± SEM 0.64 $mL.kg^{-1}.min^{-1}$; $p > 0.05$).

Table 4. The mean (± SEM) VO_2 ($mL.kg^{-1}.min^{-1}$) for stable and unstable sub-maximal tests, before and after the intervention program.

	Experimental		**Control**	
	Pre	Post	Pre	Post
Stable ($mL.kg^{-1}.min^{-1}$)	30.3 ± 2.23	30.2 ± 2.29	24.8 ± 2.71	27.3 ± 2.36
Unstable ($mL.kg^{-1}.min^{-1}$)	32.0 ± 2.68	29.9 ± 13.49	26.2 ± 2.49	27.9 ± 2.14

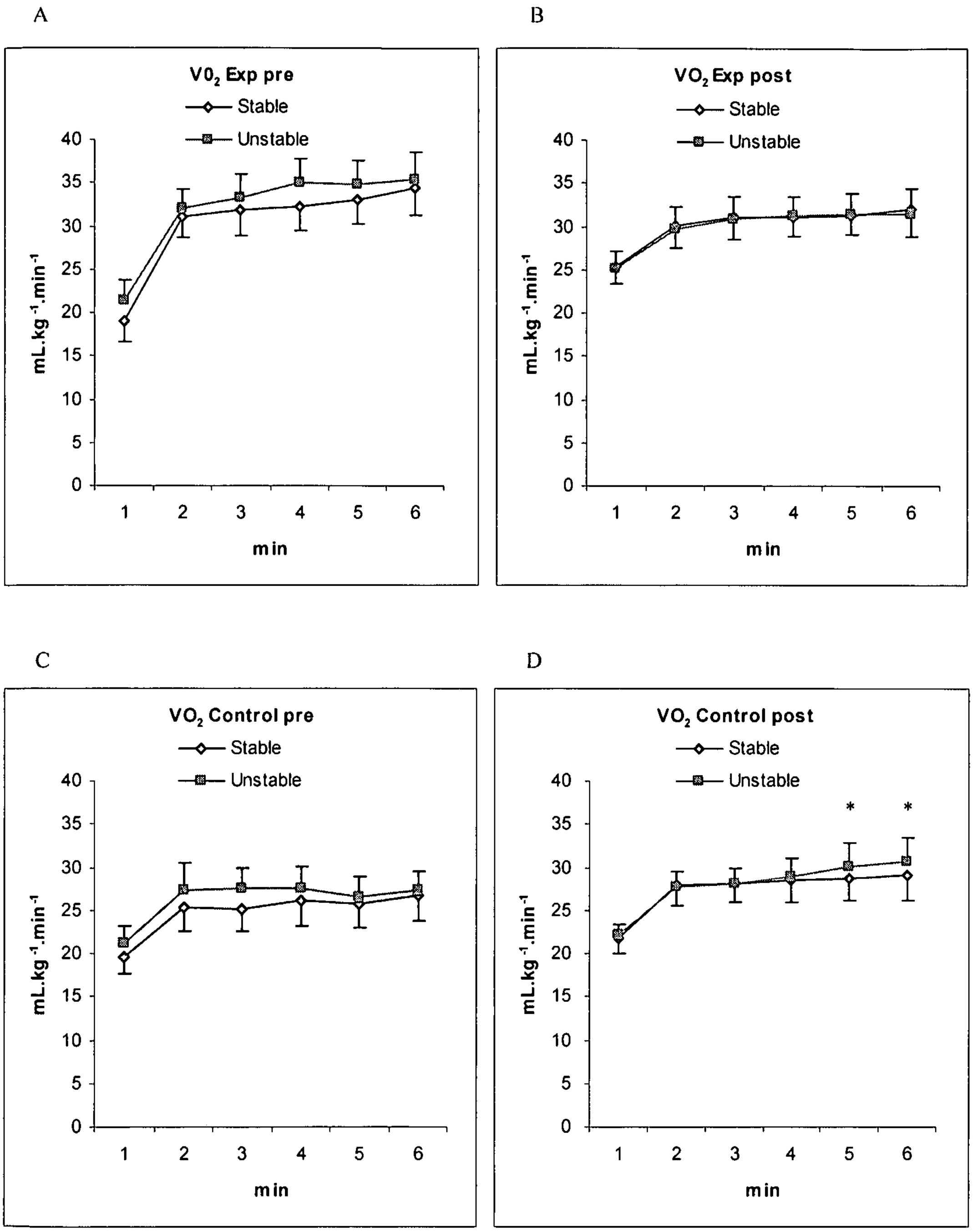

Figure 4. The oxygen consumption (VO_2) responses of the subjects for the stable and unstable sub-maximal tests, before and after the intervention program. Values are presented as means and standard errors of the means. * indicates statistically significant differences between stable and unstable conditions ($p < 0.05$).

3. Heart Rate

Heart rate increased significantly over time for both groups and for both pre- and post-tests ($p < 0.001$). For the experimental group, there were no significant differences between the stable and unstable heart rate responses (Fig 5A and B). The slightly higher heart rates for the stable test during pre-testing can be attributed to the higher mean power output (Table 3). Similarly, the experimental group's heart rate was higher for the unstable test during post-testing, due to an increase in mean power output.

The effect of the unstable condition was much more evident in the heart rate response of the control group (Fig 5C and D). During pre-testing, the heart rates were slightly higher, but not significantly so, during the stable test compared to the unstable test. This can be explained by the significantly higher mean power output during the stable test (133.4 ± SEM 19.17 W vs 121.9 ± SEM 16.15 W; $p = 0.002$).

During post-testing, the control group managed a higher power output during the unstable test (130.3 ± SEM 17.86 W), but this time their heart rate was higher throughout the test, compared to the stable test. Overall, the control group's heart rate was 11 $b.min^{-1}$ higher in the unstable test during post-testing compared to the stable test.

Table 5. The mean (± SEM) HR ($b.min^{-1}$) for stable and unstable sub-maximal tests, before and after the intervention program.

	Experimental		**Control**	
	Pre	**Post**	**Pre**	**Post**
Stable ($b.min^{-1}$)	157.4 ± 7.67	150.6 ± 5.51	144.4 ±11.76	138.2 ± 5.70
Unstable ($b.min^{-1}$)	154.5 ± 6.28	151.8 ± 5.07	138.8 ± 9.2	149.2 ± 5.96

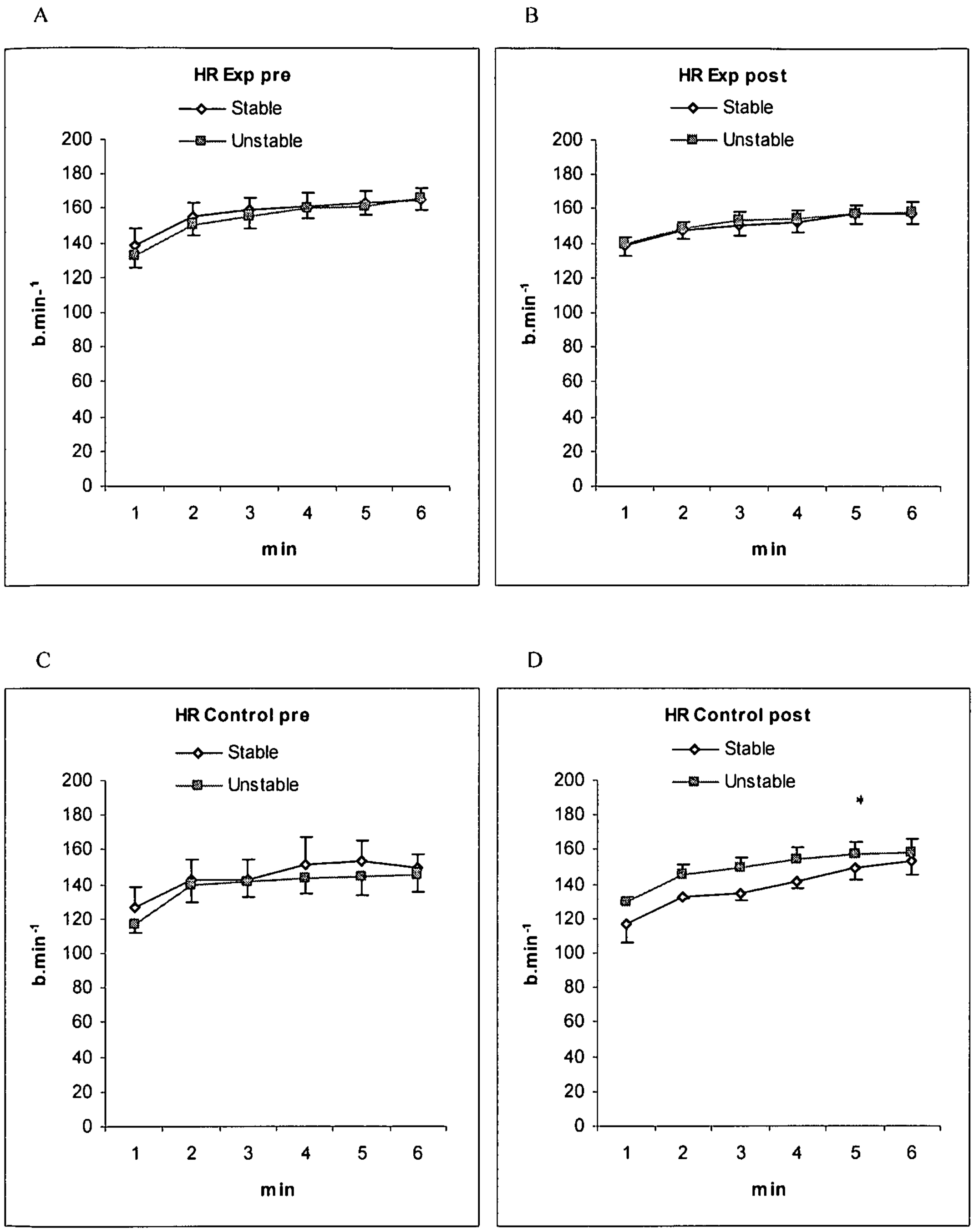

Figure 5. The heart rate (HR) responses of the subjects for the stable and unstable sub-maximal tests, before and after the intervention program. Values are presented as means and standard errors of the means. * indicates statistically significant difference between stable and unstable conditions ($p < 0.05$).

4. Minute Ventilation

There were statistically significant increases in V_E over time for both groups and for both pre- and post-testing ($p < 0.001$). Figure 6 shows that the unstable condition tests caused markedly higher ventilation rates compared to the stable condition tests, although these differences were not statistically significant ($p > 0.05$). Importantly, however, is that the ventilation rates for the experimental group decreased after the intervention, so that the mean ventilation was actually lower, although not statistically significantly lower, during the unstable test than the stable test (stable: 68.5 ± SEM 8.18 $L.min^{-1}$ vs unstable: 66.9 ± SEM 7.78 $L.min^{-1}$). During pre-testing, the ventilation rates were on average 9.2 ± SEM 5.72 $L.min^{-1}$ higher during the unstable test, whereas the mean difference after the intervention was only 1.6 ± SEM 1.92 $L.min^{-1}$. This difference was not, however, statistically significant ($p = 0.09$).

For the control group, the ventilation rates were constantly higher during the unstable tests compared to the stable tests, for both pre- and post-testing (pre: 1.7 ± SEM 4.54 $L.min^{-1}$ vs post: 4.1 ± SEM 2.16 $L.min^{-1}$). These differences were not statistically significant ($p > 0.20$).

Table 6. The mean (± SEM) V_E ($L.min^{-1}$) for stable and unstable sub-maximal tests, before and after the intervention program.

	Experimental		**Control**	
	Pre	**Post**	**Pre**	**Post**
Stable ($L.min^{-1}$)	60.6 ± 7.92	68.5 ± 8.18	57.9 ± 8.98	63.2 ± 7.85
Unstable ($L.min^{-1}$)	69.7 ± 6.96	66.8 ± 7.78	59.7 ± 6.68	67.3 ± 8.54

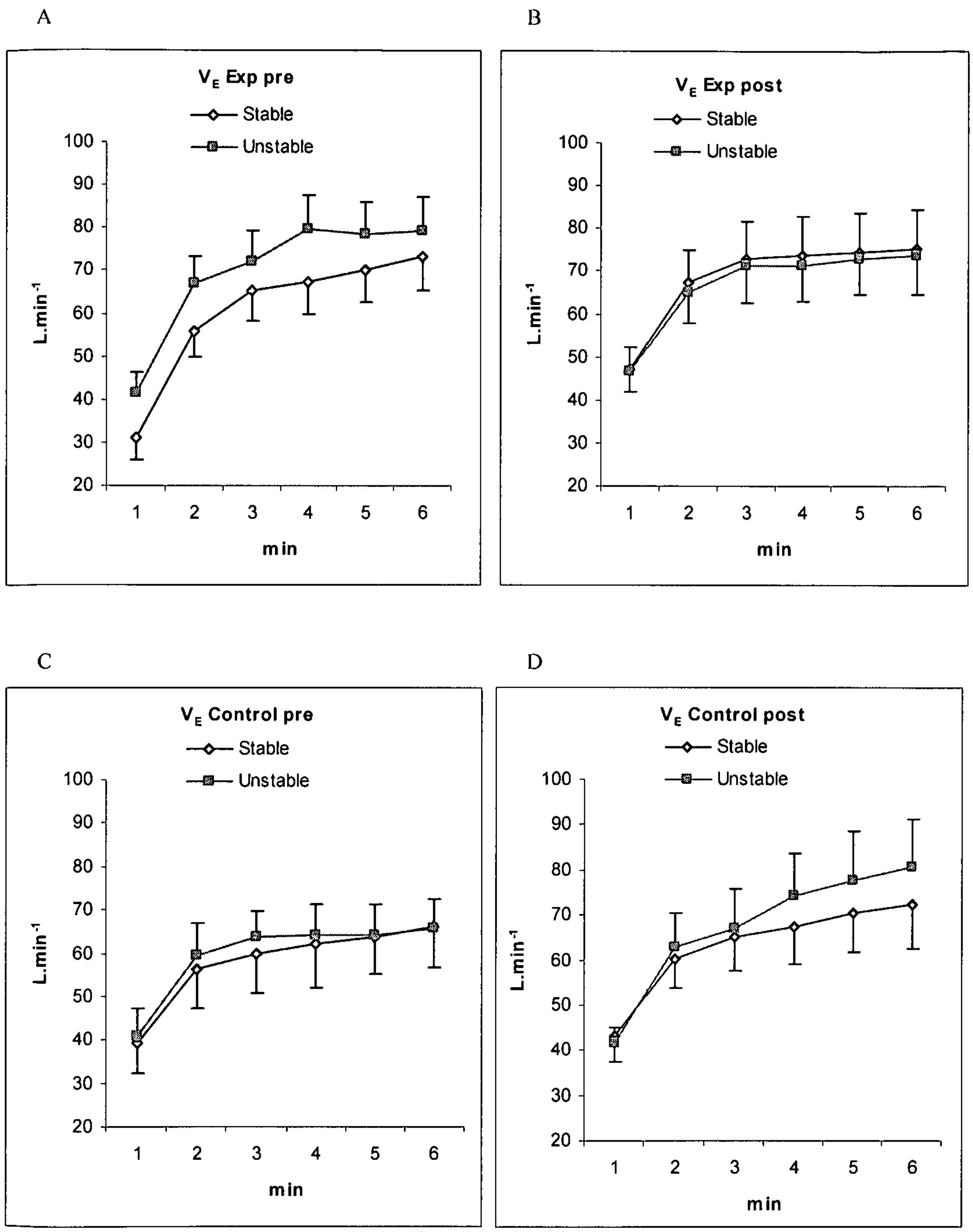

Figure 6. The minute ventilation (V_E) responses of the subjects for the stable and unstable sub-maximal tests, before and after the intervention program. Values are presented as means and standard errors of the means. * indicates statistically significant difference between stable and unstable conditions ($p < 0.05$).

CHAPTER SIX

Discussion

A. Introduction

For the past decade, the sport and fitness industry has emphasized the apparent importance and essentiality of core strength and core stability in the training of individuals, for the enhancement of both daily activities and athletic performance. Research on core stability, strength and endurance has mainly focused on spine pathology and the reduction of back pain through strengthening of the core (Tse et al, 2005). Although, theoretically, superior core strength and stability should lead to better body balance and more efficient use of the shoulder, arms and leg muscles, previous research was unable to show, unequivocally, that improved core stability and strength also translates in enhanced athletic performance.

The primary focus of the research study was to examine the effectiveness of a canoe-specific core stability and strength intervention program, with the aim to improve the strength and endurance of the main stabilizing trunk muscles. The secondary aim was to see whether improved core stability, strength and balance affect paddling economy and sprint performance.

B. Core stability, strength and balance test battery

The core stability tests in this study were part of a self-developed test battery aimed at evaluating the core muscles of canoeists. The main muscles used while paddling are the *abdominals, back* and *shoulder stabilizers.* Thus, the tests were specifically developed around the functioning of these muscles. Previous tests, like that of Liemohn et al (2005) made use of equipment, like the stability platform, to test core stability. The advantages of using equipment like the stability platform are that it is quite accurate in what it tests as well as being useful as an unstable device to train core stability. In conjunction with EMG, core stability can be accurately measured and assessed as long as the testing is specific to the sport being tested. The downside to using equipment like the stability platform and EMG are the costs involved.

The Sahrmann core stability test and the SBPSCST do not exhibit sport specific characteristics as they are performed in the sagital plane. This limits the use of these tests for sports that require rotation, like canoeing. The advantage of these tests is that they are cost-effective and easy to administer.

When developing a core stability test battery, the factors that need to be taken into consideration are the cost of tests and functionality of exercises. In retrospect, the core stability test battery in this study could have included more exercises in a seated position and made use of more unstable equipment during testing. This could have allowed for a more canoe-specific testing environment. The inclusion of EMG analysis for both the canoe performance test and core stability would have also been useful to observe exactly which core muscles play a bigger role during canoeing and during specific core stability exercises.

C. Core stability, strength and balance training program

The experimental group participated in an eight week core strength training program. Training programs in previous intervention studies lasted between 5 and 8 weeks (Cosia-Lima et al, 2003; Stanton et al, 2004; Tse et al, 2005). The exercises in the program were selected according to the muscles and the movements that are most used while paddling. Exercises increased in volume every two weeks and became more advanced as the program progressed. The reason for the volume increase and program progression was to ensure that there was sufficient demand placed upon the subjects and that they didn't become too accustomed to the intensity. In the first half of the training program the exercises were performed on the floor, whereas in the second half of the training program, the majority of the exercises were performed under unstable conditions (i.e. using the swiss ball).

The fact that half the training was done under stable conditions may be a possible reason why the experimental group did not significantly improve in all the core stability tests. In the study by Cosio-Lima et al (2003), swiss ball training was compared to conventional floor training. Significant improvements in *abdominal* and *erector spinae* EMG activity were evident after a five week period of swiss ball training, but not with floor training. Similarly, the study by Stanton et al (2004) also showed a significant improvement in core stability after a six week swiss ball training program. Anderson and Behm (2005) proposed that training under unstable conditions will stress the neuromuscular system to a greater extent than traditional methods (i.e. stable conditions). Therefore, one would expect that unstable training conditions may lead to greater neural adaptations and thus greater improvement in strength, endurance and stability. These neural adaptations include more efficient neural recruitment patters, increased nervous system activation, improved synchronization of motor units and lowering of neural inhibitory reflexes through the Golgi tendon organs (Staron et al, 1994).

Furthermore, Marlow (2001) stated that exercises using the gym ball are more specific to paddle sports than traditional exercises because just as a paddler's boat creates an unstable base against which to work, so the gym ball provides similar instability. Thus, perhaps, core training programs for water-based sports, specifically canoeing, must include primarily unstable apparatus in its training program, as it possibly provides the necessary conditions to develop core stability optimally.

Both studies by Cosio-Lima et al (2003) and Stanton et al (2004) showed that unstable or swiss ball training elicited greater improvements in core muscle stability, however, both of these studies' intervention programs exercises remained unchanged throughout the intervention. Only the sets and repetitions changed during the intervention. However, in the current study, the exercises were adapted and made progressively harder every two weeks. The inclusion of four weeks of floor training could be seen as baseline training, which prepared the subjects for more advanced core exercises later on. It was necessary to ensure that the subjects were able to perform the basic exercises effectively so that when the more advanced exercises started, that the subjects were able to adapt without technique problems. Tse et al (2005), followed a similar protocol style by starting with basic TrA activation for the first few sessions. The subjects then progressed onto postural and stability exercise for two weeks, thereafter the subjects moved from static to dynamic exercises and then finally to controlled mobility exercises for the remainder of the eight week training program. This style of training seems to be more feasible as it encourages continual adaptations in subjects' core stability, which would hypothetically produce better performances, as the subjects would be more stable in their sporting environment.

It is also possible that the loading patterns in this study's training program were not sufficient to challenge the canoeists to the extent that specific training adaptations were made. Although the subjects in this study were not in peak physical condition, they were all high level club athletes and at the time of the study, busy with pre-season training. Generally, one would expect canoeists to already have more advanced core stability compared to athletes whose activities are limited to stable conditions, because they expose themselves to more demanding environments; their core muscles should therefore already be conditioned to work harder. The lack of specific guidelines from previous research led the researcher to compile the training program according to conventional strength training principles and was further guided by the responses of the individuals in the experimental group to each session's training.

The optimal length of a core strength training program is still debatable. The fact that both the training programs of Cosio-Lima et al (2003) and Stanton et al (2004) showed improvements in core stability, suggests that training programs as short as five weeks might be sufficient enough to produce improvements in core stability. However, it must be noted that Cosia-Lima et al (2003) included relatively untrained subjects in their study, while in the current study, the subjects were relatively trained. Although the effects of an eight week training program on core stability is promising, as shown in the current study and that of Tse et al (2005), it seems that in future research, an intervention study of more than eight weeks in duration should be investigated. However, when core stability training forms part of a regular training program, it should not be viewed as a short-term training method, but similar to strength and endurance training, it must be continually trained and worked on.

D. The effect of the training intervention on balance

Although the improvements of the swiss ball balance test was not statistically significant, the experimental group improved their time to exhaustion, demonstrating that the subjects were more stable in their movement. This increased stability and balance is probably the reason why trainers and athletes advocate core stability training. Whether improved balance actually translates to improved sport performance, or whether it just makes the canoeist feel more secure in his/her craft on the water, is not clear.

The wobble board balance test did not exhibit any improvement in test scores for both the experimental and control groups. The reason for this could be related to the intervention program, as no exercises were included that targeted the stability and/or mobility of the ankle or knee joints. Canoeing does not require extensive use of the ankle joint to maintain stable in the canoe, thus its role in canoe training programs is quite limited. The purpose of the wobble board was to challenge the mobility of the ankle joint and stability of the knee joint, thus programs including proprioception training may elicit improvements with the wobble board balance test. As a result, its inclusion in land-based sports training programs warrants its use as a training apparatus. In retrospect, however, the wobble board balance test may not have been the correct choice for canoeists. Perhaps if a test can be devised where the canoeist is required to sit on the wobble board, instead of stand upright, it may prove to be a more canoe-specific test.

E. The effect of the training intervention on core stability and strength

When looking at the prone isometric extension results, the experimental group showed no change in test scores after the intervention. All the experimental subjects attained the one minute mark in accordance with the set limitations. The experimental subjects, therefore, exhibited advanced *back* and *gluteal* extensor muscles allowing them to go for the full minute. Thus, for this test, the experimental groups' core stability showed superior core strength. The control group, on the other hand, did not manage to endure the full one minute in either pre- or post-tests, despite showing slight improvements. The reason for the control group not attaining the full one minute score can be attributed to the inability of one test subject to maintain a neutral spine until the end of the test. Thus, he was subsequently stopped short of the one minute and this resulted in a mean score lower than 60 seconds for the control group. The reason for the spinal deviation was that this particular subject's core stability could not endure the exercise for the 60 seconds while maintaining a neutral spine.

In the one minute walk out test the endurance of the *spinal erectors* and *gluteal* muscles and *scapula-humeral* joints were tested. The results showed a significant improvement from pre- to post-testing in the experimental group. A possible reason for the improvement in the post-test was that in the final two weeks of the intervention program, subjects performed exercises that were similar in action as the one minute walk out test. This could have yielded an improved ability to perform more repetitions in the test and the improvement in test score could thus be due to a learning effect. The higher scores for the control group compared to the experimental group can possibly be attributed to the gender composition of the control group. The fact that there was only one woman in the control group (and three men), compared to three women (and five men) in the experimental group could have resulted in higher mean scores for the control group. To date there are no studies showing the differences in core strength and stability between men and women athletes, however, Palmer and van Someren (2003) highlighted that a well-developed upper body musculature was a key factor in the differences in performance between international and national-level kayakers. Therefore, there is the possibility that men might exhibit stronger core strength and stability due to larger musculature, especially in upper body exercises. With this in mind, having a stronger upper body benefited the subjects in the one minute walk out as it was performed in the prone position supported by the upper body.

The one minute walk out is similar to the SBPSCST, except that the SBPSCST is an isometric test, which does not require the subject to move forward in the sagital plane. In the study by Stanton et al (2004), the test subjects were only men who performed the SBPSCST. The superior upper body strength of the men may thus explain the significant improvement in their results. Furthermore, the swiss ball training program in Stanton et al (2004) study, also included exercises in the prone position which, in conjunction with the subjects' upper body strength, could have contributed to the significant improvement in scores.

The one minute modified lying leg lift used in the current study is similar to the Sahrmann core stability test used in the study by Stanton et al (2004). The purpose of this test was to test the endurance of the *rectus abdominus* and *transverse abdominus* muscles. The use of the myometer allowed the researcher to observe the manner in which the subject performed the test, ensuring that the subject used his/her core muscles during the test. The experimental group showed slight improvements in the test compared to the control group; however, the changed scores were not statistically significant.

The large improvement in the scores of the control group can be attributed to the canoeists' own training program. It is important to remember is that the pre-tests were administered during pre-season, while the post-tests were administered during the in-season. The increase in training volume and intensity, as well as regular competition during the in-season could possibly explain the improvements in the control groups' core stability results. Why then did the experimental group not exhibit the same response? There may be two reasons for this. Firstly, the canoeists may have been more fatigued during the post-testing compared to the control group, due to the added stress of the core stability training program to their regular in-season training and competitions. Secondly, it is possible that there was actually a significant decrease in some of the experimental groups' volume of training closer to the post-testing period, since six of the subjects in the experimental group were students who, at the time of post-testing, were preparing for examinations.

Interestingly, the mean scores for the experimental groups' left side (14 ± SEM 1.53 repetitions) and right side (14 ± SEM 1.38 repetitions) were the same during the post test, for the Lateral ball sway. This indicates that for this exercise, their ability to move laterally, in the horizontal position, was the same. This is important to note as superior core stability can only be achieved if there is a balance between the sides of the body to ensure a stable trunk. Moreover, the control group did not exhibit the same results as the experimental group. The mean score for the left side (12.75 ± SEM 3.01 repetitions) was greater than the right side (11.25 ± SEM 2.87 repetitions). Even though this was not significant, it showed that, overall, the control group had a difference between the left and right side which could lead to potential energy leaks and weaker core stability. Generally, a balanced core will result in a stronger core.

In the rotational oblique bridge there was a similar trend as in the lateral ball sway test, in which the experimental groups' left and right sides were equal in score. The purpose of this exercise was to test the strength and endurance of the *obliques, quadratus lumbrum and scapulo-humeral* joints. Interestingly, the experimental groups' pre-left side score (19 ± SEM 2.15 repetitions) was the same as the pre-right side score (19 ± SEM 2.16 repetitions). Although the right side score (24 ± SEM 1.96 repetitions) and left side score (25 ± SEM 1.64 repetitions) were not the same during post-testing, the fact that both sides improved to almost the same extent, is noteworthy. The results showed a significant improvement in the left-side score ($p < 0.05$), while the change in the right-side bordered on statistical significance (p= 0.09). It is likely that these results are the consequence of the core strength training program.

The control group, on the other hand, also improved for both left and right sides, but these changes were not statistically significant. Interestingly, the control group did not achieve equal scores for the left and right sides in the post tests. Again, as with the one minute walk out, the rotational bridge test requires upper body strength to perform well. This could therefore also be the reason for the higher scores in the control group and the slight improvements in test scores. However, the control group did not exhibit the same balance between their left and right sides, which not only shows an imbalance in the trunk muscles but ultimately can lead to a weaker core.

F. The effect of the training intervention on sub-maximal exercise performance

In the sub-maximal tests, the experimental group significantly improved their mean unstable power output compared to the pre-test. More importantly, this change occurred with a concomitant decrease in oxygen consumption, heart rate and minute ventilation during the post-test. These results, although not statistically significant, indicates that the subjects improved their paddling economy during the test that was specifically designed to challenge the strength and stability of their core musculature. This is in contrast to the study of Stanton et al (2004) who did not find improvements in the running economy of runners who improved their core stability with a 6 week training program. However, as previously discussed (page 16), the authors did not perform the correct exercise test to actually evaluate the running economy of the athletes.

In contrast to the experimental group, the improvement in mean power output from pre- to post-testing in the control group is associated with an increase in oxygen consumption, heart rate and minute ventilation. Therefore, the higher power output during the second unstable test could indicate a minimal learning effect, but it had no effect on the physiological responses, and thus paddling economy, of the subjects.

The improved paddling economy in the experimental group did not lead to statistically significant improvements in performance, specifically also in the sprint test which followed the sub-maximal test. However, during a race, or any longer duration exercise test, the benefit of improved paddling economy may have significant consequences for the outcome of the race. Therefore, the significance of these findings may actually prove to be very important for canoeists.

Previously it has been shown that the addition of resistance or strength training generally lead to an improvement in run performance, by improving running economy (Paavolainen et al, 1999). Paavolainen et al (1999) suggested that the improvement in running economy could be due to neural adaptations. In this study, the maximal 20m speed and 5-jump tests showed significant improvements after the nine week explosive-strength and endurance training. The resulting improvements in neuromuscular performance characteristics could have transferred into improved running economy. This may also explain the reason for the improved paddling economy of the canoeists. Possibly, the core strength training program elicited a neural adaptation, which in turn improved their core stability, which allowed the experimental group to handle the unstable demands of the cushion better, producing a more economical paddling stroke. Another possible reason for the improved paddling economy could be that the subjects did not waste excess energy balancing on the cushion while paddling. Possibly, the experimental group felt more balanced on the cushion thus, not needing to worry about remaining stable on the cushion and therefore being able to put the "reserve" energy into the paddle stroke. Therefore, the subjects' ability to maintain a better balance could have assisted the subjects to produce a higher power output.

In this study, the main variable separating the two test groups was the core strength training program. Therefore, the use of core strength training programs, particularly unstable-orientated ones, might be the key to promote a more economical canoe performance. More economical breathing will firstly ensure that a smaller percentage of the cardiac output is redistributed to the respiratory muscles during exercise, therefore making more oxygen-rich blood available to the working muscles. Secondly, a decrease in the energy cost of breathing means that the respiratory muscles will be more fatigue resistant and more energy will be available towards the end of an exercise session or race, resulting in improved performance. It has been shown that prolonged moderate intensity exercise leads to significant respiratory muscle fatigue (Ker and Schultz, 1996; Boussana et al, 2001). Although training of the respiratory muscles has now also become a popular additional training regimen for athletes (Gigliotti et al, 2006), the results of this study suggest that core stability training may actually also improve the functioning of the respiratory muscles during exercise. Similarly, a decrease in heart rate means greater cardiac efficiency and less cardiac fatigue during prolonged or high intensity exercise.

The reason why the core stability program improved the paddling economy of the subjects is therefore probably the result of the improved core stability and balance of the canoeist. Even though there were not significant changes in the latter, it seems that these small changes were sufficient to have an effect on paddling economy. The ultimate goal of core stability training for paddlers is to stabilize the torso and thus prevent energy leaks during the paddling stroke. A well developed core stability, strength and balance would therefore ensure that the paddler directs all the energy into the paddling stroke and can therefore produce high power outputs. Furthermore, if energy is not wasted in trying to maintain good posture and balance on the water, extra energy is available to produce powerful strokes. We hypothesize that the advantage of having improved paddling economy will be more pronounced in field tests or during a long distance race, where the canoeist is constantly challenged with the changing environment, compared to the laboratory test that was used in this study.

G. The effect of the training intervention on sprint performance

There were no statistically significant changes in mean power output for the sprint tests, for either the experimental or the control group. This finding is in accordance with that of Tse et al (2005) who found no significant change in 2000m rowing performance of club level rowers after an 8 week core stability training program. Similarly, Stanton et al (2004) found no change in VO_{2max} or maximal speed at VO_{2max} in runners, despite a significant improvement in core stability.

Although Tse et al (2005) mentioned a few reasons that may explain their non-significant results (i.e. too short intervention program and the lack of sensitive tests to detect small margins of improvement), it may also be possible the rowers' trunk stabilizers were not sufficiently challenged on the rowing ergometer test in the laboratory. For this reason, the laboratory tests in this study were modified, using a cushion on the seat of the kayak ergometer, to create an unstable sitting position and hopefully simulate conditions that paddlers will experience on the water. Therefore, it was hoped that the unstable conditions would stress the subjects in the same manner as when they paddle on the water, thus mimicking field performance tests. In reality, the inflatable cushion proved, at times, to be too unstable, causing some subjects to actually fall off the kayak during testing. Although this posed a true test of core stability, many subjects were cautious when paddling, which could have hampered their test results. In spite of this, many of the subjects admitted that the inflatable cushion fulfilled its purpose of simulating an unstable condition, much like that of water.

In this study, the core strength training program did not include exercises in the seated position, which would have been more specific to the conditions of paddling. This is a possible reason that the subjects failed to improve on their post unstable sprint test. It is important that when developing a core training program, that the exercises included are as specific and functional to the sport as possible. Furthermore, if the intensity of the exercises were not sufficiently high, it is unlikely that the Type I muscle fibres of the targeted muscles would have been activated. However, it is these muscles that would have been used during the sprint test and this may therefore be a further explanation of why the subjects did not significantly improve their sprint performance.

Although not statistically significant, the control group showed improvements in power output in the post-tests. This may be explained by the higher training status of some of the control group subjects, as some of these athletes were peaking for an upcoming canoe race at the time of the post-tests and therefore one can assume that their training status was significantly higher than during the pre-tests.

Bishop et al (2001) tested the effect of three different warm-up intensities on kayak performance over a two week period, whereby the tests were separated by 48 hours. This extended period of testing might be more effective in attaining more accurate results as opposed to testing subjects on the same day. In the current study we hypothesized that 30 minutes of rest would be sufficient time for the subjects to return to baseline values. Perhaps, this was too short a period of recovery and maybe 24 hours would have been more reasonable. Arguably, canoeists perform repeated bouts of sprints in between long periods of endurance paddling when racing, thus their ability to perform various intensities of paddling in a race could justify testing subjects on the same day. The reason for doing the sub-maximal and maximal sprint test in one session is also in line with the idea to simulate actual field conditions as closely as possible in the laboratory.

Current canoe training comprises of interval sprint training and endurance training. Very few canoeists include gym work to improve canoe performance. However, Liow et al (2003) concluded that slow weight training is more effective than explosive training for improving the acceleration phase of sprinting, when force is high throughout the stroke. Furthermore, explosive training may be effective in speed maintenance, when forces are developed rapidly over a short period at the start of the stroke. The training program comprised of two weight training sessions per week for six weeks, whereby the subjects performed 3-4 sets of two sport-specific exercises at 80% of 1-repetition-maximum. The two groups were randomised into slow-weight training and explosive weight training. The two groups performed the same exercises the only thing that differed was the time of the concentric phase, slow: 1.7s and explosive: <0.85s. With this in mind, the inclusion of weight training coupled with core exercises could be the key to improved canoe sprint performance.

H. Limitations of the study

Most of the results in this study showed a tendency towards statistical significance. However, there were at least two factors that caused the results not to reach statistical significance, namely the small sample size, especially in the control group ($n = 4$) and the large intersubject variability, specifically in the power output and physiological responses. The latter may have been aggravated by the fact the sample included both men and women and that the training status and level of performance varied too much between the individuals. Although all the subjects complied with the inclusion criteria of the study, the sample was nevertheless too heterogeneous.

It has been mentioned before that there may have been some shortcomings in the core stability program. It may have been too short in duration (8 weeks), or the overload was too little. The program also consisted of 4 weeks of floor training (i.e. stable conditions), and no exercises in the seated position (to simulate canoeists' sitting posture on the boat) and this may not have challenged the canoeists to the extent that significant training adaptations were caused that could be translated to canoe performance.

The researcher was also unable to control the subjects' training programs and their participation in races during the study. This may not only have influenced the test responses of the individuals, but may also have influenced their motivation during some of the tests as some subjects might have feared over exertion, which might affect their upcoming races.

I. Conclusion

To our knowledge, this is the first study where an attempt was made to simulate canoeing conditions in the laboratory, while still having the advantage to test subjects in a controlled laboratory environment. The fact that most studies thus far have used standardized performance tests to investigate the effect of improved core stability on athletic performance, may explain the lack of a clear relationship between these two parameters. The added advantage of creating "field conditions" in the laboratory is that field testing, specifically in rowing and canoeing, can be costly and very timely and it also limits the amount of information that a researcher can collect during exercise.

Overall, the experimental group showed improvements in all the sub-maximal physiological variables when performed in the unstable conditions. They managed to produce a higher mean power output without any increase in oxygen consumption, heart rate and minute ventilation. This showed that they were more economical during sub-maximal exercise and also better able to handle the demands of the unstable conditions after the core strength training program. Conversely, the control group had to compensate for a lack of core stability through increases in oxygen consumption, heart rate and minute ventilation to attain a better power output under unstable conditions. This finding alone warrants the need to include core stability training in canoe training programs.

An important factor to keep in mind is that the canoeist in this study have been paddling for a minimum of two years, thus their trunk musculature might be more developed than novice paddlers. The small margins of improvement in the core stability tests may indicate that the training program was not challenging enough, or that the core stability test battery is not able to detect small improvements in core stability and strength.

In summary, the results of this study suggest that a core strength training program improves some aspects of core muscle strength and stability of club-level canoeists. Although there were no statistically significant improvements in canoe sprint performance after the core strength training program, the intervention led to improved paddling economy. The latter finding may actually impact significantly on athletic performance in real life situations, i.e. during a race. The effect of an 8 week core stability training program on the athletic performance of canoeists thus appears promising.

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APPENDIX A

INFORMED CONSENT

Title of research project:

The effect of a core strength training program on the core muscle strength and stability of canoeists

Reference number:______________________________

Consent of Subject:

I,____________________________[ID:___________________________]
from(address)____
____.

confirm that:

1. I was invited to participate in the above-mentioned project conducted by the Department of Sport Science of Stellenbosch University.

2. It was explained to me that:

2.1 The aim of this project is to determine the effectiveness of a core strength training program to improve core muscle strength and stability.
2.2 I will participate in three tests:

2.2.1 I will undergo a series of exercises to evaluate my level of core muscle strength and core stability.
2.2.2 I will perform a 6 minute submaximal warm-up test followed by a 4 minute sprint test on a kayak ergometer to assess my anaerobic performance.
2.2.3 I will also perform two balance tests to assess my balance ability.

2.3 If I am selected for the training group, I must follow an exercise program for eight (8) weeks under the supervision of the researchers. I will be required to attend at least 2 exercise sessions per week at the Department of Sport Science. The minimum training time will be 30 minute per session and the maximum will be one hour per session. Throughout the duration of the training program I will be instructed to keep a diary of my training activities.

2.4 All tests will be repeated eight weeks after the first evaluation.

2.5 No invasive procedures (e.g. injections, draw of blood) or administrations of any substance will be administered.

3. I am warned that I might develop one or more symptoms during the exercise tests and during the training program. This includes nausea, dizziness, high or low blood pressure, heart beat disorders (too slow, too rapid, or irregular), shortness of breathe or bronchoconstriction. I understand that I can stop the tests at any time when I experience one of these symptoms.

4. I was informed that the information obtained during this study will be held confidential, but that the findings may be published in a research journal.

5. The above-mentioned information was explained to me by ____________________ in English/Afrikaans. I was also given the opportunity to ask questions and all my questions were answered satisfactorily.

6. It was explained to me that my participation is voluntarily and that I can withdraw from the project at any time. I also understand that the researchers or medical doctor may withdraw me from the study if deemed necessary for medical purposes.

7. I was informed that there are no costs linked to my participation.

With this I volunteer to participate in the above-mentioned project.

Signed at______________________on______________________20______

______________________________ ______________________________

Subject Witness

Statement of the Researcher

I,________________________declare that I:

1. Explained the information contained in this document to______________
2. Requested the subject to ask questions if anything was unclear.
3. Performed this conversation in English/Afrikaans.

Signed at______________________on______________________20______

______________________________ ______________________________

Researcher Witness

APPENDIX B

Core strength training program

WEEK ONE:

Quadrupled with alternating leg extension	5 reps/leg x 5sec hold
Supine bridge	4 sets x 20 sec hold
Bent knee abduction	3 sets x 8 reps
Quadrupled arm extension	3 sets x 8 reps per arm
Swiss ball crunch	3 sets x 8 reps
Reverse crunch	3 sets x 8 reps
Plate raise (Swiss ball)	3 sets x 8 reps

WEEK TWO:

Quadrupled with alternating leg extension	4 reps/leg x 10 sec hold
Supine bridge	3 sets x 30 sec hold
Bent knee abduction	3 sets x 12 reps
Quadrupled arm extension	3 sets x 12 reps per arm
Swiss ball crunch	3 sets x 12 reps
Reverse crunch	3 sets x 12 reps
Plate raise (Swiss ball)	3 sets x 12 reps

WEEK THREE:

Quadrupled arm and leg extension	5 sets x 15 sec
Single leg supine bridge	3 sets x 15 sec hold
Straight leg abduction	3 sets x 8 reps
Push-up plus	3 sets x 10 reps
Oblique side bridge	3 sets x 20 sec hold
Swiss ball crunch with extended arms	3 sets x 8 reps
Plate raise (Swiss ball)	3 sets x 15 reps

WEEK FOUR:

Quadrupled arm and leg extension	4 sets x 20 sec
Single leg supine bridge	3 sets x 20 sec hold
Straight leg abduction	3 sets x 12 reps
Push-up plus	3 sets x 12 reps
Oblique side bridge	3 sets x 30 sec hold
Swiss ball crunch with extended arms	3 sets x 12reps
Plate raise (medicine ball)	3 sets x 8 reps

WEEK FIVE

Swiss ball hip extension	4 sets x 20 sec hold
Supine marching bridge	4 sets x 6 reps per leg
Oblique crunches on Swiss ball	3 sets x 8 reps
Single leg supine leg extensions	3 sets x 8 reps
Russian twist on Swiss ball	3 sets x 8 reps per side
Lunge with plate raise (Swiss ball)	3 sets x 8 reps
Overhead squat (Swiss ball)	3 sets x 6 reps

WEEK SIX:

Swiss ball hip extension	3 sets x 30 sec hold
Supine marching bridge	3 sets x 10 reps per leg
Oblique crunches on Swiss ball	3 sets x 12 reps
Single leg supine leg extensions	3 sets x 8 reps
Russian twist on Swiss ball	3 sets x 8 reps per side
Lunge with plate raise (Swiss ball)	3 sets x 12 reps
Overhead squat (Swiss ball)	3 sets x 10 reps

WEEK SEVEN:

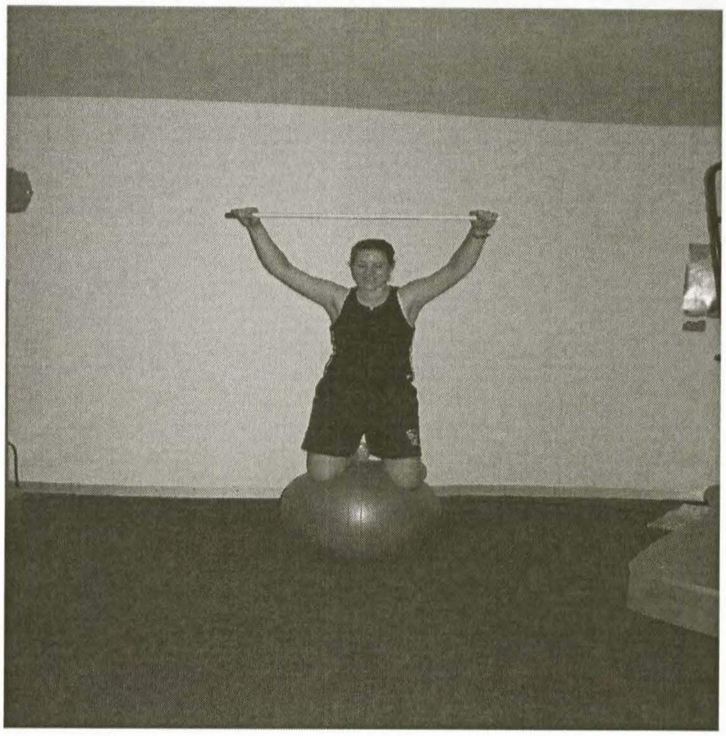
Marching bridge on Swiss ball	4 sets x 6 reps per leg
Prone leg extension on Swiss ball	4 sets x 5 reps per leg
Stick crunch	4 sets x 6 reps
Prone Swiss ball crunch	3 sets x 8 reps
Lunge with plate raise (medicine ball)	3 sets x 8 reps
Overhead squat (medicine ball)	3 sets x 8 reps

WEEK EIGHT:

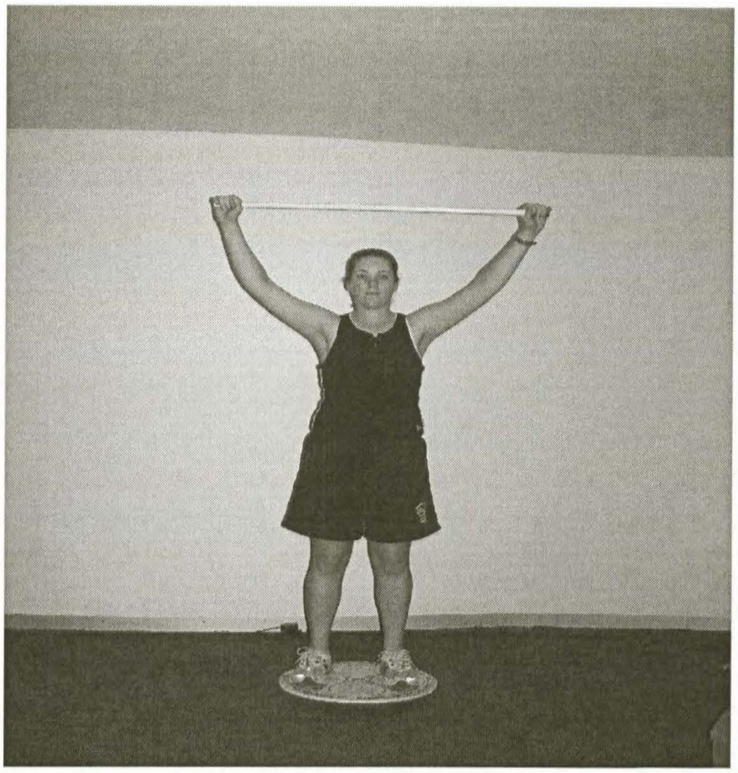
Marching bridge on Swiss ball	4 sets x 8 reps per leg
Prone leg extensions on Swiss ball with crunch	4 sets x 8 reps
Stick crunch with medicine ball	4 sets x 6 reps
Roll out on Swiss ball	3 sets x 30 sec hold
Prone bridge balance on wobble board and Swiss ball	3 sets x 30 sec hold

APPENDIX C

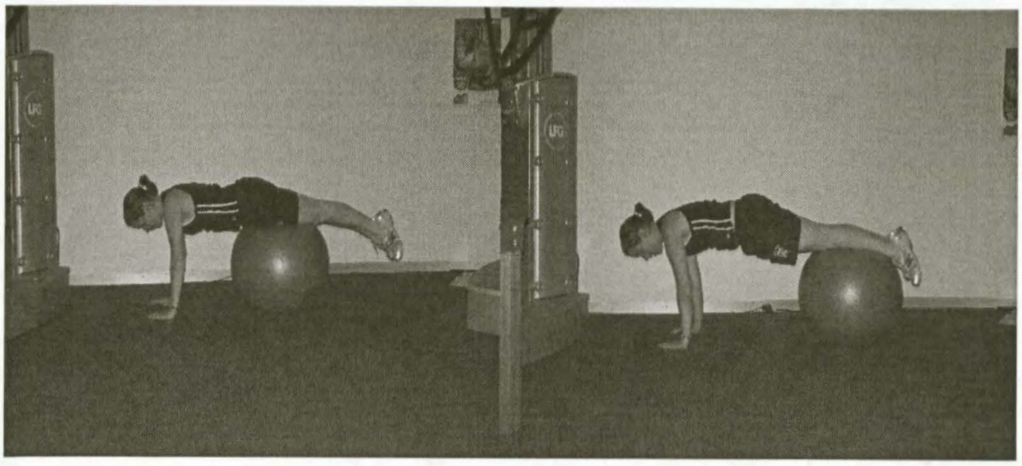
Photos of core stability and balance test battery



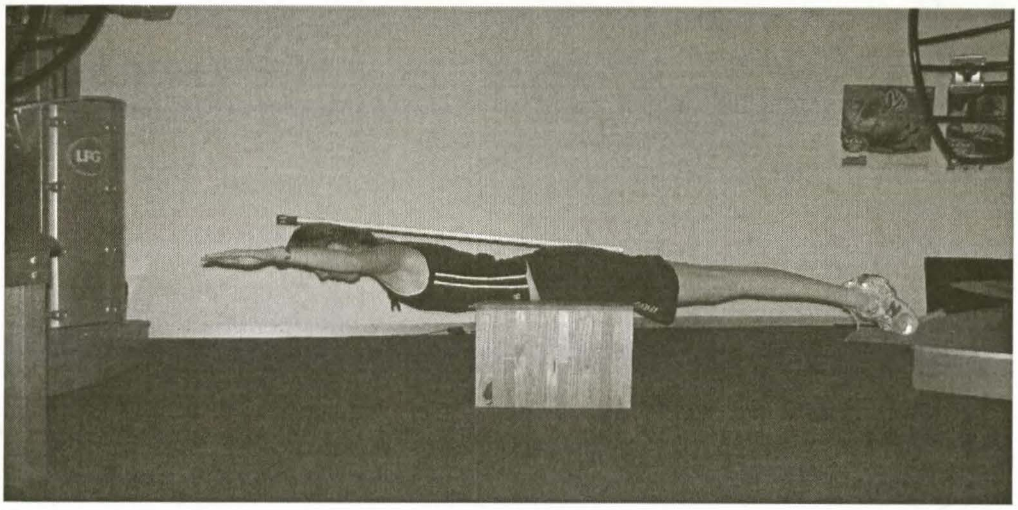
Above: Swiss ball balance test



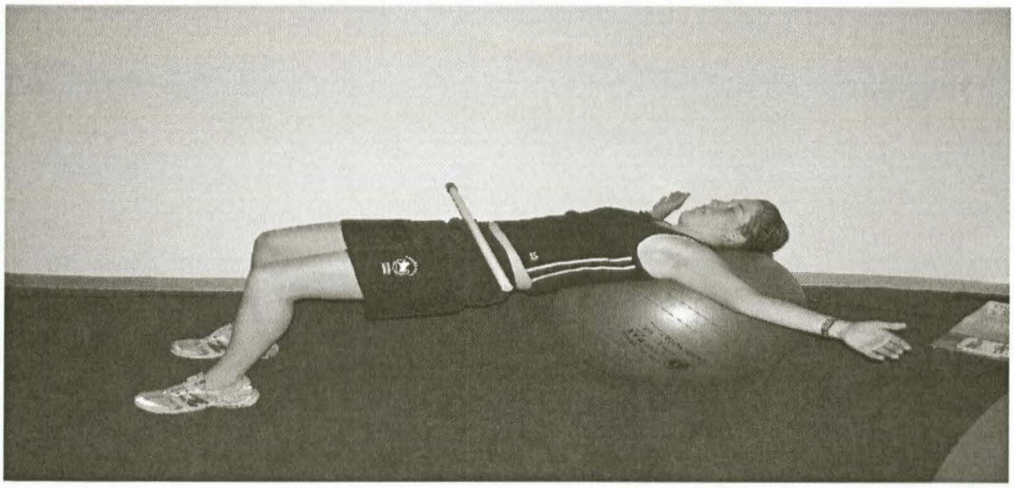
Above: Wobble board balance test



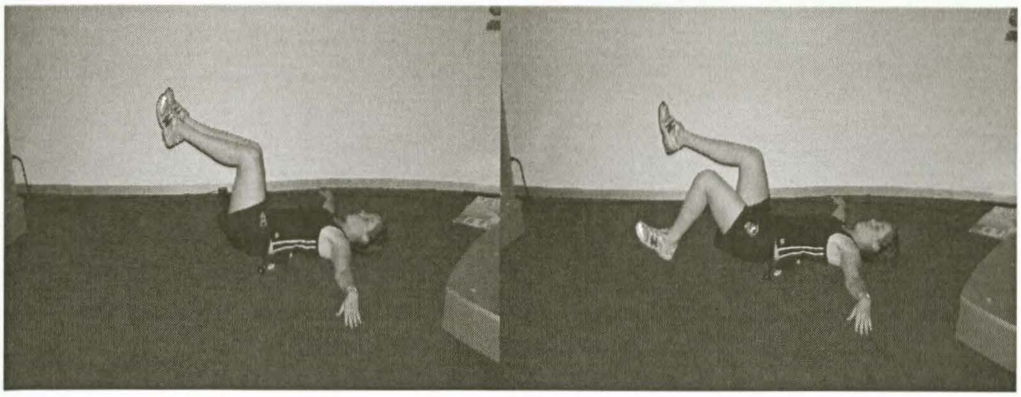
Above: One minute walk out: Left: starting position; Right: finishing position



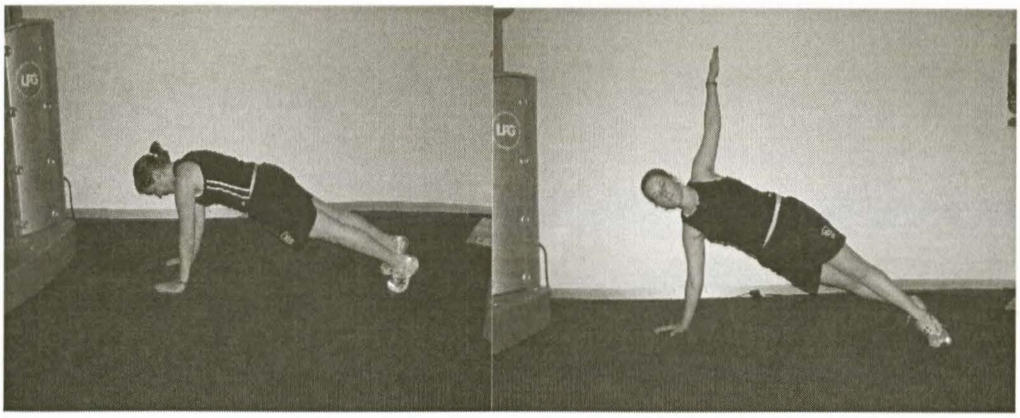
Above: Prone isometric extension



Above: Lateral ball sway



Above: One minute modified lying leg lifts: Left: starting position; Right: finishing position



Above: Rotational oblique bridge: Left: starting position; Right: finishing position