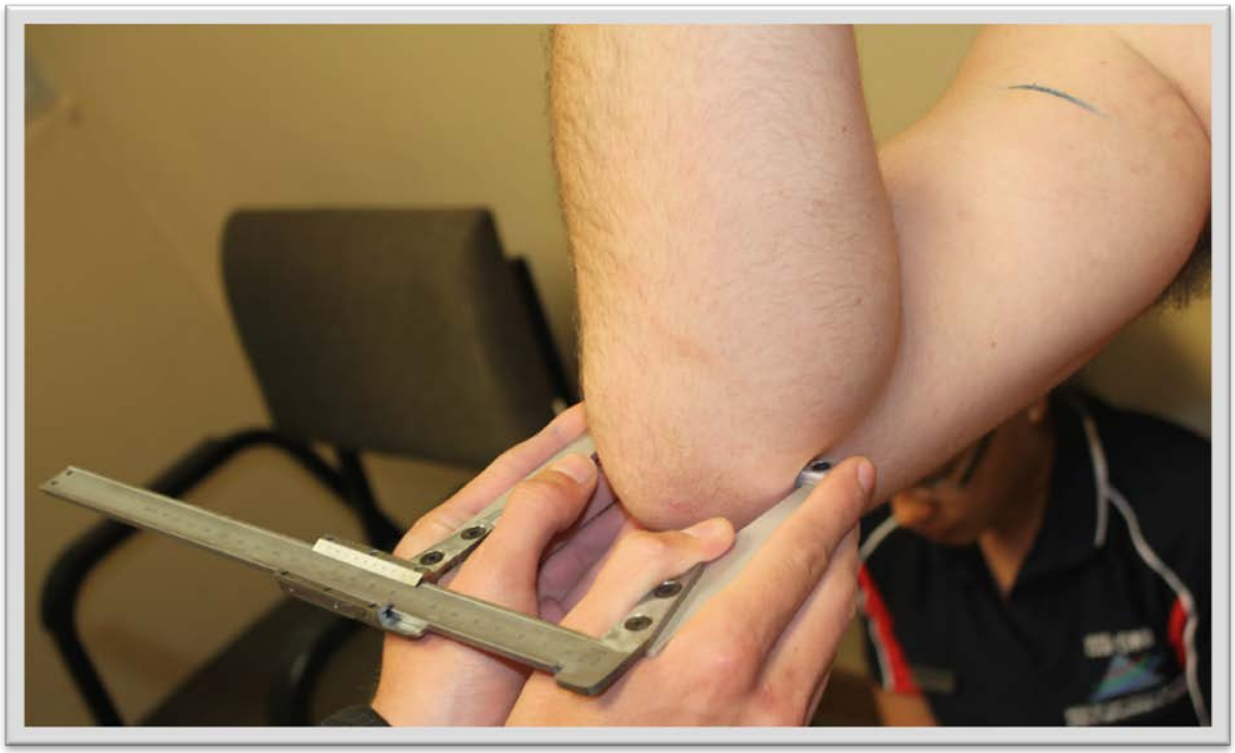
APPENDIX



APPENDIX A, B, C

APPENDIX A	GENERAL INFORMATION QUESTIONNAIRE, INFORMED CONSENT AND RAW DATA FORMS FOR THE LONG-TERM VERTIMAX PROJECT
APPENDIX B	GENERAL INFORMATION QUESTIONNAIRE, INFORMED CONSENT AND RAW DATA FORMS FOR THE ACUTE VERTIMAX PROJECT
APPENDIX C	SUBMISSION GUIDELINES FOR AUTHORS AND ARTICLE EXAMPLES

APPENDIX A

GENERAL INFORMATION QUESTIONNAIRE, INFORMED CONSENT AND RAW DATA FORMS FOR THE LONG-TERM VERTIMAX PROJECT

NORTH-WEST UNIVERSITY
YUNIBESITI YA BOKONE-BOPHIRIMA
NOORDWES-UNIVERSITEIT
POTCHEFSTROOMKAMPUS

General Information Questionnaire, Informed Consent and Test Protocol to determine the effects of long-term Vertimax-training

GENERAL INFORMATION

Please write clearly!

1. GEOGRAPHICAL INFORMATION

1.1 Surname:	Initials	First Name

1.2 Age:

Years:	Months:

1.3 Birth date:

Year:	Month:	Day:

1.4 Permanent residential address in South Africa:

_____

_____

1.5 Permanent postal address in South Africa:

_____

_____

1.6 Phone numbers:

Home:	Work:
Fax:	Cell:
E-mail:	

1.7 Ethnic group

White	Coloured	Black	Indian

In the next few question cross out the answers that are applicable to you!!

2. INFORMATION REGARDING TRAINING HABITS

2.1 Years you've been playing rugby - since you started to specialise in rugby.

1-2 years	3-4 years	5-6 years	7-8 years	8-9 years	10-11 years	12 or more

2.2 Frequency of training - how many days per week do you normally train?

1 day	2 days	3 days	4 days	5 days	6 days	7 days

2.3 Frequency of training - how many days per week do you normally do weight training?

1 day	2 days	3 days	4 days	5 days	6 days	7 days

2.4 Frequency of training - how many days per week do you normally have field sessions?

1 day	2 days	3 days	4 days	5 days	6 days	7 days

2.5 How many hours per day do you normally train?

1 hour	2 hours	3 hours	4 hours	5 hours	6 hours	7 or more

2.6 How many hours per day do you normally spend on weight training?

1 hour	2 hours	3 hours	4 hours	5 hours	6 hours	7 or more

2.7 How many hours per day do you normally spend on training on the field?

1 hour	2 hours	3 hours	4 hours	5 hours	6 hours	7 or more

2.8 Do you spend any time on psychological preparation for rugby and competitions?

Never	*Sometimes	*Often	*Always

*** Please specify the type of psychological preparation you do if you marked any of these three options:**

_____

_____

_____

3. MEDICAL INFORMATION

3.1 Please describe any past or current musculoskeletal conditions you have incurred (i.e., muscle pulls, sprains, fractures, surgery, back pain, or any general discomfort):

Head/Neck:

_____

_____

_____

Shoulder/Clavicle:

_____

_____

_____

Arm/Elbow/Wrist/Hand:

_____

_____

_____

Back:

_____

_____

_____

Hip/Pelvis:

_____

_____

_____

Thigh/Knee:

_____

_____

Lower leg/Ankle/Foot:

_____

_____

3.2 Please list any medication being taken currently and/or taken during the last year:

3.3 List any other illness or disorder that a physician has told you of:

4. COMPETITION DATA

4.1 At what level are you competing this year?

4.2 What is the highest level that you competed at last year?

Club:	Provincial:	National:	International:

4.3 How many matches, approximately, have you played?

Club:	Provincial/National:

4.4 What were the highest achievements you attained the past two years?

Achievement	Competition	Date

4.5 What position/s do you usually play during matches?

1.
2.
3.

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NOORDWES-UNIVERSITEIT
POTCHEFSTROOMKAMPUS

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Informed consent form
PART 1

1. **School/Institute:**
   School for Biokinetics, Recreation and Sport Science

2. **Title of project/trial:**
   The effects of a combined resisted jump training and rugby-conditioning program on selected physical, motor ability and anthropometric components of rugby players.

3. **Full names, surname and qualifications of project leader:**
   Ben Coetzee, B.Sc., B.Sc. (Hons), M.Sc. and Ph.D

4. **Rank/position of supervisor:**
   (Professor, Lecturer, Research scientist etc.)
   Senior Lecturer

5. **Full names, surname and qualifications of supervisor of the project:**
   (Complete only if not the same person named in 4.)
   Same as above.

6. **Name and address of supervising medical officer *(if applicable)*:**
   Not applicable

7. **Aims of this project**
   The aims of this project are:

- To determine the effects of a four-week combined rugby conditioning and resisted jump training program compared to a rugby conditioning program alone, on selected physical, motor ability and anthropometric components of university-level rugby players.
- To determine the significant acute effects of a resisted jump training session on selected physical and motor ability components of university-level rugby players.

8. **Explanation of the nature of all procedures, including identification of new procedures:**

a) ***Collection procedures and selection of rugby players.***
The subjects will consist of two groups of rugby players. Thirty u/19 and u/21 rugby players of the North-West University in Potchefstroom (South Africa) will be randomly selected. The thirty players will in turn also be randomly divided into two groups of fifteen players each. One group will form the experimental group and the other the
control group. After the treatment period of 4 weeks, a crossover design will be implemented by subjecting the control group to the treatment and allowing the initial experimental group to form the control group. The acute study will follow the same research design.

b) ***Procedures***

i. Demographic and general information questionnaire:
The players' demographic and personal information will be collected by means of a demographic and general information questionnaire. The players' ages, exercising habits, injury incidence and competing levels will be obtained by means of this questionnaire. Anthropometric data will be collected by taking a few body measurements and the physical and motor ability performance data by means of a test battery.

ii. Anthropometric measurements and components:
The following anthropometric components will be determined in accordance with the methods of Marfell–Jones *et al*. (2006). Body composition, fat mass and skeletal mass will be analyze in this section. Body fatness will be determined through the sum of the following skinfolds (SUM6SF): triceps, subscapular, abdominal, supraspinale, front thigh and calf skinfolds and according to the formulas of Withers *et al.* (1987:198). Muscle and skeletal mass will be calculated using the formulas of Lee *et al*. (2000:796) and Martin *et al*. (as quoted by Drinkwater & Mazza, 1994:103). The following anthropometric variables will be measured under the section of muscle and skeletal mass: body stature and body mass; relaxed arm, thigh and calf girth; triceps, thigh and calf skinfolds as well as ankle, femur, humerus and wrist breadths.

iii. Physical and motor ability components:
The players will be subjected to a test battery for the measurement of lower body flexibility (The Passive-straight-leg-raise- (PSLRT) and The Modified Thomas Quadriceps Test (MTQT), lower body explosive power output (vertical jump test (VJT)), speed and acceleration (20m-speed test), agility (Illinois Agility Run Test (IART) and leg strength (6RM (repetition maximum) Smith Machine Squat Test (SMST)).

iv. More long-term treatment – testing procedure:
The players will undergo four days of testing, namely two pre and two post-test days respectively. The first visit to the sport science laboratory will be a habitation trial to familiarize the players to the apparatus to be used and to practise the exercises on the Vertimax. On this visit, players will also complete an informed consent form and a general information questionnaire regarding their exercising habits, playing positions, best performances of the last two years and injury incidence. Once they had completed the last-mentioned forms the exercises and research project will be explained to each player. This will be followed by the execution of the different exercises on the Vertimax. A week after the familiarization period the first testing day will commence. On the first pre-test day the anthropometric measurements, lower body flexibility, explosive leg power, speed and acceleration as well as the agility and lower body muscle strength tests will be executed. The experimental group will then be subjected to four weeks of a combined resisted jump training and rugby conditioning program. The rugby conditioning program
will comprise field sessions twice a day and resistance training sessions three times a week. The experimental group will also participate in resisted jump training sessions three times a week, for a 4-week period over and above their normal rugby training. All control group subjects will be requested to refrain from any resisted jump training and will only follow their normal rugby conditioning program during the 4-week period.

Following the four weeks each of the player groups will again be subjected to the last-mentioned tests at the exact same time of day so as to minimize the effects of circadian variations on the different metabolic responses. A week after the last post-test the second pre-test will be conducted in exactly the same manner as explained above. The control group will, however, be subjected to a 4-week combined resisted jump training and rugby conditioning program while the experimental group will only perform the rugby conditioning program. The post-test will again be performed four weeks after the treatment period.

v. Acute treatment – testing procedure:
The first visit to the sport science laboratory will be a habitation trial to familiarize the players to the apparatus to be used and to practise the exercises on the Vertimax. On this visit, players will also complete an informed consent form and a general information questionnaire regarding their exercising habits, playing positions, best performances of the last two years and injury incidence. Once they had completed the last-mentioned forms the exercises and research project will be explained to each player. This will be followed by the execution of the different exercises on the Vertimax. A week after the familiarization period the first testing day will commence. At the start of the session the players will firstly be subjected to a thorough warm-up of more or less 15 min that will consist of aerobic running exercises for more or less 8 min after which a specific warm-up period of shorter, high intensity movements and dynamic stretches will follow. Next, each player will be subjected to a test battery that will consist of the PSLRT, MTQT, VJT, speed and acceleration test, the IART and the SMST. Ten minutes after completion of the test battery the experimental group will be subjected to the resisted jump training session that will consist of three exercises (¼ stick jump, lunge jump and drop jump) that will be executed at a resistance of level 3 for each of the cords that will be attached to the waist belt of each player. Players will perform three sets of six repetitions for each of the exercises and sets. The control group will receive passive rest (sit on chair) during the time period that the experimental group perform the resisted jump training session. Directly after the training session each of the players will again complete the test battery. The identical testing protocol will then be repeated 48 hours later, at the exact same time of day, so as to minimize the effects of circadian variations and different metabolic responses. The control group will then be subjected to the resisted jump training session while the experimental group will undergo the passive rest period.

9. Description of the nature of discomfort or hazards of probable permanent consequences for the subjects which may be associated with the project:
(Including possible side-effects of and interactions between drugs or radio-active isotopes which may be used.)
The subjects may experience a bit of muscle discomfort and nausea.

10. Precautions taken to protect the subjects:
The players will perform a proper warm-up before the physical and motor ability tests commence and the testing procedures and methods will be thoroughly explained to each of the players.

11. Description of the benefits which may be expected from this project:
The results should provide coaches, sport scientists and other sport-related professionals with information regarding the effectiveness of a four-week combined sport-specific and resisted

jump program as well as an acute resisted jump training session for improving rugby players' physical, motor ability and anthropometric profile.

12. Alternative procedures which may be beneficial to the subjects:
(Complete only if applicable.)
Training on the Vertimax-apparatus should benefit players more with regard to their physical and motor ability components compared to non-Vertimax training.

Signature:..... **Date:** 02/05/2011
Project leader

PART 2
To the subject signing the consent as in part 3 of this document:
You are invited to participate in a research project as described in paragraph 2 of Part 1 of this document. It is important that you read/listen to and understand the following general principles, which apply to all participants in this research project:

1. Participation in this project is voluntary.
2. It is possible that you personally will not derive any benefit from participation in this project, although the knowledge obtained from the results may be beneficial to other people.
3. You will be free to withdraw from the project at any stage without having to explain the reasons for your withdrawal. However, we would like to request that you would rather not withdraw without a thorough consideration of your decision, since it may have an effect on the statistical reliability of the results of the project.
4. The nature of the project, possible risk factors, factors which may cause discomfort, the expected benefits to the subjects and the known and the most probable, permanent consequences which may follow from your participation in this project, are discussed in Part 1 of this document.

5. We encourage you to ask questions at any stage about the project and procedures to the project leader or the personnel, who will readily give more information. They will discuss all procedures with you.
6. If you are a minor, we need the written approval of your parent or guardian before you may participate.
7. We require that you indemnify the University from any liability due to detrimental effects of treatment by University staff or students or other subjects to yourself or anybody else. We also require indemnity from liability of the University regarding any treatment to yourself or another person due to participation in this project, as explained in Part 1. Lastly it is required to abandon any claim against the University regarding treatment of yourself or another person due to participation in this project as described in Part 1.

PART 3
Consent
Title of the project: The effects of a combined resisted jump training and rugby-conditioning program on selected physical, motor ability and anthropometric components of rugby players.

I, the undersigned …… (Full names) read/listened to the information on the project in PART 1 and PART 2 of this document and I declare that I understand the information. I had the opportunity to discuss aspects of the project with the project leader and I declare that I participate in the project as a volunteer. I hereby give my consent to be a subject in this project.

I indemnify the University, also any employee or student of the University, of any liability against myself, which may arise during the course of the project.

I will not submit any claims against the University regarding personal detrimental effects due to the project, due to negligence by the University, its employees or students, or any other subjects.

……
(Signature of the subject)

Signed at ..... on ……..

Witnesses

1. .....

2. .....

Signed at ..... on ……

For non-therapeutic experimenting with subjects under the age of 18 years the written approval of a parent or guardian is required.
I, ……. ..... (Full names)
Parent or guardian of the subject named above, hereby give my permission that he/she may participate in this project and I also indemnify the University and any employee or student of the University, against any liability which may arise during the course of the project.

Signature: ..... Date: …….……

Relationship: …….

NORTH-WEST UNIVERSITY
YUNIBESITI YA BOKONE-BOPHIRIMA
NOORDWES-UNIVERSITEIT
POTCHEFSTROOMKAMPUS

Test Protocol to determine the effects of more long-term Vertimax-training

RAW DATA FOR THE LONG-TERM VERTIMAX PROJECT

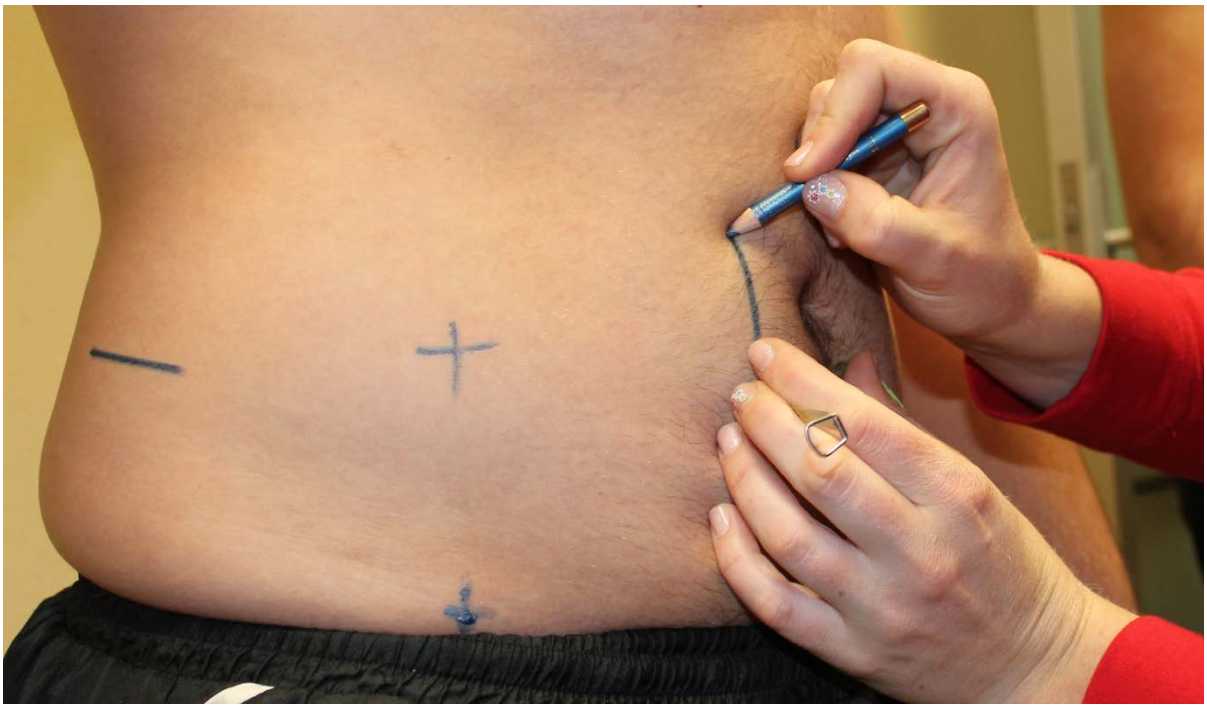
NAME OF PLAYER:

TEST COMPONENT	1ST READING	2ND READING	MEAN
BODY MASS (KG)			
BODY STATURE (CM)			
TEST COMPONENT	**1ST READING**	**2ND READING**	**MEAN**
R: BICEPS SKINFOLD (MM)			
R: TRICEPS SKINFOLD (MM)			
R: SUBSCAPULAR SKINFOLD (MM)			
R: SUPRASPINALE SKINFOLD (MM)			
ABDOMINAL SKINFOLD (MM)			
R: FRONT THIGH SKINFOLD (MM)			
R: MEDIAL CALF SKINFOLD (MM)			
TEST COMPONENT	**1ST READING**	**2ND READING**	**MEAN**
R: HUMERUS BREADTH (CM)			
R: WRIST BREADTH (CM)			
R: FEMUR BREADTH (CM)			
R: ANKLE BREADTH (CM)			
TEST COMPONENT	**1ST READING**	**2ND READING**	**MEAN**
R: RELAXED ARM GIRTH (CM)			
R: FLEXED ARM GIRTH (CM)			
TEST COMPONENT	**1ST READING**	**2ND READING**	**MEAN**
R: MID THIGH GIRTH (CM)			
R: MAXIMUM CALF GIRTH (CM)			
R: FOREARM GIRTH (CM)			

TEST COMPONENT	1ST READING	2ND READING	BEST
L: PASSIVE KNEE EXTENSION TEST (°)			
R: PASSIVE KNEE EXTENSION TEST (°)			
L: ACTIVE KNEE EXTENSION TEST (°)			
R: ACTIVE KNEE EXTENSION TEST (°)			
L: MODIFIED THOMAS QUADS TEST (°)			
R: MODIFIED THOMAS QUADS TEST (°)			
TEST COMPONENT	**1ST TIME**		
VERTEX POLE HEIGHT – REACHING (CM)			
VERTICAL JUMP REACHING HEIGHT (CM)	A		
FINAL VERTICAL JUMP HEIGHT A-B (CM)			
VERTEX POLE HEIGHT – JUMPING (CM)			
TEST COMPONENT	**1ST READING**	**2ND READING**	**HIGHEST**
VERTICAL JUMP HEIGHT (CM)			B
TENDO PEAK POWER (W)			
TENDO SPEED (M/SEC)			
TEST COMPONENT	**1ST READING**	**2ND READING**	**LOWEST**
5M SPEED (SEC)			
10M SPEED (SEC)			
20M SPEED (SEC)			
TEST COMPONENT	**1ST READING**	**2ND READING**	**HIGHEST**
ILLINOIS AGILITY RUN TEST (SEC)			
TEST COMPONENT	**1ST TIME**		
6RM SMITH MACHINE SQUAT TEST (KG)			

APPENDIX B

GENERAL INFORMATION QUESTIONNAIRE, INFORMED CONSENT AND RAW DATA FOR THE ACUTE VERTIMAX PROJECT



NORTH-WEST UNIVERSITY
YUNIBESITI YA BOKONE-BOPHIRIMA
NOORDWES-UNIVERSITEIT
POTCHEFSTROOMKAMPUS

General Information Questionnaire, Informed Consent and Test Protocol to determine the acute effects of Vertimax-training

GENERAL INFORMATION

Please write clearly!

1. GEOGRAPHICAL INFORMATION

1.1 Surname:	Initials	First Name

1.2 Age:

Years:	Months:

1.3 Birth date:

Year:	Month:	Day:

1.4 Permanent residential address in South Africa:

_____

_____

_____

_____

1.5 Permanent postal address in South Africa:

_____

_____

_____

_____

1.6 Phone numbers:

Home:	Work:
Fax:	Cell:
E-mail:	

1.7 Ethnic group

White	Coloured	Black	Indian

In the next few question cross out the answers that are applicable to you!!

2. INFORMATION REGARDING TRAINING HABITS

2.1 Years you've been playing rugby - since you started to specialise in rugby.

1-2 years	3-4 years	5-6 years	7-8 years	8-9 years	10-11 years	12 or more

2.2 Frequency of training - how many days per week do you normally train?

1 day	2 days	3 days	4 days	5 days	6 days	7 days

2.3 Frequency of training - how many days per week do you normally do weight training?

1 day	2 days	3 days	4 days	5 days	6 days	7 days

2.4 Frequency of training - how many days per week do you normally have field sessions?

1 day	2 days	3 days	4 days	5 days	6 days	7 days

2.5 How many hours per day do you normally train?

1 hour	2 hours	3 hours	4 hours	5 hours	6 hours	7 or more

2.6 How many hours per day do you normally spend on weight training?

1 hour	2 hours	3 hours	4 hours	5 hours	6 hours	7 or more

2.7 How many hours per day do you normally spend on training on the field?

1 hour	2 hours	3 hours	4 hours	5 hours	6 hours	7 or more

2.8 Do you spend any time on psychological preparation for rugby and competitions?

Never	*Sometimes	*Often	*Always

*** Please specify the type of psychological preparation you do if you marked any of these three options:**

_____

_____

_____

_____

_____

_____

3. MEDICAL INFORMATION

3.1 Please describe any past or current musculoskeletal conditions you have incurred (i.e., muscle pulls, sprains, fractures, surgery, back pain, or any general discomfort):

Head/Neck:

_____

_____

_____

_____

_____

Shoulder/Clavicle:

_____

_____

_____

_____

_____

_____

Back:

_____

_____

_____

_____

Hip/Pelvis:

Thigh/Knee:

Lower leg/Ankle/Foot:

3.2 Please list any medication being taken currently and/or taken during the last year:

3.3 List any other illness or disorder that a physician has told you of:

4. COMPETITION DATA

4.1 At what level are you competing this year?

4.2 What is the highest level that you competed at last year?

Club:	Provincial:	National:	International:

4.3 How many matches, approximately, have you played?

Club:	Provincial/National:

4.4 What were the highest achievements you attained the past two years?

Achievement	Competition	Date

4.5 What position/s do you usually play during matches?

1.
2.
3.

NORTH-WEST UNIVERSITY
YUNIBESITI YA BOKONE-BOPHIRIMA
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POTCHEFSTROOMKAMPUS

CONFIDENTIAL

Informed consent form
PART 1

1. **School/Institute:**
   School for Biokinetics, Recreation and Sport Science

2. **Title of project/trial:**
   The acute effects of a resisted jump training session on selected physical and motor ability components of university-level rugby players.

3. **Full names, surname and qualifications of project leader:**
   Ben Coetzee, B.Sc., B.Sc. (Hons), M.Sc. and Ph.D

4. **Rank/position of supervisor:**
   (Professor, Lecturer, Research scientist etc.)
   Senior Lecturer

5. **Full names, surname and qualifications of supervisor of the project:**
   (Complete only if not the same person named in 4.)
   Same as above.

6. **Name and address of supervising medical officer *(if applicable)*:**
   Not applicable

7. **Aims of this project**
   The aim of this project is:

- To determine the significant acute effects of a resisted jump training session on selected physical and motor ability components of university-level rugby players.

8. **Explanation of the nature of all procedures, including identification of new procedures:**

a) ***Collection procedures and selection of rugby players.***
The subjects will consist of two groups of rugby players. Thirty u/19 and PUK1 rugby players of the North-West University in Potchefstroom (South Africa) will be randomly selected. The thirty players will in turn also be randomly divided into two groups of fifteen players each. One group will form the experimental group and the other the control group. After the treatment period, a crossover design will be implemented by subjecting the control group to the treatment and allowing the initial experimental group to form the control group.

b) ***Procedures***

i. Demographic and general information questionnaire:
The players' demographic and personal information will be collected by means of a demographic and general information questionnaire. The players' ages, exercising habits,

injury incidence and competing levels will be obtained by means of this questionnaire. Anthropometric data will be collected by taking a few body measurements and the physical and motor ability performance data by means of a test battery.

ii. Anthropometric measurements and components:
The following anthropometric components will be determined in accordance with the methods of Marfell–Jones *et al*. (2006). Body composition, fat mass and skeletal mass will be analyze in this section: Body stature and body mass.

iii. Physical and motor ability components:
The players will be subjected to a test battery for the measurement of lower body flexibility (The Passive-straight-leg-raise- (PSLRT) and The Modified Thomas Quadriceps Test (MTQT), lower body explosive power output (vertical jump test (VJT)), speed and acceleration (20m-speed test), agility (Illinois Agility Run Test (IART) and leg strength (6RM (repetition maximum) Smith Machine Squat Test (SMST)).

iv. Acute treatment – testing procedure:
The first visit to the sport science laboratory will be a habitation trial to familiarize the players to the apparatus to be used and to practise the exercises on the Vertimax. On this visit, players will also complete an informed consent form and a general information questionnaire regarding their exercising habits, playing positions, best performances of the last two years and injury incidence. Once they had completed the last-mentioned forms the exercises and research project will be explained to each player. This will be followed by the execution of the different exercises on the Vertimax. A week after the familiarization period the first testing day will commence. At the start of the session the players will firstly be subjected to a thorough warm-up of more or less 8 min that will consist of aerobic running exercises for more or less 3 min after which a specific warm-up period of shorter, high intensity movements and dynamic stretches will follow. Next, each player's body mass and stature will be taken, after which each player will be subjected to a test battery that will consist of the PSLRT, MTQT, VJT, speed and acceleration test, the IART and the SMST. Five minutes after completion of the test battery the experimental group will be subjected to the resisted jump training session that will consist of three exercises (¼ stick jump, lunge jump and drop jump) that will be executed at a resistance of level 3 for each of the cords that will be attached to the waist belt of each player. Players will perform three sets of six repetitions for each of the exercises and sets. The control group will do the same exercises on the ground without being connected to the Vertimax during the time period that the experimental group perform the resisted jump training session. Directly after the training session each of the players will again complete the test battery. The identical testing protocol will then be repeated a week later, at the exact same time of day, so as to minimize the effects of circadian variations and different metabolic responses. The control group will then be subjected to the resisted jump training session while the experimental group will undergo the normal jump training period. **Description of the nature of discomfort or hazards of probable permanent consequences for the subjects which may be associated with the project:**
(Including possible side-effects of and interactions between drugs or radio-active isotopes which may be used.)
The subjects may experience a bit of muscle discomfort and nausea.

9. Precautions taken to protect the subjects:
The players will perform a proper warm-up before the physical and motor performance tests commence and the testing procedures and methods will be thoroughly explained to each of the players.

10. Description of the benefits which may be expected from this project:
The results should provide coaches, sport scientists and other sport-related professionals with information regarding the acute benefits of a resisted jump training session for improving rugby players' physical, motor ability and anthropometric profile.

11. Alternative procedures which may be beneficial to the subjects:
(Complete only if applicable.)
Training on the Vertimax-apparatus should benefit players more with regard to their physical and motor performance components compared to non-Vertimax training.

Signature:..... **Date:** 26/07/2012
Project leader

PART 2
To the subject signing the consent as in part 3 of this document:
You are invited to participate in a research project as described in paragraph 2 of Part 1 of this document. It is important that you read/listen to and understand the following general principles, which apply to all participants in this research project:

1. Participation in this project is voluntary.
2. It is possible that you personally will not derive any benefit from participation in this project, although the knowledge obtained from the results may be beneficial to other people.
3. You will be free to withdraw from the project at any stage without having to explain the reasons for your withdrawal. However, we would like to request that you would rather not withdraw without a thorough consideration of your decision, since it may have an effect on the statistical reliability of the results of the project.
4. The nature of the project, possible risk factors, factors which may cause discomfort, the expected benefits to the subjects and the known and the most probable, permanent consequences which may follow from your participation in this project, are discussed in Part 1 of this document.
5. We encourage you to ask questions at any stage about the project and procedures to the project leader or the personnel, who will readily give more information. They will discuss all procedures with you.
6. If you are a minor, we need the written approval of your parent or guardian before you may participate.
7. We require that you indemnify the University from any liability due to detrimental effects of treatment by University staff or students or other subjects to yourself or anybody else. We also require indemnity from liability of the University regarding any treatment to yourself or another person due to participation in this project, as explained in Part 1. Lastly it is required to abandon any claim against the University regarding treatment of yourself or another person due to participation in this project as described in Part 1.

PART 3
Consent
Title of the project: The effects of a combined resisted jump training and rugby-conditioning program on selected physical, motor ability and anthropometric components of rugby players.

I, the undersigned …… (Full names) read/listened to the information on the project in PART 1 and PART 2 of this document and I declare that I understand the information. I had the opportunity to discuss aspects of the project with the project leader and I declare that I participate in the project as a volunteer. I hereby give my consent to be a subject in this project.

I indemnify the University, also any employee or student of the University, of any liability against myself, which may arise during the course of the project.

I will not submit any claims against the University regarding personal detrimental effects due to the project, due to negligence by the University, its employees or students, or any other subjects.

……
(Signature of the subject)

Signed at ..... on ……..

Witnesses

1. .....

2. .....

Signed at ..... on ……

For non-therapeutic experimenting with subjects under the age of 18 years the written approval of a parent or guardian is required.

I, ……. ..... (Full names)
Parent or guardian of the subject named above, hereby give my permission that he/she may participate in this project and I also indemnify the University and any employee or student of the University, against any liability which may arise during the course of the project.

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Test Protocol to determine the effects of acute Vertimax-training

RAW DATA FOR THE ACUTE VERTIMAX-PROJECT

NAME OF PLAYER:

TEST COMPONENT	1ST READING	2ND READING	MEAN
BODY MASS (KG)			
BODY STATURE (CM)			
TEST COMPONENT	**1ST READING**	**2ND READING**	**BEST**
L: PASSIVE KNEE EXTENSION TEST (°)			
R: PASSIVE KNEE EXTENSION TEST (°)			
L: ACTIVE KNEE EXTENSION TEST (°)			
R: ACTIVE KNEE EXTENSION TEST (°)			
L: MODIFIED THOMAS QUADS TEST (°)			
R: MODIFIED THOMAS QUADS TEST (°)			
TEST COMPONENT	**1ST TIME**		
VERTEX POLE HEIGHT – REACHING (CM)			
VERTICAL JUMP REACHING HEIGHT (CM)	A		
FINAL VERTICAL JUMP HEIGHT A-B (CM)			
VERTEX POLE HEIGHT – JUMPING (CM)			
TEST COMPONENT	**1ST READING**	**2ND READING**	**HIGHEST**
VERTICAL JUMP HEIGHT (CM)			B
TENDO PEAK POWER (W)			
TENDO SPEED (M/SEC)			
TEST COMPONENT	**1ST READING**	**2ND READING**	**LOWEST**
5M SPEED (SEC)			
10M SPEED (SEC)			
20M SPEED (SEC)			
TEST COMPONENT	**1ST READING**	**2ND READING**	**HIGHEST**
ILLINOIS AGILITY RUN TEST (SEC)			
TEST COMPONENT	**1ST TIME**		
6RM SMITH MACHINE SQUAT TEST (KG)			

APPENDIX C

SUBMISSION GUIDELINES FOR AUTHORS AND ARTICLE EXAMPLES

ARTICLE ONE

Journal of Strength & Conditioning Research
Online Submission and Review System

The Journal of Strength and Conditioning Research (JSCR) is the official research journal of the National Strength and Conditioning Association (NSCA). The JSCR is now published monthly. Membership in the NSCA is not a requirement for publication in the journal. JSCR publishes original investigations, reviews, symposia, research notes, and technical and methodological reports contributing to the knowledge about strength and conditioning in sport and exercise. All manuscripts must be original works and present practical applications to the strength and conditioning professional or provide the basis for further applied research in the area. Manuscripts are subjected to a ‘‘double blind’’ peer review by at least two reviewers who are experts in the field. Editorial decisions will be based on the quality, clarity, style, and importance of the submission relative to the goals and objectives of the NSCA and the journal. Tips for writing a manuscript for the JSCR can be found at http://www.nsca-lift.org/publications/JSCRtips.shtml. Please read this document carefully prior to preparation of a manuscript. Manuscripts can be rejected on impact alone as it relates to how the findings impact evidence based practice for strength and conditioning professionals, end users, and clinicians. Thus, it is important authors realize this when submitting manuscripts to the journal.

The JSCR will now administratively REJECT a paper before review if it is deemed to have very low impact on practice, poor experimental design, and/or poorly written. Additionally, upon any revision the manuscript can be REJECTED if experimental issues and impact are not adequately addressed. The formatting of the paper is also of importance and manuscripts will be sent back if not PROPERLY formatted.

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The editorial mission of the JSCR, formerly the Journal of Applied Sport Science Research (JASSR), is to advance the knowledge about strength and conditioning through research. Since 1978 the NSCA has attempted to ‘‘bridge the gap’’ from the scientific laboratory to the field practitioner. A unique aspect of this journal is the inclusion of recommendations for the practical use of research findings. While the journal name identifies strength and conditioning as separate entities, strength is considered a part of conditioning. This journal wishes to promote the publication of peer-reviewed manuscripts that add to our understanding of conditioning and sport through applied exercise and sport science. The conditioning process and proper exercise prescription impact a wide range of populations from children to older adults, from youth sport to professional athletes. Understanding the conditioning process and how other practices such as such

as nutrition, technology, exercise techniques, and biomechanics support it is important for the practitioner to know.

Original Research

JSCR publishes research on the effects of training program on physical performance and function to the underlying biological basis for exercise performance as well as research from a number of disciplines attempting to gain insights about sport, sport demands, sport profiles, conditioning, and exercise such as biomechanics, exercise physiology, motor learning, nutrition, and psychology. A primary goal of JSCR is to provide an improved scientific basis for conditioning practices.

Article Types

JSCR publishes symposia, brief reviews, technical reports and research notes that are related to the journal's mission. A symposium is a group of articles by different authors that address an issue from various perspectives. The brief reviews should provide a critical examination of the literature and integrate the results of previous research in an attempt to educate the reader as to the basic and applied aspects of the topic. We are especially interested in applied aspects of the reviewed literature. In addition, the author(s) should have experience and research background in the topic area they are writing about in order to claim expertise in this area of study and give credibility to their recommendations.

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Manuscript Clarifications will be considered and will be published online if accepted. Not all requests for manuscript clarifications will be published due to costs or content importance. Each will be reviewed by a specific sub-committee of Associate Editors to determine if it merits publication. A written review with needed revisions will be provided if it merits consideration. Clarifications questions are limited to 400 words and should only pose professional questions to the authors and not editorial comments (as of 19.2). If accepted, a copy will be sent to the author of the original article with an invitation to submit answers to the questions in the same manner again with a 400 word limit.

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The title page should include the manuscript title, brief running head, laboratory(s) where the research was conducted, authors' full name(s) spelled out with middle initials, department(s), institution(s), full mailing address of corresponding author including telephone and fax numbers, and email address, and disclosure of funding received for this work from any of the following organizations: National Institutes of Health (NIH); Wellcome Trust; Howard Hughes Medical Institute (HHMI); and other(s).

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The text must contain the following sections with titles in ALL CAPS in this exact order:

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All references must be alphabetized by surname of first author and numbered. References are cited in the text by numbers [e.g., (4,9)]. All references listed must be cited in the manuscript and referred to by number therein. For original investigations, please limit the number of references to fewer than 45 or explain why more are necessary. The Editorial Office reserves the right to ask authors to reduce the number of references in the manuscript. Please check references carefully for accuracy. Changes to references at the proof stage, especially changes affecting the numerical order in which they appear, will result in author revision fees. End Note Users: The Journal of Strength & Conditioning Research reference style ,ftp://support.isiresearchsoft.com/ pub/pc/styles/endnote4/J Strength Condition Res.ens. may be downloaded for use in the End Note application:ftp://support.isiresearchsoft.com/pub/pc/styles/endnote4/J%20Strength%20Condition %20Res.ens.

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Journal Article

Hartung, GH, Blancq, RJ, Lally, DA, and Krock, LP. Estimation of aerobic capacity from submaximal cycle ergometry in women. Med Sci Sports Exerc 27: 452–457, 1995.

Book

Lohman, TG. Advances in Body Composition Assessment. Champaign, IL: Human Kinetics, 1992.

Chapter in an edited book

Yahara, ML. The shoulder. In: Clinical Orthopedic Physical Therapy. J.K. Richardson and Z.A. Iglarsh, eds. Philadelphia: Saunders, 1994. pp. 159–199.

Software

Howard, A. Moments ½software_. University of Queensland, 1992.

Proceedings

Viru, A, Viru, M, Harris, R, Oopik, V, Nurmekivi, A, Medijainen, L, and Timpmann, S. Performance capacity in middle-distance runners after enrichment of diet by creatine and

creatine action on protein synthesis rate. In: Proceedings of the 2nd Maccabiah-Wingate International Congress of Sport and Coaching Sciences. G. Tenenbaum and T. Raz-Liebermann, eds. Netanya, Israel, Wingate Institute, 1993. pp. 22–30.

Dissertation/Thesis
Bartholmew, SA. Plyometric and vertical jump training.Master's thesis, University of North Carolina, Chapel Hill, 1985.

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Selected conversion factors:

_ 1 N = 0.102 kg (force);

_ 1 J = 1 N_m = 0.000239 kcal = 0.102 kg_m;

_ 1 kJ = 1000 N_m = 0.239 kcal = 102 kg_m;

_ 1 W = 1 J_s-1 = 6.118 kg_m_min-1.

When using nomenclature for muscle fiber types please use the following terms. Muscle fiber types can be identified using histochemical or gel electrophoresis methods of classification. Histochemical staining of the ATPases is used to separate fibers into type I (slow twitch), type IIa (fast twitch) and type IIb (fast twitch) forms.Thework of Smerdu et. al (AJP 267:C1723, 1994) indicates that type IIb fibers contain type IIxmyosin heavy chain (gel electrophoresis fiber typing). For the sake of continuity and to decrease confusion on this point it is recommended that authors use IIx to designate what use to be called IIb fibers. Smerdu, V, Karsch-Mizrachi, I, Campione, M, Leinwand, L, and Schiaffino, S. Type IIx myosin heavy chain transcripts are expressed in type IIb fibers of human skeletal muscle. Am J Physiol 267 (6 Pt 1): C1723–1728, 1994.

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Changes in Selected Physical, Motor Performance and Anthropometric Components of University-Level Rugby Players After One Microcycle of a Combined Rugby Conditioning and Plyometric Training Program

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Abstract

Pienaar, C and Coetzee, B. Changes in selected physical, motor performance and anthropometric components of university-level rugby players after one microcycle of a combined rugby conditioning and plyometric training program. *J Strength Cond Res* 27(2): 398–415, 2013. The purpose of this study was to determine the effects of a microcycle (4 weeks) combined rugby conditioning plyometric compared with a nonplyometric rugby conditioning program on selected physical and motor performance components and anthropometric measurements of university-level rugby players. Players (18.94 ± 0.40 years) were assigned to either a control ($n = 16$) or experimental group ($n = 19$) from the U/19 rugby teams of the North-West University (South Africa). Twenty-six direct and indirect anthropometric measurements were taken, and the players performed a battery of 5 physical and motor performance tests before and after a microcycle (4 week) combined rugby conditioning plyometric (experimental group) and a nonplyometric rugby conditioning program (control group). The dependent *t*-test results showed that the control group's upper-body explosive power decreased significantly, whereas the stature, skeletal mass, and femur breadth increased significantly from pre- to posttesting. The experimental group showed significant increases in wrist breadth, speed over 20 m, agility, and power and work measurements of the Wingate anaerobic test (WAnT). Despite these results, the independent *t*-test revealed that speed over 20 m, average power output at 20 seconds, relative work of the WAnT, and agility were the only components of the experimental group that improved significantly more than the control group. A microcycle combined rugby conditioning plyometric program therefore leads to significantly bigger changes in selected physical and motor performance components of university-level rugby players than a nonplyometric rugby conditioning program alone. Based on these findings, coaches and sport scientists should implement 3 weekly combined rugby conditioning plyometric programs in rugby players' training regimens to improve the players' speed, agility, and power.

Key Words explosive power, agility, speed, body composition, WAnT

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27(2)/398-415

Journal of Strength and Conditioning Research

Introduction

Plyometrics is a specialized high-intensity training technique that enables an athlete's muscles to deliver as much strength as possible in the shortest period for power development to take place (9,13,50). Based on this, it is apparent why plyometric training is regarded as a useful training tool for athletes who participate in dynamic explosive types of sports (52). Research also seems to indicate that team sports such as soccer, baseball, basketball, and volleyball (8,35,53,55) will benefit from plyometric training. Despite the power requirements of rugby union, no studies to date have made an attempt to determine the possible benefits of a combined rugby conditioning and plyometric training program on the physical and motor performance components of rugby union players. It is also unclear whether plyometric training will benefit rugby players' anthropometry in general.

Rugby players need a higher degree of power in the execution of tackles, in acceleration from a static position and during rucking and mauling when scrumming and forceful play take place (17). Line out jumping, breaking through tackles, and fast and effective changes in running direction (agility) when attacking will also require from players to develop their muscle power output optimally (31).

Despite reports that plyometric training does have a significant positive effect on the physical and motor performance components such as agility, speed, the explosive and anaerobic power output of team sport players, few researchers have investigated the effects of a combined sport-specific and plyometric training program on the different components of team sport players. Dodd and Alvar (14) reported greater increases in the vertical jump performance of baseball players when combining heavy resistance and plyometric training programs, over 12 weeks, than when doing either only heavy resistance training or plyometric training alone. Marques et al. (35) found that combining regular volleyball training with plyometric training led to increased performances in maximal strength and in medicine ball throw and countermovement jump tests. Similar findings were reported by Martel et al. (36) who found that combining plyometric training with a traditional volleyball training program led to significantly bigger increases in vertical jump height compared with volleyball training alone. In contrast to the previously mentioned studies, Ronnestad et al. (53) implemented a 7-week plyometric program in addition to regular soccer and resistance training and found no additional benefits by including plyometric training.

Despite the fact that body size and composition (anthropometry) play an important role in the performances of rugby players and determine playing position (5,16), no studies could be traced in which the anthropometric changes of team sport players because of a plyometric training program have been reported. Despite this observation, studies by Paavolainen et al. (43,44) and Luebbers et al. (30) found that the body mass values of runners, cross-country skiers, and physically active college students, respectively, increased significantly during a 9-week period of plyometric training. A 1.3% change in lean body mass after 9 weeks of plyometric training among competitive male cyclists (2) seems to suggest that the positive change in body mass because of plyometric training may possibly be attributed to an increase in lean body mass. This conclusion was also supported by Witzke and Snow (66) who presented evidence that a plyometric program of 9 weeks among adolescent girls brought about a significant increase in peak bone mass, which may possibly influence an athlete's lean body mass positively. An average increase of 7.3% in type II muscle fiber cross-sectional area, which may also benefit a lean body mass–related component, namely, muscle mass, after 8 weeks of plyometric training might also explain the increase in lean body mass (49). The results of research by Ronnestad et al. (53), Mikkola et al. (40), Paton and Hopkins (45), and Spurrs et al. (56) on soccer players, endurance athletes, cyclists, and distance runners did not coincide with the results of the last-mentioned studies. They all concluded that a plyometric program between 5 and 8 weeks did not appear to offer any significant benefit in terms of body mass increases. Similarly, Luebbers et al. (30) and Potteiger et al. (49) failed to demonstrate that a plyometric training program between 4 and 8 weeks among physically active males would lead to any significant changes in body fat percentage.

According to literature, both bone mass and muscle fiber cross-sectional area can be improved by making use of load-bearing activities such as jumping (37), running, and climbing (29). A bone and muscle mass–related body composition characteristic, namely, somatotype and especially the mesomorphic component, will probably also be influenced positively because of an increase in bone and muscle mass (7). In this regard, plyometrics will probably benefit these anthropometric variables because of the load-bearing activities it contains. Also, because of the direct relationships between these anthropometric variables and power, which is a requirement for rugby (17,25), certain plyometric-related anthropometric changes would benefit rugby performance in the long run.

Despite the availability of ample literature that demonstrates the positive effect of plyometric training on performance (10,13), it is still not clear whether combined sport-specific conditioning and plyometric training programs should be implemented and whether the benefits could be extended to team sports such as rugby union. Literature also does not seem to give a clear indication of the period over which a plyometric program must be followed in order to gain significant benefits. The plyometric program durations vary between 4 weeks (6) and 12 weeks (19) with one study that showed improvements after just 3 weeks of training (39).

The purpose of the present study therefore was to investigate the effects of a 4-week combined rugby conditioning and plyometric training program on selected physical, motor performance and anthropometric components of university-level rugby players compared to the effects of a rugby conditioning program alone. This study was the first to explore the effects of a combined rugby conditioning and plyometric training program on rugby players' physical, motor performance and anthropometric components. The results from this study may possibly provide coaches and other sport professionals with information and guidelines that will enable them to plan and set up more effective combined sport-specific conditioning programs.

Methods

Experimental Approach to the Problem

The specific hypothesis under scrutiny was that a rugby conditioning program, combined with plyometric training, will lead to significantly bigger changes in selected speed, agility, anaerobic power output values, body size, lean body, muscle, fat, and skeletal mass and somatotype among university-level rugby players than a rugby conditioning program alone. Therefore, a pre- to posttest randomized design was used for the study, and subjects were randomly assigned to either a control or experimental group. The

experimental group completed 4 weeks of plyometric program in addition to their normal rugby training, whereas the control group continued with their normal rugby conditioning program. Both groups were subjected to the same testing protocol before and after the 4-week conditioning program.

Subjects

Forty rugby players (18.94 ± 0.40 years) from the first and second U/19 rugby teams of the North-West University (Potchefstroom Campus, South Africa) were randomly selected to participate in the study. Approval for the research was granted by the Ethics Committee of the North-West University (number: 06M02). The competitive rugby playing experience of these players varied between 10 and 12 years with an average of 11.26 years. The study design, purpose, and possible risks were explained to the subjects, and written informed consent was obtained from the subjects before the investigation. Subjects also completed a general information questionnaire regarding their exercising habits, injury incidence, and competing level and were randomly assigned to either a control ($n = 20$; age = 18.94 ± 0.38 years; competitive experience in rugby union = 11.25 ± 1.00 years) or experimental group ($n = 20$; age = 18.94 ± 0.42 years; competitive experience in rugby union = 11.26 ± 0.99 years). Positionally, each group consisted of 7 backs (numbered 9–15), whereas 12 forwards (numbered 1–8) made up the experimental group and 9 forwards the control group.

Subjects volunteered to participate in the study and were healthy and free of any injuries during the time of testing and participation in the rugby conditioning training programs. Each subject was instructed to sleep at least 8 hours during the evening and morning before different testing sessions. They also had to abstain from ingesting any drugs or participating in strenuous physical activity that may influence the physical or physiologic responses of the body for at least 48 hours before the scheduled tests. Subjects had to maintain the same diet during the weeks of testing. The subjects arrived at the testing sessions in a rested and fully hydrated state. Only 16 subjects in the control group and 19 subjects in the experimental group executed all the tests, which meant that 5 subjects were excluded from the study. One subject in each of the groups also did not complete the agility T-test but was still included in the study because of the fact that they completed all the other tests.

Training

All subjects were participating in the same rugby conditioning program before, during, and after the testing period. At the time of the study, players were following a preseason program, which was conducted by the same coach and sport scientist to ensure consistency in coaching techniques and

Table 1. Four-week long plyometric training program.

Week	Day	Plyometric exercises
1	1	Power skip, squat jump, double-leg tuck jump, chest pass, step and throw, and two-arm put.
	2	Pike jump, standing long jump, standing jump over barrier, prone back extension, single arm put, and supine leg lift.
	3	Front cone hops, side-to-side push-off, split squat jumps, medicine ball V-sit, rocky full twist, and medicine ball crossover push-ups.
2	1	Double-leg zigzag hop, cycled split squat jumps, lateral jump over barrier, partner straddle sit passes, seated solo twist, and single clap push-up.
	2	Barrier hops, standing long jump with sprint, cone hops with change of direction, pullover throws, kneeling side throw, and bench press throws.
	3	Lateral step-up, alternate push-off, side jumps and sprint, seated Russian twists, plyometric bench press throws, and push-up with weights.
3	1	Front box jump, lateral box jump, side-to-side box shuffle, hammer throw, medicine ball sit-up, and 2 ball medicine push-ups.
	2	Depth jump, depth jump to second box, 3-point stance with single-leg hurdle hop, standing side-to-side pass, medicine ball sit-up and twist, and medicine ball push-ups with a partner.
	3	Pyramiding box hops, depth jump with 180° turn, depth jump with standing long jump, Russian twist walking, depth push-up, and drop and catch push-up.
4	1	Multiple box-to-box jump, depth jump with 360° turn, depth jump over barrier, hip rolls, over the head backward throw, and incline push-up with depth jump.
	2	30-, 60-, and 90-s box drill, depth jump with reach, single-leg depth jump with barrier hop, forward through the legs, lateral shuffle and pass, and quarter-eagle chest pass.
	3	Depth jump with lateral movement, depth jump with pass catching, depth jump with blocking bag, medicine ball grab, power drops, and catch and pass with jump and reach.

programming. The program consisted of field sessions once a day and resistance training sessions 3 times a week that each lasted for more or less 2 hours per training session. The field sessions included skill activities, offensive and defensive drills, and conditioning intervals. Resistance training sessions consisted of more or less 12–16 medium- to high-intensity resistance exercises (70–85% of the 1RM) that were focused on the attainment of muscle hypertrophy and strength. The experimental group also had to participate in plyometric training sessions 3 times a week, for a 4-week period, over and above their normal rugby training. Subjects completed 2 sets of 10 repetitions with a 30-second rest period between sets. These guidelines were followed throughout the 4-week training period. A qualified sport scientist, who was in charge of the U/19 rugby teams' conditioning, supervised all sessions. The plyometric exercises executed are presented in Table 1. All control group subjects were requested to refrain from any plyometric training. Subjects were required to attend at least 92% of all training sessions and not join other type of fitness training programs to be included in the study. The 4-week training period was deemed to be sufficient because of the suggestion made by Luger and Pook (31) that the necessary period for preseason rugby players' training is 4–6 weeks. Furthermore, combined sport conditioning and plyometric training or combined resistance and plyometric training programs of 4 weeks seem to be sufficient in causing significant improvements in speed (over 20, 40, and 60 yd), standing broad jump, T-agility performance and vertical jump height and power, respectively, among groups of trained baseball (14) and volleyball players (39).

Testing Procedures

The players underwent 4 days of testing: 2 pretest and 2 posttest days, respectively. A week before the official testing week, each player was familiarized with the testing procedures and plyometric training programs. On the first pretest day, subjects completed a questionnaire, together with the informed consent form after which the anthropometric measurements were taken and this was followed by the execution of an intensive, dynamic, rugby-specific warm-up for more or less 15 minutes. Finally, a test battery that consisted of the 3-kg medicine ball put, vertical jump, acceleration, and speed and the Wingate anaerobic tests (WAnT) was performed. After a period of 48 hours, the next testing session followed on the exact same time of day so as to minimize the effects of circadian variations in different test results. Again, a warm-up was performed before the completion of the agility T-test. All experimental group subjects were then subjected to 4 weeks of plyometric training, which was performed in conjunction with their normal rugby training program. The control group only continued with their normal rugby conditioning program for the 4-week period. After the 4-week period, the players were again tested at the exact same time of day (posttest day) and same day of the week as the

Table 2. Descriptive statistics and range for the pre- and posttest and group result differences for body fat–related measurements.*†

	Control group ($n = 16$)		Experimental group ($n = 19$)	
Measurements	Pre	Post	Pre	Post
SUM6SF (mm)	66.19 ± 22.20	65.11 ± 21.75	73.64 ± 29.53	72.30 ± 28.42
Range	35.00–117.00	31.75–105.50	30.50–137	36.50–138.25
Body fat %	11.11 ± 3.47	10.94 ± 3.39	12.28 ± 4.62	12.07 ± 4.43
Range	6.20–19.11	5.71–17.20	5.52–22.22	6.43–22.42
Biceps SF (mm)	4.77 ± 1.97	4.97 ± 2.34	5.24 ± 2.80	5.04 ± 2.91
Range	2.75–9.50	3.00–11.50	2.50–15.00	2.00–14.25
Triceps SF (mm)	9.61 ± 3.33	9.41 ± 4.20	10.42 ± 4.08	9.96 ± 3.89
Range	5.50–16.50	5.00–20.50	4.25–18.75	4.50–19.25
Subscapular SF (mm)	9.91 ± 2.88	9.59 ± 2.59	11.95 ± 6.24	11.93 ± 6.34
Range	6.50–15.00	6.00–13.25	5.50–29.00	6.00–28.50
Abdominal SF (mm)	14.14 ± 5.93	14.14 ± 6.03	16.51 ± 8.00	15.67 ± 7.61
Range	5.75–26.00	5.25–25.50	6.00–32.00	6.50–31.75
Supraspinale SF (mm)	8.41 ± 4.01	8.14 ± 3.15	10.14 ± 6.44	9.57 ± 4.87
Range	3.00–17.75	3.75–16.25	3.50–31.00	4.00–23.00
Front thigh SF (mm)	14.59 ± 6.57	14.62 ± 5.09	14.70 ± 5.51	14.93 ± 5.38
Range	7.00–34.00	6.75–26.00	4.50–24.50	7.75–26.25
Calf SF (mm)	9.53 ± 3.35	9.20 ± 2.97	10.03 ± 3.68	10.24 ± 3.93
Range	4.75–16.25	5.00–14.50	3.50–17.75	4.00–18.00

*SUM6SF = sum of the 6 skinfolds; SF = skinfold.
†Values are presented as mean ± *SD*; range = minimum–maximum.

Table 3. Descriptive statistics and range for the pre- and posttest and group result differences for girth and breadth measurements.*

	Control group ($n = 16$)		Experimental group ($n = 19$)	
Measurements	Pre	Post	Pre	Post
Relaxed arm girth (cm)	32.64 ± 2.62	32.42 ± 2.64	32.68 ± 3.44	33.22 ± 2.89
Range	28.65–36.80	27.90–36.50	23.85–37.85	29.00–37.70
Flexed arm girth (cm)	35.62 ± 2.65	35.70 ± 2.39	36.25 ± 2.39	36.57 ± 2.67
Range	32.00–40.00	32.00–39.65	31.60–39.85	32.55–40.30
Forearm girth (cm)	28.97 ± 1.69	28.77 ± 1.36	29.69 ± 1.77	29.51 ± 1.99
Range	25.65–31.50	26.50–31.00	27.35–33.70	26.00–34.00
Thigh girth (cm)	56.60 ± 4.10	55.93 ± 4.14	58.23 ± 5.75	57.70 ± 6.08
Range	49.30–62.80	49.05–62.55	51.20–73.80	48.70–74.80
Calf girth (cm)	37.79 ± 2.83	37.74 ± 2.66	39.47 ± 3.84	39.47 ± 3.83
Range	34.30–44.05	34.80–43.50	33.35–48.55	33.35–48.20
Ankle breadth (cm)	7.44 ± 0.52	7.55 ± 0.43	7.79 ± 0.49	7.86 ± 0.51
Range	6.70–8.35	6.85–8.25	6.80–8.60	6.80–8.70
Femur breadth (cm)	9.91 ± 0.53	10.08 ± 0.62†‡	10.34 ± 0.58	10.48 ± 0.77
Range	9.00–10.85	9.00–11.05	9.35–11.40	9.25–11.80
Humerus breadth (cm)	7.17 ± 0.35	7.22 ± 0.50	7.36 ± 0.40	7.38 ± 0.48
Range	6.40–7.80	6.30–7.85	6.55–7.90	6.35–7.95
Wrist breadth (cm)	5.80 ± 0.38	5.91 ± 0.35	7.79 ± 0.49	7.86 ± 0.51†‡
Range	5.20–6.65	5.30–6.50	6.80–8.60	6.80–8.70

*Values presented as mean ± *SD*, range = minimum–maximum.
†Pre- and postvalues within group are significantly different ($p \leq 0.05$).
‡Small effect size (ES = 0.2).

pretest day to minimize the effect of circadian variations in the test results.

Anthropometric Measurements

Firstly, each subject was landmarked by one of the certified anthropometrists, after which they were directed stations where the different anthropometric measurements were taken. Body fatness was determined by means of a Harpenden skinfold caliper (Holtain Limited, Crosswell, Crymych, Pembrokeshire, United Kingdom) with a constant pressure of 10 g/mm^2, to measure subcutaneous adipose tissue, and was calculated through the sum of the following skinfolds: triceps, subscapular, abdominal, supraspinal, front thigh, and calf skinfolds as per the formulas of Withers et al. (65). All measurements were taken at the right side of the body and recorded to the nearest 0.2 mm. Muscle and skeletal mass was calculated according to the formulas of Lee et al. (28) and Drinkwater and Mazza (15). Body stature was recorded to the nearest 1 cm by means of a stadiometer (Harpenden Portable Stadiometer; Holtain Limited, United Kingdom), and body mass was recorded to the nearest 0.1 kg with a portable electronic scale (BFW 300 Platform Scale; Adam Equipment Co. Ltd., Milton Keynes, United Kingdom). Ankle, femur, humerus, and wrist breadths were measured

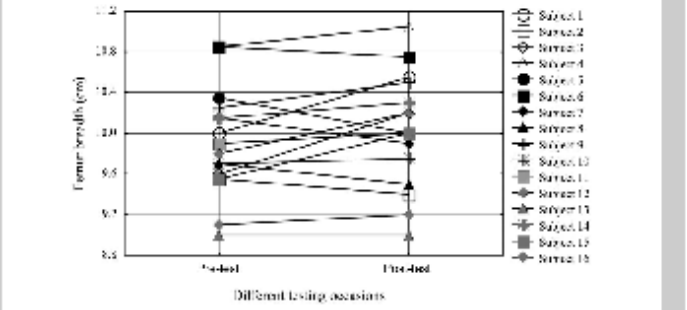

Figure 1. Changes in femur breadth measurements from pre- to posttesting for the control group.

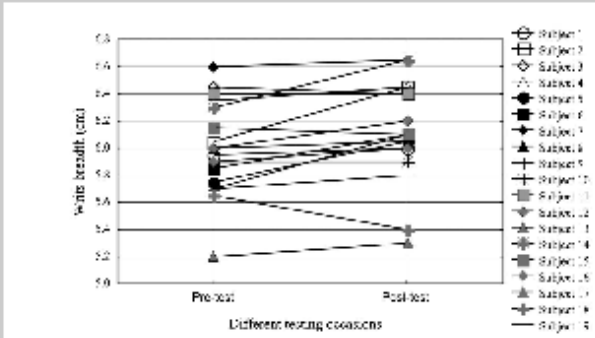

Figure 2. Changes in wrist breadth measurements values from pre- to posttesting for the experimental group.

by making use of a small sliding caliper (Holtain Bicondylar Calipers; Holtain Limited, United Kingdom) and recorded to the nearest 0.1 cm. Girth measurements were taken with a flexible steel tape (Lufkin W606PM; Cooper Industries, Sparks, MD, USA) and were also recorded to the nearest 0.1 cm. Girth measurements included the relaxed and contracted upper arm, forearm, thigh, and calf girths. All measurements were taken by International Society for the Advancement of Kinanthropometry Level 2–accredited anthropometrists.

Arm, midthigh, and calf girth were corrected for the different skinfolds at these sites, by using the following formula: corrected girth = girth − (π × skinfold thickness). The average technical error of measurement (46) for all the anthropometric measurements was 6.36%. The average test-retest reliability coefficient of the pretest day's anthropometric measurements was calculated to be 0.88 compared with the average value of 0.95 for the posttest day.

Performance Tests

Explosive Power Test. Upper-body explosive power was measured by means of the seated 3 kg Medicine Ball Put

Table 4. Descriptive statistics, range, and significance for the pre- and posttest and group result differences for body stature, body mass, muscle and skeletal mass, and somatotype measurements.*

	Control group (n = 16)		Experimental group (n = 19)	
Measurements	Pre	Post	Pre	Post
Body stature (cm)	179.81 ± 7.88	180.33 ± 8.2†‡	183.38 ± 7.94	183.76 ± 8.10†‡
Range	166.40–199.30	166.70–199.10	166.40–199.80	166.90–202.00
Body mass (kg)	82.58 ± 10.74	82.91 ± 10.72	89.96 ± 13.49	90.05 ± 13.47
Range	62.20–98.50	63.20–98.60	62.40–115.10	62.60–116.00
Muscle mass (kg)	28.34 ± 2.35	28.4 ± 2.4	30.16 ± 3.18	30.14 ± 3.22
Range	24.38–32.4	24.55–32.88	24.58–36.72	23.80–37.13
Muscle mass %	34.59 ± 2.09	34.47 ± 2.04	33.79 ± 2.28	33.71 ± 2.09
Range	31.64–39.20	32.04–38.85	29.68–39.40	30.49–38.03
Skeletal mass (kg)	9.97 ± 1.34	10.30 ± 1.46†‡	10.95 ± 1.30	11.22 ± 1.50
Range	7.52–12.51	7.72–12.73	8.48–13.00	8.16–13.21
Skeletal mass %	12.14 ± 1.26	12.46 ± 1.23	12.28 ± 1.18	12.56 ± 1.42
Range	10.18–14.70	10.74–14.88	10.29–14.79	9.97–14.90
Mesomorphy	6.20 ± 1.18	6.33 ± 1.15	5.82 ± 1.49	5.93 ± 1.56
Range	4.27–8.33	4.45–8.54	3.32–8.14	3.15–8.64
Endomorphy	2.63 ± 0.91	2.54 ± 0.97	2.97 ± 1.52	2.88 ± 1.38
Range	1.36–4.22	1.31–4.88	1.26–6.78	1.31–6.27
Ectomorphy	1.73 ± 1.07	1.77 ± 1.11	1.71 ± 1.15	1.75 ± 1.15
Range	0.08–3.75	0.05–3.74	0.10–3.52	0.10–3.71

*Values presented as mean ± *SD*, range = minimum–maximum.
†Pre- and postvalues within group are significantly different ($p \leq 0.05$).
‡Small effect size (ES = 0.2).

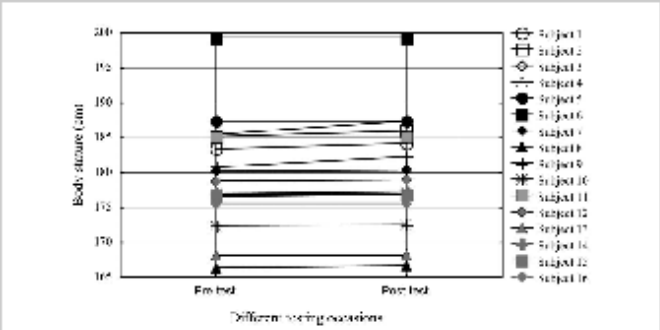

Figure 3. Changes in body stature measurements from pre- to posttesting for the control group.

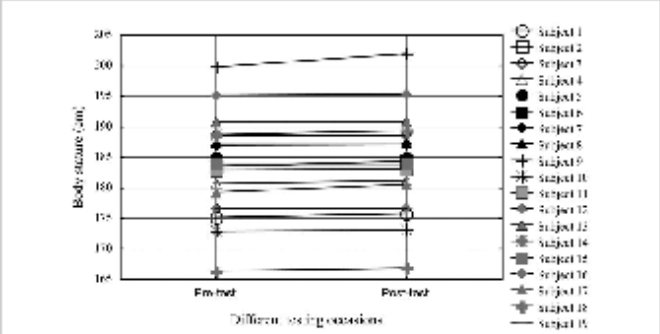

Figure 4. Changes in body stature measurements from pre- to posttesting for the experimental group.

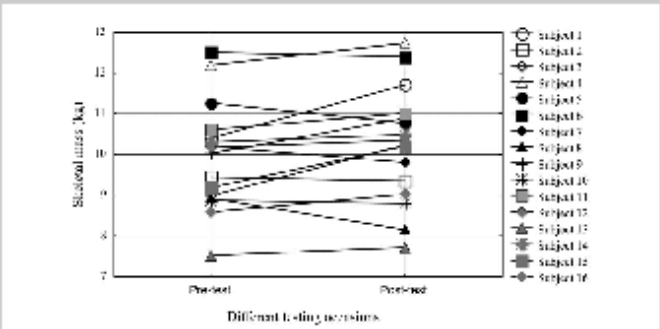

Figure 5. Changes in skeletal mass values from pre- to posttesting for the control group.

Test (3 kg MBPT) according to the method of Ball (1). The seated medicine ball put test is regarded as an objective ($r = 0.99$) (20), valid ($r = 0.77$–0.90) (21,26), and reliable test ($r = 0.77$–0.99) (20) to assess the muscular power of the arms and shoulder girdle (1). Subjects were instructed to sit up straight with the upper back area against a wall and the legs extended straight to the front. Subjects were not allowed to move the upper back from the wall during the put action with a view to eliminate the use of momentum. Subjects were instructed to place the palms of their hands on the sides of the ball in a manner as to prevent cocking of the wrists. When ready, the subjects drew the ball back against the chest and forcefully pushed it forward and upward. The arc of the ball was controlled by a ring that was positioned 2 m in front of the subject at a height that controlled the angle of release to be approximately 45°. Subjects were given 2 practice trials, followed by 3 maximal efforts with a rest period of 30 seconds between each effort. The best distance of the 3 maximal efforts was recorded to the nearest centimeter. The test-retest reliability for the 3 measurements of the pretest day was found to be 0.63 and for the posttest day 0.53.

Lower body explosive power was measured by means of the vertical jump test (VJT) according to the method of Ellis et al. (18). The VJT is regarded as an objective ($r = 0.90$) and valid test ($r = 0.93$) to determine the peak anaerobic power output of subjects (54). Subjects were instructed to stand against a wall to which a measuring stick was attached, with the dominant arm's shoulder and the

Table 5. Descriptive statistics, range, and significance of the pre- and posttest and group result differences for the explosive power, speed, and agility measurements.*†

	Control group (n = 16)		Experimental group (n = 19)	
Measurements	Pre	Post	Pre	Post
3 kg MBPT (m)	4.78 ± 0.36	4.41 ± 0.42‡§	4.64 ± 0.44	4.63 ± 0.49
Range	3.97–5.31	3.75–5.54	4.00–5.68	3.70–5.98
VJT (cm)	50.63 ± 6.8	51.56 ± 6.22	50.84 ± 6.59	51.84 ± 7.49
Range	41.00–69.00	40.00–63.00	43.00–67.00	43.00–70.00
VJT (W)	1,268.5 ± 169.06	1,286.65 ± 175.52	1,386.63 ± 214.65	1,401.10 ± 223.65
Range	981.27–1,539.21	978.84–1,610.73	956.16–1,728.04	978.22–1,777.47
Speed 5 m (s)	1.14 ± 0.17	1.14 ± 0.18	1.22 ± 0.16	1.14 ± 0.1
Range	0.98–1.58	0.80–1.45	1.04–1.59	1.00–1.31
Speed 10 m (s)	1.90 ± 0.19	1.90 ± 0.16	1.98 ± 0.18	1.92 ± 0.12
Range	1.70–2.40	1.60–2.25	1.77–2.43	1.78–2.19
Speed 20 m (s)	3.22 ± 0.24	3.26 ± 0.19	3.34 ± 0.25	3.25 ± 0.16‖¶#**
Range	2.94–3.80	2.90–3.65	3.03–3.91	3.01–3.66
ATT	10.28 ± 0.57‡	10.35 ± 0.5‡	10.72 ± 0.49††	10.42 ± 0.54‖¶‡‡††§§
Range	9.45–11.23‡	9.80–11.39‡	10.04–11.57††	9.56–11.38††

*Data are mean ± SD.
†MBPT = Medicine Ball Put Test.
‡n = 15.
‖Pre- and postvalues within group are significantly different ($p \leq 0.05$).
§Pre and post-values within control group show large practically significant differences (ES ≥ 0.8).
¶Changes in pre- and posttraining values within the control vs. experimental group are significant ($p \leq 0.05$).
#Small effect size (ES ~ 0.2).
**Medium effect size: control vs. experimental group (ES ~ 0.5).
††n = 18.
‡‡Medium/moderate effect size (ES ~ 0.5).
§§Large effect size: control vs. experimental group (ES ≥ 0.8).

dominant leg's foot against the wall. By keeping the heels on the floor, the subjects were requested to reach upward as high as possible. An arm swing and countermovement was allowed after which the players had to jump as high as possible and touch the measuring stick at the highest possible point. This distance was then recorded as the highest jumping distance. The difference between the reaching and jumping distance was then calculated and recorded to the nearest 1 cm. The subjects performed a minimum of 2 trials with a 30-second rest period between each trial. The better of the 2 trials were recorded for the purpose of data analysis. The test-retest reliability for the 2 measurements of the pretest day was found to be 0.84 and for the posttest day 0.95. Power values were derived from the formula of Foster et al. (20): power (W) = 21.67 × body mass (kg) × vertical displacement (m)$^{0.5}$.

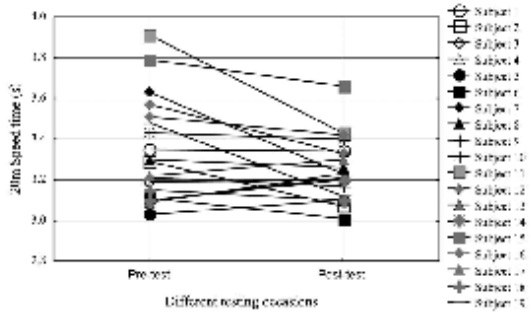

Figure 6. Changes in 20 m sprint times from pre- to posttesting for the experimental group.

Acceleration and Speed. The acceleration and running speed of the players were determined by means of a 5-, 10-, and 20-m maximal sprinting effort. The sprint over a specified distance is seen as an objective, reliable, and valid test to determine the acceleration and speed of subjects (22). Ellis et al. (18) reported that players rarely run further than 20 m in a straight line during a game,

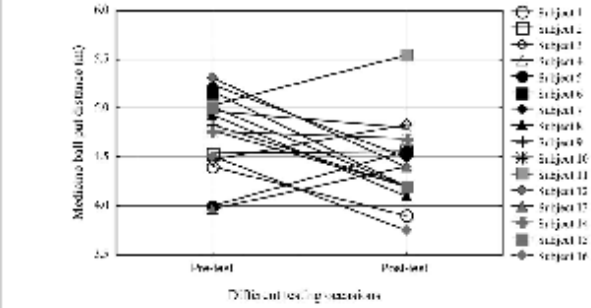

Figure 7. Changes in medicine ball put test distances from pre- to posttesting for the control group.

and this is the reason for a 20 m sprint test. Intermediate beam electronic timing gates (Brower Timing Systems, Draper, UT, USA) were set at 0-, 5-, 10-, and 20-m intervals on a section of the rugby field. The subjects were instructed to start when ready from a standing position with the front foot on the starting line, so as to eliminate the possible influence of reaction time. Subjects were also instructed to wear their rugby boots during testing. The subjects were requested to sprint as fast as possible through the finishing line, making sure not to slow down before the finishing line. Split times (at 5 and 10 m) and final time (20 m) for 3 trials, with a 2-minute rest period between each, were recorded to the nearest 0.01 seconds. The best times for 5, 10, and 20 m were used in the final analysis. The average test-retest reliability coefficient of the pretest day's speed measurements was calculated to be 0.80 compared with the average value of 0.47 for the posttest day.

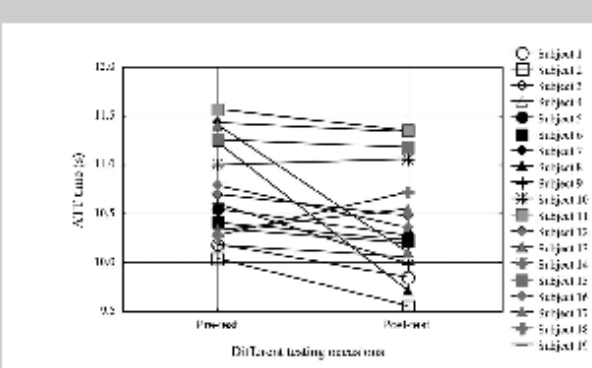

Figure 8. Changes in ATT times pre- to posttesting for the experimental group. ATT = agility T-test.

Agility T-Test. Players' agility was evaluated by using the ATT according to the method of VanHeest et al. (62). The T-test was also performed on the rugby field, and subjects were again instructed to perform the test in their rugby boots. The subjects were instructed to sprint from a standing starting position to a cone 9 m away, followed by a side shuffle left to a cone 4.5 m away. After touching the cone, the subjects side shuffled to the cone 9 m away and then side shuffled back to the middle cone. The test was concluded by back pedaling to the starting line. The test score was recorded as the best time of 2 trials, to the nearest 0.01 second. A 2-minute rest period was allowed between each trial. Subjects were disqualified if they failed to touch the base of any cone, crossed the one foot in front of the other, or failed to face forward for the entire test. The test-retest reliability for the 2 measurements of the pretest day was found to be 0.89 and for the posttest day 0.80.

Wingate Anaerobic Test. The WAnT was implemented to evaluate the anaerobic power and capacity of the players. The WAnT is considered an objective ($r = 0.84–0.88$) and valid ($r = 0.94–0.98$) test to determine the anaerobic power and capacity of subjects (24). The test was conducted as per the method described by Inbar et al. (24). The WAnT consisted of a 30-second period during which the subjects were instructed to pedal maximally on a Monark 834 bicycle ergometer (Monark Exercise AB, Varberg, Sweden), at a resistance of 0.1 g/kg body mass for the duration of the period. The players prepared for the test with a 5-minute standardized submaximal warm-up. The test began with a pedal frequency of about 60 revolutions per minute and a low braking force to facilitate the control of pedal cadence. When the players were able to maintain a constant pedal cadence, a countdown started and the full braking force was applied to signal the start of the test. The feet were stabilized to the pedals with stirrups. The players were

Table 6. Descriptive statistics, range, and significance of the pre- and posttest and group result differences for the WAnT.*

Measurements	Control group ($n = 16$)		Experimental group ($n = 19$)	
	Pre	Post	Pre	Post
Peak power (W)	1,129.62 ± 234.46	1,134.21 ± 160.38	1,097.35 ± 190.17	1,170.03 ± 199.54†
Range	828.18–1,635.54	863.80–1,396.11	760.20–1,424.17	832.00–1,524.41
Average power (W)	760.51 ± 92.51	782.57 ± 94.21	763.71 ± 127.49	811.40 ± 127.52†
Range	575.29–897.91	619.74–994.78	515.87–1,016.19	565.10–1,098.82
Relative peak power (W/kg)	13.83 ± 2.94	13.82 ± 2.05	12.32 ± 2.05	13.15 ± 2.4†
Range	8.53–19.92	8.92–17.64	8.61–15.52	9.43–17.54
Average relative power (W/kg)	9.30 ± 1.27	9.54 ± 0.94	8.49 ± 1.52	9.10 ± 1.38‡
Range	6.26–11.82	6.93–10.94	5.61–10.91	6.18–11.19
Total work (J)	22,815.34 ± 2,775.34	23,476.99 ± 2,826.43	22,911.30 ± 3 824.70	24,341.92 ± 3,825.52‡
Range	17,258.70–26,937.30	18,592.20–29,843.40	15,476.10–30,485.70	16,953.00–32,964.60
Relative total work (J/kg)	279.13 ± 37.99	284.95 ± 28.00	257.78 ± 43.63	272.86 ± 39.36‡§
Range	187.79–354.63	210.70–328.32	168.77–323.71	185.28–335.66
Fatigue ratio (%)	52.71 ± 10.79	51.15 ± 5.68	49.55 ± 10.01	51.04 ± 8.89
Range	31.76–64.77	42.70–64.55	31.76–72.42	29.37–62.54
Average W 5 s	1,129.25 ± 233.5	1134.13 ± 160.46	1097.32 ± 190.15	1,170.05 ± 199.47†
Range	828.00–1,636.00	864.00–1,396.00	760.00–1,424.00	832.00–1,524.00
Average W 10 s	818.69 ± 108.64	875.06 ± 106.58	833.42 ± 184.73	898.21 ± 159.50‡
Range	542.00–949.00	719.00–1,118.00	454.00–1,164.00	559.00–1,233.00
Average W 15 s	773.69 ± 118.38	793.63 ± 102.59	785.42 ± 136.83	814.74± 139.54†
Range	512.00–1,029.00	591.00–1,007.00	486.00–1,079.00	551.00–1,127.00
Average W 20 s	710.75 ± 107.32	705.31 ± 84.79	693.32 ± 129.70	748.16 ± 130.47‡§
Range	524.00–938.00	542.00–914.00	477.00–949.00	506.00–1,031.00
Average W 25 s	601.44 ± 99.01	632.38 ± 87.97	636.11 ± 107.10	673.74 ± 125.12†
Range	407.00–724.00	469.00–832.00	447.00–847.00	407.00–895.00
Average W 30 s	516.31 ± 69.34	551.19 ± 84.31	545.68 ± 108.14	566.32 ± 108.96
Range	354.00–628.00	410.00–701.00	297.00–730.00	380.00–782.00

*Data are mean ± *SD*.
†Pre- and postvalues within group are significantly different ($p \leq 0.05$).
‡Pre- and postvalues within group are significantly different ($p \leq 0.01$).
§Changes in pre- and posttraining values within the control vs. experimental group are significant ($p \leq 0.05$).

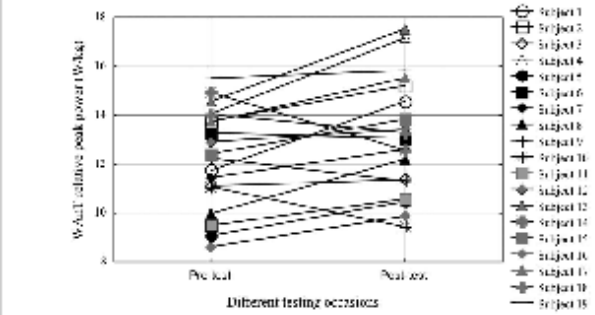

Figure 9. Changes in WAnT relative peak power values from pre- to posttesting for the experimental group.

instructed to sprint maximally from the start of the test and were requested not to pace themselves through the testing period. The peak power, relative peak power, average power, relative average power, total work, relative total work, and fatigue rate of each subject were then calculated from the test. The average test-retest reliability coefficient of the pretest day's measurements was calculated to be 0.66 compared with the average value of 0.93 for the posttest day.

Statistical Analyses

The Statistical Consultation Services of the North-West University determined the statistical methods and procedures for the analyses of the research data. The Statistical Data Processing Package (57), which is available on the North-West University Web site, was used to process the data. The descriptive statistics (averages, *SD*s, and minimum and maximum values) of each test variable and anthropometric measurement were first calculated. This was followed by the calculation of technical error of measurement for all the anthropometric measurements according to the method of Pederson and Gore (46). Next, the Cronbach's alpha coefficient of reliability was calculated for each measurement that was taken on the separate test days. Dependent *t*-tests were done to reveal the significant changes between the pre- and posttest results, and independent *t*-tests were then done to determine the significance of pre- and posttest changes between the control and experimental groups. In all analyses, the level of significance was set at $p \leq 0.05$. Effect sizes (ESs) were calculated for pre- and posttest results in each group and for differences between the experimental and control groups to determine practical significance for all the values, which showed statistical significance. Effect sizes (expressed as Cohen's *d* value) can be interpreted as follows: an ES of more or less 0.8 is large, an ES of more or less 0.5 is moderate, and an ES of more or less 0.2 is small (59). Last, spaghetti graphs were compiled for each of the test variables and anthropometric measurements that revealed significant changes from pre- to posttesting to identify responders and nonresponders.

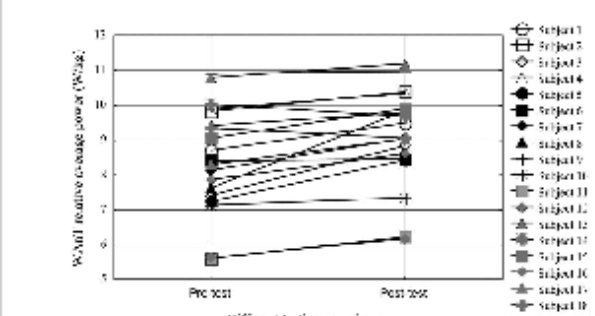

Figure 10. Changes in WAnT relative average power values of from pre- to posttesting for the experimental group.

Results

Anthropometric Measurements

Results of the descriptive statistics for the pre- and posttest and group result differences (dependent and independent *t*-test results) for the experimental and control groups with regard to body fat–related measurements are presented in Table 2. No statistical or practical significance was observed for pre- to posttest changes in any of the body fat–related measurements.

Results of the descriptive statistics with regard to the girth and breadth measurements are presented in Table 3. No statistical or practical significance

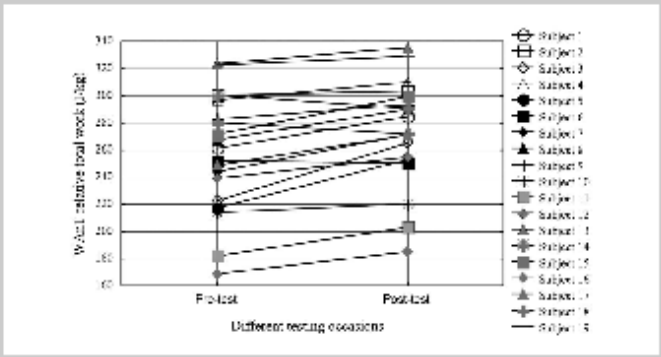

Figure 11. Changes in WAnT relative total work values from pre- to posttesting for the experimental group.

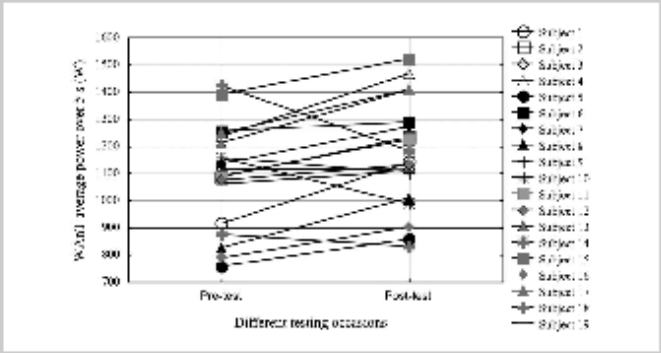

Figure 12. Changes in WAnT average power over 5 seconds from pre- to posttesting for the experimental group.

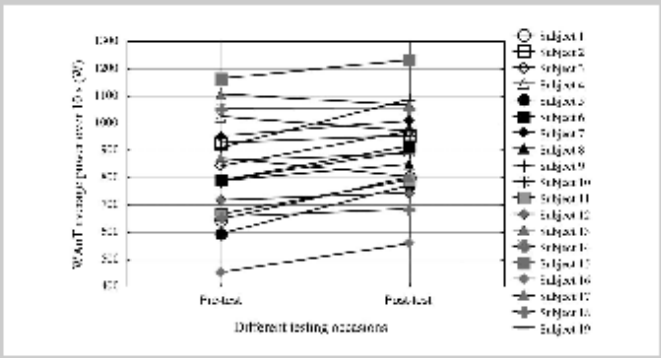

Figure 13. Changes in WAnT average power over 10 seconds from pre- to posttesting for the experimental group.

was observed in any of the girth measurement changes of the test subjects. However, statistically significant increases were seen for femur breadth among the control group subjects and for wrist breadth among the experimental group subjects. The pre- to posttest changes did, however, not obtain high practically significant values.

Figures 1 and 2 display the spaghetti graphs of the pre- and posttest values for femur breadth of the control group and for wrist breadth of the experimental group. From the figures, it is clear that 10 control group subjects responded positively to the rugby conditioning program with regard to femur breath, whereas 13 experimental group subjects showed positive responses with regard to wrist breadth after completion of the combined rugby conditioning and plyometric training program.

Results of the descriptive statistics for the pre- and posttest and group result differences (dependent and independent *t*-test results) of the experimental and control groups for body stature, body mass, muscle and fat percentage, and somatotype are presented in Table 4. Body stature showed a significant increase ($p \leq 0.05$) from pre- to posttesting for both the control and experimental groups, whereas skeletal mass showed a significant increase ($p \leq 0.05$) for only the control group. No statistically or practically significant changes were observed in any of the somatotype-related values for the different groups or between groups. Again, none of the last-mentioned measurements showed high practically significant changes.

Figures 3 and 4 display the spaghetti graphs of the

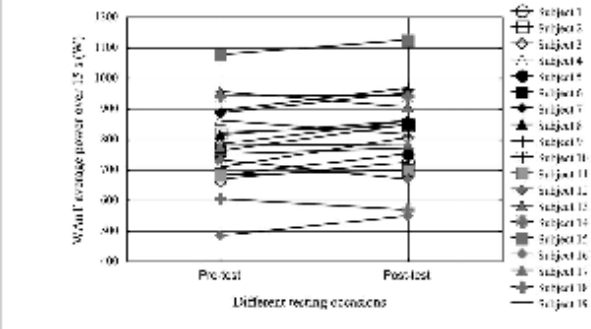

Figure 14. Changes in WAnT average power over 15 seconds from pre- to posttesting for the experimental group.

pre- and posttest values for body stature of the control and experimental groups, respectively. Ten of the control and 10 of the experimental group subjects showed increases in body stature height from pre- to posttesting. The spaghetti graphs for skeletal mass changes of the control group from pre- to posttesting are displayed in Figure 5. Ten of the control subjects responded positively with regard to their skeletal mass values.

Explosive Power, Speed, and Agility Measurements

As Table 5 indicates, the experimental group experienced statistically significant decreases in speed over 20 m and ATT times during the training period. Cohen's effects size revealed a small (ES ~ 0.2) and medium practical significance (ES ~ 0.5) for the named measurements. The independent *t*-test results of the last-mentioned variables also showed statistically and medium and large practically significant values, respectively, when the control group was compared with the experimental group. The control group obtained a statistically ($p \leq 0.01$) and practically significant (ES $\geq$ 0.8) lower medicine ball put test result from pre- to posttesting.

Figures 6–8 present the spaghetti graphs of the pre- and posttest values for the medicine ball put test of the control group and 20-m speed and ATT times of the experimental group, respectively. Eleven of the control group subjects responded negatively with regard to the rugby conditioning program when their medicine ball put test values were analyzed. Thirteen subjects of the experimental group decreased their speed and 15 subjects their ATT times from pre- to posttesting.

Wingate Anaerobic Test Measurements

Table 6 lists the WAnT results. A significant training effect ($p \leq 0.05$) was seen in the experimental group for peak power, average power, relative peak power, relative average power, total work, relative total work, and average power over 5, 10, 15, 20, and 25 seconds. None of the variables, which displayed statistically significant changes, obtained large practically significant values. The change in average power at 20 seconds was significantly better for the experimental group than for the control group. Again, only a medium ES value was obtained when this change was analyzed.

Figures 9–16 present the spaghetti graphs of the pre- and posttest values for the different WAnT results of the experimental group, which displayed significant changes. The number of subjects who responded positively to the combined rugby conditioning and plyometric training program, with regard to the named WAnT variables, is as follows: 15 subjects in relative peak power and average power over 15 seconds, 17 subjects in relative average power and average power over 20 seconds,

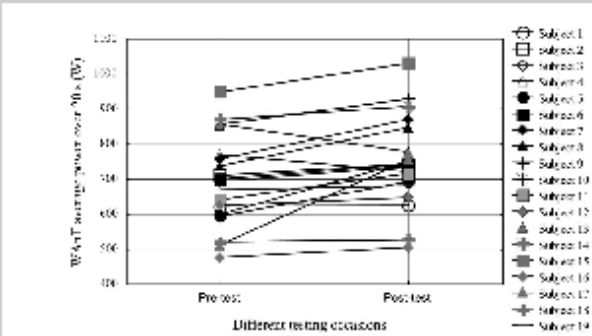

Figure 15. Changes in WAnT average power over 20 seconds from pre- to posttesting for the experimental group.

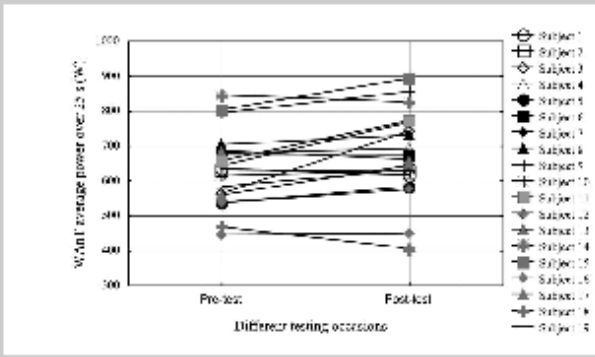

Figure 16. Changes in WAnT average power over 25 seconds from pre- to posttesting for the experimental group.

16 subjects in relative total work and average power over 10 seconds, and 14 subjects in average power over 5 seconds and average power over 25 seconds.

Discussion

The study succeeded in showing that a combined rugby conditioning and plyometric training program of 4 weeks led to significantly bigger changes in certain speed, agility, and anaerobic power output values among university-level rugby players than a rugby conditioning program alone. Furthermore, the results of the present study indicated that both types of conditioning programs had a significantly positive effect on the wrist breadth measurements of the players. Finally, the study results revealed that femur breadth and skeletal mass was significantly increased by participation in a 4-week long rugby conditioning program. None of the anthropometric components did, however, display a significantly bigger change because of the combined rugby conditioning and plyometric training program, compared to a rugby conditioning program alone.

No other studies have been conducted to assess the effects of a combined rugby conditioning and plyometric training program on selected physical, motor performance and anthropometric components, which made it difficult to directly compare the results of this study with similar studies. However, several studies have investigated the effects of combined sport-specific and plyometric programs on a wide range of variables. In this regard, a study by Wilkerson et al. (63) showed no significant improvements in ATT times after completion of a 6-week combined plyometric and basketball conditioning program by female basketball players. In the present study, the combined plyometric and rugby conditioning program resulted in a statistically and practically significant decrease in average ATT times. The group that participated in the combined program also displayed significant pre- to posttest ATT time changes compared with the group that only executed the rugby conditioning program alone. The combined program had a similar effect on the 20 m speed times when the pre- to posttest changes of the control and experimental groups were compared. Dissimilarly, a 7-week combined plyometric and soccer conditioning program did not lead to significantly lower 40 m sprint times than those of a soccer conditioning program alone in a group of professional soccer players (53).

Although this study design may not explain the reasons underlying the improvements in agility and speed because of the combined plyometric training program in this study, several authors have purposed the following: plyometric-related programs may promote changes within the neuromuscular system that enhances neuromuscular efficiency. In this regard, research evidence suggests that more motor units are stimulated and activated or the neural firing frequency is enhanced because of plyometric training (38). The activation of more motor units would enable the muscle to generate more power compared with what was previously possible. Furthermore, Swanik et al. (58) concluded that the sensitivity of the muscle spindle system may increase because of a plyometric training program and that this adaptation may lead to enhanced joint proprioception of the participants. Plyometric training also seems to enhance kinesthesia, which, together with an enhanced joint proprioception, may increase functional stability (58). Moreover, Kubo et al. (27) demonstrated that the jump performance gains after plyometric training can be attributed to changes in the mechanical properties of the muscle-tendon complex. Notably, the authors observed that plyometric training significantly increased the maximal Achilles tendon elongation and the amount of stored elastic energy together with an increase in the stretch-shortening cycle jumping performance. It can be postulated that a more compliant muscle-tendon unit would improve stretch-shortening cycle jumping performance by allowing the muscle fibers to operate at a more optimal length over the first part of the shortening phase (34).

Another possible neuromuscular adaptation that plyometric training appears to induce is the reduction in the time required for voluntary muscle activation, which may facilitate faster changes in movement direction and an accompanied decrease in the ATT time (63). This finding was also supported by Hutchinson et al. (23), who presented evidence that a leap training program led to significant improvements ($p < 0.002$) in floor reaction time among rhythmic gymnasts.

According to Hutchinson et al. (23), it is also possible that a cognitive learned effect, rather than a purely motor strengthening effort, is the reason for an increase in the selected physical and motor performance components because of the plyometric training program.

No studies could be found that investigated the effects of a combined sport-specific and plyometric training program on the WAnT results of team players. Most of the WAnT-derived variables displayed significant positive changes because of the combined plyometric and rugby conditioning program, except for fatigue ratio and the average power output at 30 seconds. The finding of Pincivero et al. (47) that those subjects who exert a lower peak power output at the start of the WAnT will develop lower levels of fatigue may possibly serve as an explanation for the lack of significance in the last-mentioned variables. The experimental group displayed significantly higher relative and absolute peak power output values during posttesting than pretesting, which possibly had a detrimental effect on the fatigue ratios and average power output values at the end of the WAnT. Despite the favorable results the dependent *t*-test delivered with regard to the effects of a 4-week combined program, the independent *t*-test did not show the same kind of results. The experimental group only achieved significantly better pre- and posttest differences than those of the control group in average power output at 20 seconds. Considering these results, it is possible that the plyometric program had a more pronounced effect on the muscle power endurance than on the peak power output values of the rugby players. The prescribed rest periods of 30 seconds between sets of plyometric exercises may have resulted in an increase in muscle power endurance instead of muscle peak power because of the fact that the rest periods were too short to allow for the resynthesis of high-energy phosphates (11). The anaerobic alactic energy system is usually depleted after 5–10 seconds of high-intensity activities and needs at least 3–5 minutes for the total resynthesis of the relevant energy sources (10,11). The high-energy phosphates are the major contributors to energy for high-intensity plyometric exercises (11). Consequently, the short rest periods will result in insufficient high-energy phosphates for the following plyometric exercises and a reliance on the anaerobic lactic system. Naturally, players will therefore decrease their plyometric exercise intensities and focus more on the completion of the prescribed number of repetitions than on the quality of the exercises.

Somewhat unexpected results of this study were that the explosive power tests (3 kg MBPT and VJT) showed no significant changes because of participation in the combined rugby and plyometric conditioning program. Again, these results may be related to the short rest periods between the different sets of the plyometric program. The 3 kg MBPT result is, however, consistent with those of Lyttle et al. (32) and Mangine et al. (33), who also did not obtain significant increases in upper-body power output values after the completion of an upper-body plyometric program. In this regard, Bieze (4) states that only elite athletes are able to execute upper-body plyometric exercises in such a way that the amortization phase is kept short. Energy that is stored during the eccentric phase of the plyometric exercise will dissipate as heat and will not be used to increase the force of the concentric phase if the amortization phase lasts too long (9,48). What the statement of Bieze (4) therefore suggests is that the young inexperienced university rugby players in this study would not have been able to train the upper body successfully because of their inability to perform the upper-body plyometric exercises correctly.

It is interesting to note that the control group that followed the rugby conditioning program experienced a statistically and practically significant decrease in 3 kg MBPT distance. The results show that the rugby conditioning program alone was detrimental for the upper-body power development of players. As previously mentioned, the rugby conditioning program primarily consisted of field and resistance training sessions. The primary aim of the field sessions was to increase the players' fitness and to improve their rugby-specific skills. Resistance training focused on general conditioning, muscle hypertrophy, and strength. What this indicates is that rugby conditioning programs should include exercises and programs that are specifically aimed at improving explosive power. The fact that the experimental group, which also performed plyometric exercises in their program, maintained their 3 kg MBPT values from pre- to posttesting further accentuates the last-mentioned fact.

The nonsignificant VJT results after completion of a combined sport-specific conditioning and plyometric training program are similar to those of Marques et al. (35), Martel et al. (36), Mihalik et al. (39), Paavolainen et al. (43), Rahimi and Behpur (51), and Timmons (60) but in contrast to the findings of Bauer et al. (3), Chimera et al. (9), Mangine et al. (33), Moore et al. (41), Ronnestad et al. (53), and Turner et al. (61). The nonsignificant results with regard to the VJT pre- to posttest change was unexpected and can possibly be attributed to the following reasons: Outliers among the rugby players who completed the combined program could have "pulled" the *t*-test results skew because of the rather small sample size in this study. For example, 3 players of the experimental group achieved negative results (−5 cm) when the pre- and posttest VJT heights were compared. These players also achieved negative results with regard to the VJT power output values with values that ranged between −91.47 and −17.40 W. A further analysis revealed that these players lost 2.3 kg in body weight on average during the intervention period, which had a detrimental effect on their calculated power output values.

The significant increase in body stature after completion of the training programs is most likely because of the growth in body stature among the young group of male rugby players. The average age of the players in this study was 18.94 ± 0.40 years, and according to Wilmore et al. (64), some boys do not reach their mature stature until

their early '20s. This would suggest that body stature was not influenced by the training programs but rather by the growth factor. Additionally, a statistically significant ($p \leq 0.05$) increase in average wrist breadth was detected for the experimental group. Upper-body plyometric exercises such as the single clap push-up, medicine ball grab, and power drops and the upper-body resistance exercises executed in the rugby conditioning program may have facilitated bone growth in the load-bearing site. The control group also experienced a significant increase in femur breadth and skeletal mass despite the fact that they did not participate in the plyometric program. Again, the increase in femur breadth and skeletal mass can probably be attributed to the load-bearing resistance and on-field rugby-specific training exercises that the players performed. These results are similar to those of Nelson and Bouxsein (42) who found a significant increase in breadth measurements of the area that was subjected to a load-bearing activity among females who participated in racquet sports. However, a study of Dean et al. (12) showed that athletes who achieve lower pretraining values will normally experience the largest gains in terms of the variables measured. This may account for the significant changes experienced by the control group who displayed lower pretraining values compared with the experimental group in the majority of the variables.

The above-mentioned results would suggest that only the minority of anthropometric components were significantly affected by either the combined rugby conditioning and plyometric training program or the rugby conditioning program alone that the players followed during the 4-week period. The hypothesis that a 4-week combined rugby conditioning and plyometric training program will have a significantly bigger effect on selected speed, agility, anaerobic power output values, body size, lean body, muscle, fat, and skeletal mass and somatotype of subjects, compared with a rugby conditioning program alone, is therefore only partly accepted. Several researchers have made similar observations for a variety of sport events. For example, a study on cross-country skiers by Mikkola et al. (40) failed to show any training-induced hypertrophic adaptations as determined by means of the calf and thigh circumferences when a part of the 8-week training period was replaced with plyometric training. The same researchers also did not observe any significant changes in body weight or fat percentage because of the change in the training program. Similarly, runners and cyclists did not show significant changes after a 5-week and 4- to 5-week combined running and plyometric and a combined cycling and plyometric program, respectively (45,56). The findings of the present study are, however, not consistent with those of Luebbers et al. (30) and Bastiaans et al. (2) who found an increase in body mass and lean body mass after completion of a 4- and 9-week sport-specific and plyometric training program, respectively.

The nonsignificant results with regard to the anthropometric components of this study can also possibly be attributed to the high individual variability in the different pre- and postmeasurements, which might have influenced the *t*-test results. For instance, the individual skeletal mass pre- to posttest differences for the experimental group varied between −0.493 (minimum) and 1.656 (maximum) with an *SD* of 0.587; the values of muscle mass differences varied between −0.406 (minimum) and 0.582 (maximum) with an *SD* of 0.301 for the control group and between −0.461 (minimum) and 1.490 (maximum) with an *SD* of 0.766 for the experimental group. The values for fat percentage differences varied between −2.388 (minimum) and 4.227 (maximum) with an *SD* of 1.818 for the control group and between −4.126 (minimum) and 6.618 (maximum) with an *SD* of 2.409 for the experimental group. The variability of all these values could have influenced the *t*-test results negatively.

Another factor that could explain the lack of significance in, especially, the anthropometric results could be the fitness levels of the rugby players who participated in the study. Players in this study had already been subjected to a general rugby conditioning program for 6 months before this intervention. It might therefore be expected that their fitness levels were already high and their anthropometric profile already developed because of participation in the rugby conditioning program. In this regard, Paton and Hopkins (45) failed to prove any significant increases in the performance of competitive cyclists after the inclusion of plyometric training into their existing cycling training program. Notably, the authors attributed the outcome of their research to the fact that the cyclists were already in the competitive cycle of their training period and had already attained a high fitness level. Athletes who have already attained a certain fitness level and anthropometric profile will probably not be so sensitive and reactive to conditioning programs when compared with untrained subjects. The conclusion of the study of Turner et al. (61) , namely, that the significant improvement in running economy due to a 6-week plyometric training period was because of the inexperience and the untrained state of the subjects, as confirmed by the last-mentioned statement.

In view of the fact that several researchers adjusted the number of sets and repetitions of the plyometric program on a weekly basis in their studies (8,32,61), this may also be something to consider. A continuous adjustment in the last-mentioned exercise variables would probably give rise to more muscle overload and more pronounced changes in the different speed, agility, power, and anthropometric measurements.

To conclude, the research in this study seems to suggest that a 4-week combined rugby conditioning and plyometric training program may only lead to neural adaptations and not to morphologic changes. Hence, it is conceivable that a longer training period would have been more beneficial in a study in which changes in the anthropometric makeup of players was

the aim. However, there is no agreement between different researchers concerning this aspect (2,30,40,56).

Practical Applications

This study was the first to report on the effects of a combined rugby conditioning and plyometric training program on the physical, motor performance and anthropometric components of university-level rugby players. The study results revealed that if the goal of training is to significantly improve the speed, agility, and power of young rugby players, then a 4-week combined program of sport-specific conditioning and plyometric training can be implemented. Although not significant in altering the overall anthropometric profile of the rugby players, the significant results in some of the measurements do indicate that certain anthropometric components might be positively influenced by a combined sport-specific and plyometric training program. However, the results of the present study and those of Marques et al. (35), Martel et al. (36), Mihalik et al. (39), Paavolainen et al. (43,44), Witzke and Snow (66), Rahimi and Behpur (51), and Luebbers et al. (30) indicate that a combined sport-specific conditioning and plyometric training program of 4 weeks may not be as effective in increasing all power-related and anthropometric components as a longer combined training program. Therefore, in conclusion, practitioners can apply plyometric training in sport-specific programs in an attempt to improve rugby performance by increasing speed, agility, and power in rugby players. Future studies on rugby union should probably rather focus on the possible influence of a combined rugby conditioning and plyometric training on the performance outcome of players. Coaches, trainers, and sport scientists of rugby union teams can implement plyometric training in their regular training programs, and we would suggest a minimum training period longer than 4 weeks.

References

1. Ball, TE. Medicine ball put (sitting on the floor) test. In: *Kirby's Guide to Fitness and Motor Performance Tests*. Kirby, RF, ed. Cape Girardeau, MO: BenOak Publishing Company, 1991. pp. 331–332.
2. Bastiaans, JJ, van Diemen, AB, and Veneberg, T. The effects of replacing a portion of endurance training by explosive strength training on performance in trained cyclists. *Eur J Appl Physiol* 86: 79–84, 2001.
3. Bauer, T, Thayer, RE, and Baxa, G. Comparison of training modalities for power development in the lower extremity. *J Appl Sports Sci Res* 4: 115–121, 1990.
4. Bieze, J. Plyometrics researchers struggle to prove benefits in upper body. *Biomech 11: 11–12, 2004.*
5. Bloomfield, J, Ackland, TR, and Elliot, BC. *Applied Anatomy and Biomechanics in Sport*. Melbourne, Australia: Blackwell Scientific Publications, 1994.
6. Boesio, D, Maffiuletti, NA, and Bemben, MG. Effects of four weeks plyometric training on tumbler athletes power output: A pilot study. Presented at Science in Gymnastics Symposium: Gymnastics Excellence through Education, Anaheim, CA. pp.1-12.
7. Bolonchuk, WW and Lukaski, HC. Changes in somatotype and body composition of college football players over a season. *J Sports Med* 27: 247–252, 1987.
8. Carter, AB, Kaminski, TW, Douex, AT, Knight, CA, and Richards, JG. Effects of high volume upper extremity plyometric training on throwing velocity and functional strength ratios of the shoulder rotators in collegiate baseball players. *J Strength Cond Res* 21: 208–215, 2007.
9. Chimera, NJ, Swanik, KA, Swanik, CB, and Straub, SJ. Effects of plyometric training on muscle-activation strategies and performance in female athletes. *J Athl Train* 39: 24–31, 2004.
10. Chu, DA. *Jumping into Plyometrics* (2nd ed.). Champaign, IL: Human Kinetics Publishers, 1998.
11. Conley, M. Bioenergetics of exercise and training. In: *Essentials of Strength Training and Conditioning: National Strength and Conditioning Association* (2nd ed.). Beachle, TR and Earle, R, eds. Champaign, IL: Human Kinetics, 2000. pp. 73–90.
12. Dean, WP, Nishihara, M, Romer, J, Murphy, KS, and Mannix, ET. Efficacy of a 4-week supervised training program in improving components of athletic performance. *J Strength Cond Res* 12: 238–242, 1998.
13. Debnam, M. Plyometrics, training for power. *Modern Athl Coach* 45: 5–7, 2007.
14. Dodd, DJ and Alvar, BA. Analysis of acute explosive training modalities to improve lower-body power in baseball players. *J Strength Cond Res* 21: 1177–1182, 2007.
15. Drinkwater, DT and Mazza, JC. Body composition. In: *Kinanthropometry in Aquatic Sports*. Carter, JEL, Ackland, TR, Mazza, JC, and Ross, WD, eds. Champaign, IL: Human Kinetics Publishers, 1994. pp. 102–137.
16. Duthie, GM. A framework for the physical development of elite rugby union players. *Int J Sports Physiol Perform* 1: 2–13, 2006.
17. Duthie, G, Pyne, D, and Hooper, S. Applied physiology and game analysis of rugby union. *Sports Med* 33: 973–991, 2003.
18. Ellis, L, Gastin, P, Lawrence, S, Savage, B, Shields, A, Stapff, A, Timilty, D, Quinn, A, Woolford, SN, and Young, W. Protocols for the physiological assessment of team sport players. In: *Physiological Tests of Elite Athletes*. Gore, CJ, ed. Champaign, IL: Human Kinetics Publishers, 2000. pp. 128–144.
19. Fatouros, IG, Jamurtas, AZ, Leontsini, D, Taxildaris, K, Aggelousis, N, Kostopoulos, N, and Buckenmeyer, P. Evaluation of plyometric exercise training, weight training, and their combination on vertical jumping performance and leg strength. *J Strength Cond Res* 14: 470–476, 2000.
20. Foster, C, Hector, LL, McDonald, KS, and Snider, AC. Measurements of anaerobic power and capacity. In: *Physiological Assessment of Human Fitness*. Maud, PJ and Foster, C, eds. Champaign, IL: Human Kinetics Publishers, 1995. pp. 73–85.
21. Gillespie, J and Keenum, S. A validity and reliability analysis of the seated shot put as a test of power. *J Hum Mov Stud* 13: 97–105, 1987.
22. Hetzler, RK. Dash for specified distance test. In: *Kirby's Guide to Fitness and Motor Performance Tests*. Kirby, RF, ed. Cape Girardeau, MO: BenOak Publishing Company, 1991. pp. 394–395.
23. Hutchinson, MR, Tremain, L, Christiansen, J, and Beitzel, J. Improving leaping ability in elite rhythmic gymnasts. *Med Sci Sports Exerc* 30: 1543–1547, 1998.
24. Inbar, O, Bar-or, O, and Skinner, JS. *The Wingate Anaerobic Test*. Champaign, IL: Human Kinetics Publishers, 1996.
25. Jenkins, D and Reaburn, P. Protocols for the physiological assessment of rugby union players. In: *Physiological Test for Elite Athletes*. Gore, CJ, ed. Champaign, IL: Human Kinetics, 2000. pp. 327–333.
26. Johnson, BL and Nelson, JK. *Practical Measurements for Evaluation in Physical Education* (4th ed.). New York, NY: Macmillan, 1986.
27. Kubo, K, Morimoto, M, Komuro, T, Yata, H, Tsunoda, N, Kanehisa, H, and Fukunaga, T. Effects of plyometric and weight training on muscle-tendon complex and jump performance. *Med Sci Sports Exerc* 39: 1801–1810, 2007.

28. Lee, RC, Wang, Z, Heo, M, Ross, R, Janssen, I, and Heymsfield, SB. Total body skeletal muscle mass: Development and cross-validation of anthropometric prediction models. *Am J Clin Nutr* 72: 796–803, 2000.
29. Lindén, C, Alwis, G, Ahlborg, H, Gardsell, P, Valdimarsson, O, Stenevi-Lundgren, S, Besjakov, J, and Karlsson, MK. Exercise, bone mass and bone size in prepubertal boys: One-year data from the pediatric osteoporosis prevention study. *Scand J Med Sci Sports* 17: 340–347, 2007.
30. Luebbers, PE, Potteiger, JS, Hulver, MW, Thyfault, JP, Carper, MJ, and Lockwood, RH. Effects of plyometric training and recovery on vertical jump performance and anaerobic power. *J Strength Cond Res* 17: 704–709, 2003.
31. Luger, D and Pook, P. *Complete Conditioning for Rugby*. Champaign, IL: Human Kinetics Publishers, 2004.
32. Lyttle, AD, Wilson, GJ, and Ostrowski, KJ. Enhancing performance: Maximal power versus combined weights and plyometrics training. *J Strength Cond Res* 10: 173–179, 1996.
33. Mangine, GT, Ratamess, NA, Hoffman, JR, Faigenbaum, AD, Kang, J, and Chilakos, A. The effects of combined ballistic and heavy resistance training on maximal lower- and upper-body strength in recreationally trained men. *J Strength Cond Res* 22: 132–139, 2008.
34. Markovic, G and Mikulic, P. Neuro-musculoskeletal and performance adaptations to lower-extremity plyometric training. *Sports Med* 40: 859–895, 2010.
35. Marques, MS, Van Den Tillaar, R, Vescovi, JD, and González-Badillo, JJ. Changes in strength and power performance in elite senior female professional volleyball players during the in-season: A case study. *J Strength Cond Res* 22: 1147–1155, 2008.
36. Martel, GF, Harmer, ML, Logan, JM, and Parker, CB. Aquatic plyometric training increases vertical jump in female volleyball players. *Med Sci Sports Exerc* 37: 1814–1819, 2005.
37. McKay, HA, MacLean, L, Petit, M, MacKelvie-O'Brien, K, Janssen, P, Beck, T, and Khan, KM. "Bounce at the Bell": A novel program of short bouts of exercise improves proximal femur bone mass in early pubertal children. *Br J Sports Med* 39: 521–526, 2005.
38. McLaughlin, EJ. A comparison between two training programs and their effects on fatigue rates in women. *J Strength Cond Res* 15: 25–29, 2001.
39. Mihalik, JP, Libby, JJ, Battaglini, CL, and McMurray, RG. Comparing short-term complex and compound training programs on vertical jump height and power output. *J Strength Cond Res* 22: 47–53, 2008.
40. Mikkola, JS, Rusko, HK, Nummela, AT, Paavolainen, LM, and Häkkinen, K. Concurrent endurance and explosive type strength training increases activation and fast force production of leg extensor muscles in endurance athletes. *J Strength Cond Res* 21: 613–620, 2007.
41. Moore, EWG, Hickey, MS, and Reiser, RF. Comparison of two twelve week off-season combined training programs on entry level collegiate soccer players' performance. *J Strength Cond Res* 19: 791–798, 2005.
42. Nelson, DA and Bouxsein, ML. Exercise maintains bone mass, but do people maintain exercise. *J Bone Miner Res* 16: 202–205, 2001.
43. Paavolainen, L, Häkkinen, K, Hämäläinen, I, Nummela, A, and Rusko, H. Explosive-strength training improved 5-km running time by improving running economy and muscle power. *J Appl Physiol* 86: 1527–1533, 1999.
44. Paavolainen, L, Häkkinen, K, and Rusko, H. Effects of explosive type strength training on physical performance characteristics in cross-country skiers. *Eur J Appl Physiol* 62: 251–255, 1991.
45. Paton, CD and Hopkins, WG. Combining explosive and high-resistance training improves performance in competitive cyclists. *J Strength Cond Res* 19: 826–830, 2005.
46. Pederson, D and Gore, C. Anthropometry measurement error. In: *Anthropometrica: A Textbook of Body Measurement for Sports and Health Courses*. Norton, KI. and Olds, TS, eds. Marrickville, Australia: Southwood Press, 1996. pp. 77–96.
47. Pincivero, DM, Gear, WS, Sterner, RL, and Karunakara, RG. Gender differences in the relationship between quadriceps work and fatigue during high-intensity exercise. *J Strength Cond Res* 14: 202–206, 2000.
48. Potach, DH and Chu, DA. Plyometric training. In: *Essentials of Strength Training and Conditioning: National Strength and Conditioning Association* (2nd ed.). Beachle, TR and Earle, R, eds. Champaign, IL: Human Kinetics, 2000. pp. 427-470.
49. Potteiger, JA, Lockwood, RH, Haub, MD, Dolezal, BA, Almuzaini, KS, Schroeder, JM, and Zebas, CJ. Muscle power and fiber characteristics following 8 weeks of plyometric training. *J Strength Cond Res* 13: 275–279, 1999.
50. Radcliffe, JC and Farentinos, RC. Plyometrics: Explosive power training (2nd ed.). Champaign, IL: Human Kinetics Publishers, 1999.
51. Rahimi, R and Behpur, N. The effects of plyometric, weight and plyometric-weight training on anaerobic power and muscular strength. *Phys Educ Sport* 3: 81–91, 2005.
52. Rimmer, E and Sleivert, G. Effects of a plyometrics intervention program on sport performance. *J Strength Cond Res* 14: 295–301, 2000.
53. Ronnestad, BR, Kvamme, NH, Sunde, A, and Raastad, T. Short-term effects of strength and plyometric training on sprint and jump performance in professional soccer players. *J Strength Cond Res* 22: 773–780, 2008.
54. Safrit, MJ. *Introduction to Measurement in Physical Education and Exercise* (2nd ed.). St Louis, MO: Times Mirror/Mosby College Publishing, 1990.
55. Santos, EJ and Janeira, MA. Effects of complex training on explosive strength in adolescent male basketball players. *J Strength Cond Res* 22: 903–909, 2008.
56. Spurrs, RW, Murphy, AJ, and Watsford, ML. The effect of plyometric training on distance running performance. *Eur J Appl Physiol* 89: 1–7, 2003.
57. Statsoft, Inc. *STATISTICA* Potchefstroom Campus, South Africa: North West University, 2008.
58. Swanik, KA, Lephart, SM, Swanik, B, Lephart, SP, Stone, DA, and Fu, FH. The effects of shoulder plyometric training on proprioception and selected muscle performance characteristics. *J Shoulder Elbow Surg* 11: 579–586, 2002.
59. Thomas, JR and Nelson, JK. *Research Methods in Physical Activity* (4th ed.). Champaign, IL: Human Kinetics, 2001.
60. Timmons, SA. *Increasing Vertical Jump: A Comparison Between Two Training Programs* [master's thesis]. Muncie, IN: Ball State University, 1996.
61. Turner, AM, Owings, M, and Schwane, JA. Improvement in running economy after 6 weeks of plyometric training. *J Strength Cond Res* 17: 60–67, 2003.
62. VanHeest, JL, Stoppani, J, Scheett, TP, Collins, V, Roti, M, Anderson, J, Allen, GJ, Hoffman, J, Kraemer, WJ, and Maresh, CM. Effects of ibuprofen and vicoprofen on physical performance after exercise-induced muscle damage. *J Sport Rehabil* 11: 224–234, 2002.
63. Wilkerson, GB, Colston, MA, Short, NI, Neal, KL, Hoewischer, PE, and Pixley, JJ. Neuromuscular changes in female collegiate athletes resulting from a plyometric jump-training program. *J Athl Train* 39: 17–23, 2004.
64. Wilmore, JH, Costill, DL, and Kenney, WL. *Physiology of Sport and Exercise* (4th ed.). Champaign, IL: Human Kinetics, 2008.
65. Withers, RT, Whittingham, NO, Norton, KI, La Forgia, J, Ellis, MW, and Crockett, A. Relative body fat and anthropometric prediction of body density of male athletes. *Eur J Appl Physiol* 56: 191–200, 1987.
66. Witzke, KA and Snow, CM. Effects of plyometric jump training on bone mass in adolescent girls. *Med Sci Sports Exerc* 32: 1051–1057, 2000.

ARTICLE 2

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European Journal of Sport Science
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Impact of an acute bout of vibration on muscle contractile properties, creatine kinase and lactate dehydrogenase response

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Published online: 11 Mar 2013.

To cite this article: Moisés de Hoyo, Luis Carrasco, Marzo E. Da Silva-Grigoletto, Borja Sañudo, Javier Caballero-Villarraso, Eva Arriaza & Maria Del Carmen Escobar (2013) Impact of an acute bout of vibration on muscle contractile properties, creatine kinase and lactate dehydrogenase response, European Journal of Sport Science, 13:6, 666-673, DOI: 10.1080/17461391.2013.774052

To link to this article: http://dx.doi.org/10.1080/17461391.2013.774052

European Journal of Sport Science, 2013
Vol. 13, No. 6, 666–673, http://dx.doi.org/10.1080/17461391.2013.774052

ORIGINAL ARTICLE

Impact of an acute bout of vibration on muscle contractile properties, creatine kinase and lactate dehydrogenase response

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Abstract
The aim of this study was to assess the effects of a bout of whole body vibration (WBV) on muscle response and to determine whether this stimulus leads to muscle damage. Thirty healthy and physically active participants (mean ± SD; age: 21.8 ± 2.0 years; height: 176.7 ± 5.8 cm; body mass: 76 ± 6.8 kg and BMI: 23.1 ± 3.7 kg·m^{-2}) participated in this study. Participants were randomly allocated in one of two groups, one of them performed a bout of 360 s WBV (frequency: 30 Hz; peak-to-peak displacement: 4 mm) (VIB) and the other one adopted a sham position (CON). Muscle contractile properties were analysed in the rectus femoris (RF) by using tensiomyography (TMG) 2 min before the warm-up and 2 min after intervention. Muscle damage was assessed by determining plasma creatine kinase (CK) and lactate dehydrogenase (LDH) levels at three time points; 5 min before warm-up and 1 h and 48 h after the intervention. TMG results showed a significant decrease in maximal displacement ($p < 0.05$) and delay time ($p < 0.05$) in VIB and in delay time ($p < 0.05$) and relaxation time ($p < 0.05$) in CON. Muscle damage markers showed significant group differences ($p < 0.05$) for CK 1 h after the intervention. In addition, differences for CK 1 h after the intervention from baseline ($p < 0.05$) were also observed in VIB. In conclusion, a 6-min bout of WBV results in an increase of muscle stiffness in RF and increased CK levels 1 h after intervention (returning to baseline within 48 h).

Keywords: *Muscle damage, vibration training, tensiomyography*

Introduction

Whole body vibration (WBV) training is a relatively new neuromuscular training method that is gaining popularity. Studies using vibration training have shown different effects on muscle performance, such as strength (McBride et al., 2010), jump ability (Da Silva-Grigoletto, De Hoyo, Sañudo, Carrasco, & García-Manso, 2011) and power output (Da Silva-Grigoleto et al., 2009, 2011).

Improvements in muscle function with WBV are thought to be associated with enhanced neural excitation (Cardinale & Bosco, 2003; Rittweger, Mutschelknauss, & Felsenberg, 2003) and possibly by increased reflex activation (Cardinale & Bosco, 2003). Sensory receptors that modulate muscle stiffness detect this through reflex muscular activity and attempt to dampen the vibratory waves (Cardinale & Bosco, 2003). Every cycle of WBV induces a successive and frequency-dependent activation of the muscle spindles, which leads to muscle contraction (Ritzmann, Kramer, Gruber, Gollhofer, & Taube, 2010). During the WBV training, muscle excitation is transmitted via Ia afferents and generates numerous discharges at the α-motoneuron pool, which lead to muscle stiffness to mitigate the vibration transmission (Ritzmann et al., 2010). However, the adaptations following WBV are inconsistently reported in the literature (Rittweger, 2009). Recently, Ritzmann, Kramer, Gollhofer, and Taube (2011) showed that after WBV the reflex response was depressed

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returning to baseline values after just a few minutes. Thus, according to these authors, performance improvements after WBV are not likely to be caused by spinal facilitation, therefore an alternative mechanism must be responsible for the performance improvements reported in some studies.

Possible explanations for the reported improvements in muscle function with WBV include the effects of WBV on muscle temperature (Cochrane, Stannard, Firth, & Rittweger, 2010) and some authors attribute improvements to what they describe as post-activation potentiation (PAP; Cardinale & Bosco, 2003; McBride et al., 2010). The PAP is commonly associated with a maximum or submaximal muscle contraction, which results in improved muscle response (Tillin & Bishop, 2009). The mechanisms, which facilitate PAP, are related to the phosphorylation of light chain regulatory myosin (RCL), increased recruitment of motor neurons and a possible change in pennation angle. However, a previous stimulation could also lead to fatigue and therefore, a subsequent response may be determined by the PAP-fatigue balance (Sale, 2002). Consequently, this phenomenon is similar to a bell-shape where muscle stiffness contributes to the potentiation effects but muscle fatigue or even muscle damage may decrease it (Hunter et al., 2012). However, the links between muscle damage and muscle stiffness are not well defined, several studies seem to indicate a clinically significant relationship between muscle stiffness and muscle damage (Brockett, Morgan, & Proske, 2004; Hody, Rogister, Leprince, Wang, & Croisier, 2011; McHugh et al., 1999). In this sense, McHugh et al. (1999) demonstrated greater strength loss, pain, muscle tenderness, and muscle damage in those participants with stiff muscles compared to those with compliant muscles. These authors found that participants with stiffer hamstring muscles experienced greater muscle damage, despite exercising at the same relative intensity.

One possible explanation to this interaction was attribute to the presence of eccentric muscle contractions in WBV training (Rittweger et al., 2003), which are known to induce, in some situations, muscle fibre damage (Zhou, Li, & Wang, 2011). In this sense a significant correlation between muscle damage (plasma creatine kinase – CK – concentrations) and muscle stiffness was found after intense eccentric exercise (Hody et al., 2011).

On the other hand, in order to better understand this relation, several studies have analysed the muscle damage associated with different exercise interventions using biological markers together with strength, stiffness, pain and electromyographic response (Chapman, Newton, McGuigan, & Nosaka, 2008; Miyama & Nosaka, 2007). However, while markers such as CK and LDH are commonly used for diagnosis of muscle damage, even after WBV training (Gojanovica, Feihlb, Liaudetb, Gremiona, & Waeberb, 2011), techniques to assess complementary muscle contractile properties test are infrequently used.

Recently, a new technique known as tensiomyography (TMG) is being used in studies focused on muscle contractile properties and function in response to a low-level electrical stimulus (Tous-Fajardo et al., 2010). TMG uses a high precision (4 μm) digital pre-tension displacement transducer sensor placed perpendicular to the muscle belly to record radial muscle belly displacement (Hunter et al., 2012). TMG has also been used to assess the level of muscle activation and even muscle stiffness in different sporting activities (García-Manso et al., 2011; Križaj, Simunic, & Zagar, 2008; Rey, Lago-Peñas, Lago-Ballesteros, & Casáis, 2012). Moreover, this technique has been used to effectively detect fatigue after cycling at maximal oxygen uptake power output (Carrasco, Sañudo, de Hoyo, Pradas, & da Silva, 2011) and following an ultra-endurance triathlon (Garcia-Manso et al., 2011). To our knowledge, only Hunter et al. (2012) correlated different TMG parameters with muscle damage measured with CK levels after an eccentric elbow flexion.

Therefore, and considering that none studies have been conducted after vibration and the causes of the adaptations to WBV observed in training studies have not been pinpointed yet, the aim of the current study was to assess the effects of one bout of WBV on muscle response and to determine whether this stimulus leads to muscle damage. Consequently, we hypothesised that an acute bout of WBV would induce muscle damage (assessed by CK and LDH levels), accompanied by elevated muscle stiffness and fatigue (assessed by TMG).

Methods

Participants

Thirty healthy male volunteers were recruited for this study (mean $\pm$SD; age: 21.82 $\pm$2.01 years; height: 176.67 $\pm$5.79 cm; body mass: 76 $\pm$6.81 kg and BMI: 23.14 $\pm$3.66 kg·m^{-2}). Medical histories were reviewed by a physician to assess suitability for the study. Each subject completed 'The International Physical Activity Questionnaire' (IPAQ; Craig et al., 2003) in order to determine the level of physical fitness prior to the study, this allowed recruitment of recreationally active subjects, according to the criteria established by Varo et al. (2003). Additionally, subjects with osteoarticular conditions (including fracture or injury) were excluded. The study was conducted according to the Declaration of Helsinki, and the protocol was fully approved by the local research

ethics committee before recruitment. After a detailed explanation about the aims, benefits and risks involved in this investigation, all participants gave written informed consent. Table I shows the descriptive data of the selected participants.

Study design and procedure

Subjects were randomly allocated to one of two different protocols: continuous WBV protocol (VIB; $n=15$) or a sham position (CON; $n=15$). All participants were familiarised with the vertical vibrating platform (Pro5 Airdaptive, Power Plate North America, Inc., Northbrook, IL) and the proper positioning. In the VIB group the WBV stimulus was induced during 360 s to the plantar surfaces of the feet at a frequency of 30 Hz with a peak-to-peak displacement of 4 mm according to that indicated by the manufacturer, considered the optimal combination to get the greater muscle performance (Da Silva-Grigoletto et al., 2009, 2011). CON participants received no vibration (360 s). All participants adopted a squat position, knees and ankles flexed at 60° (knee extension = 0°) and 90°, respectively, as measured by an electronic goniometer. This position was reported to be the one where the electromyographic activity was highest in the RF according to Ritzmann, Golhofer, and Kramer (2012). To avoid bruising, all participants wore no sport shoes. All tests were preceded by a 5-min warm-up consisting of cycling on a cycloergometer (Ergoline 900®, Ergometrics, Bitz, Germany) at 60 W and 60 rpm. The blood samples were obtained 5 min before warm-up and 1 h and 48 h after intervention and TMG tests were performed 2 min before the warm-up and 2 min after the bout of WBV. All tests and interventions were performed at the same time of day. Participants were not allowed to consume water and food during and until 1 h after the intervention.

TMG measurements

Displacement-time curve recordings allow for muscle contractile properties to be assessed (Valenčič & Knez, 1997). The validity of the TMG parameters has been reported in previous studies (Križaj et al., 2008; Pišot et al., 2008). Despite the aforementioned validity, some limitations have been reported with this technique. TMG-derived contractile parameters were very sensitive to alterations in regard to inter-electrodes position and also variations in muscle response. The difficulties in repositioning both the sensor and the electrodes in the same area may also affect TMG measurements and may affect its reliability. Finally, some other intrinsic factors such as skin conductivity, subcutaneous fat thickness or motor nerve branching may also affect inter-individual variability (Tous-Fajardo et al., 2010). Therefore, to ensure the reliability of the measurement in the current study we proceeded according to indications proposed by the authors (Tous-Fajardo et al., 2010).

Table I. Characteristics of the participants (Mean±SD).

	Age (years)	Height (cm)	Body mass (kg)	BMI ($kg \cdot m^{-2}$)
VIB	22.12±3.14	176.21±4.90	77±5.46	23,65±3.48
CON	20.87±1.69	176.98±6.07	75±3.21	23.24±1.88

VIB = vibration group; CON = control group.

The main outcome variables determined in the current study were: maximal radial displacement (Dm), time from the onset of electrical stimulus to 10% of Dm (Td), time from 10 to 90% of Dm in the ascending curve (Tc), time between 50% of Dm on both sides of the curve (Ts), and time from 90 to 50% of Dm on the descending curve (Tr). These outcomes were previously assessed in the literature with low Dm values indicating greater muscle stiffness (Dahmane, Valencic, Knez, & Erzen, 2001; Križaj et al., 2008; Valencic, Knez, & Simunic, 2001; Rey et al., 2012; Hunter et al., 2012), meanwhile with these changes are associated with increments in Td and Tr seems to indicate muscle fatigue (Dahmane, Djordjevic, Simunic, & Valencic, 2005; Garcia-Manso et al., 2011).

Radial displacements were measured under static and relaxed conditions, with the participant in the supine position and the knee joint fixed at an angle of 60° (0° corresponding to full extension of the knee). The measured limb was positioned on a wedge foam cushion to keep a fixed knee angle. A digital displacement transducer (GK 40®, Panoptik d.o.o., Ljubljana, Slovenia), which incorporates a spring of 0.17 $N \cdot mm^{-1}$, was set perpendicular to the muscle belly to acquire radial displacement. Sensor location was determined anatomically according to Delagi, Perotto, Iazzetti, and Morrison (1975) and marked with a dermatological pen. Two square (5×5 cm) 2 mm thick self-adhesive electrodes (Compex Medical SA, Ecublens, Switzerland) were placed symmetrically 5 cm (±3 cm) to the sensor tip.

A TMG-S1 stimulator (EMF-Furlan and Co. d.o.o., Ljubljana, Slovenia) was used to induce electrical pulses (duration: 1 ms; initial intensity: 30 mA). For each TMG assessment intensity was progressively increased (10 mA intervals) until there was no further increase in Dm or the maximal device output (110 mA) was reached. Between consecutive measurements rest periods of 15 s were allowed to minimise the effects of fatigue and potentiation. In any case, none of the participants reported discomfort during electrical stimulation.

CK and LDH measurements

For the assessment of both enzymes, blood samples (10 ml) were obtained from the antecubital vein before and 1 h and 48 h after a bout of WBV. Blood samples were dispensed immediately into a tube (5 ml) containing potassium EDTA $3K^+$ or an eppendorf tube (5 ml) for haemoglobin concentration and cell volume determination and stored on ice (−4°C). After 20 min of mixing (Spiramix-10, Denley Instruments, Sussex, UK), haemoglobin concentration (in duplicate by the cyanmethaemoglobin method) and packed cell volume (in triplicate by spun haematocrit) were measured to allow calculation of changes in plasma volume relative to the volume in different moment. Then blood samples (5 ml) were centrifuged at 3000 rpm for 10 min at 20°C in a centrifuge AllegraTM X-12R (Beckman Coulter, Inc., Fullerton, CA, USA). After removing the plasma, the aliquots were stored at a temperature of −80°C in eppendorf tubes labelled for later analysis. Measurements were carried out by two chains Accellerator Core-Lab (Abbott, Chicago, IL, USA), each composed of six analyzers: three teams Architec i2000 immunoassay and three Architect c16,000 spectrophotometry (used in the CK and LDH analysis). In each biochemical quantity gauges were used and reagents specific to the commercial house. All parameters have been subjected to daily internal quality control of Inter-QC (VITROS®) and monthly external quality control of the Spanish Society of Clinical Biochemistry and Molecular Pathology (SEQC).

Statistical analyses

Means and standard deviations of the mean (SD) were calculated for each variable. Normality was checked using the Kolmogorov-Smirnov test and all variables were normally distributed. A 2 ×2 analysis of variance (ANOVA) was performed to compare TMG measurements between protocol (VIB and CON) and moment (before and after intervention). A 2 ×3 repeated measures ANOVA was performed to compare changes in the muscle damage enzymes and haemoglobin concentrations and haematocrit levels between protocols (VIB and CON) and moment (before, 1 h and 48 h after intervention). When a significant *F*-value interaction was achieved, a Tukey post hoc test was used to examine where significant differences occurred. The level of significance was set at $p<0.05$. All analyses were performed using SPSS v.18 (SPSS Inc., Chicago, IL).

Results

Table II represents the TMG response on RF before and after the interventions. ANOVA test showed no significant inter-group differences before and after the intervention. Intra-group analysis revealed statistically significant changes for Dm (−22.78%; $F(1,29) = 6.718$; $p<0.05$) and Td (−7.45%; $F(1,29) = 5.289$; $p<0.05$) in the VIB group, while significant differences in Td (−8.96%; $F(1,29) = 6.070$; $p<0.05$) and Tr (−41.54%; $F(1,29) = 4.349$; $p<0.05$) were observed for the CON group.

No significant differences in percentage changes in haemoglobin and haematocrit levels between interventions and time points considered were found. Figure 1 shows the time course of CK and LDH in both groups. ANOVA test showed no significant group interaction on both CK and LDH levels before the intervention. However, significant differences were observed for CK 1 h after intervention ($p<0.05$), although these differences were not found at 48 h. The group by moment analysis showed significant differences for CK 1 h after intervention in the VIB group (+11.05±2.03%; $F(1,29) = 4.289$; $p<0.05$), but not for the CON group. There were no significant differences in the LDH levels at any of the measurement time points.

Discussion

This study aimed to assess the acute effect of a bout of WBV on muscle stiffness or local muscle fatigue assessed by TMG. In addition, we wanted to determine whether continuous exposure to WBV might cause a change in muscle damage markers (CK and LDH). Results showed a significant decrease in Td in

Table II. Tensiomyographic parameters from rectus femoris in VIB and CON groups (Mean±SD).

	Dm (mm)			Td (ms)			Tc (ms)			Ts (ms)			Tr (ms)		
	PRE	POST	*p*	PRE	POST	*p*	PRE	POST	*p*	PRE	POST	*p*	PRE	POST	*p*
VIB	9.13± 2.12	7.05± 2.26	0.015	23.48± 1.98	21.73± 2.17	0.029	30.82± 6.71	28.87± 5.94	0.408	120.03± 61.63	89.62± 47.60	0.142	73.42± 53.91	43.96± 34.62	0.086
CON	9.51± 2.77	7.75± 3.06	0.112	23.65± 1.97	21.53± 2.17	0.020	31.97± 4.14	30.11± 6.94	0.382	117.93± 52.03	96.30± 53.60	0.272	75.09± 48.04	43.90± 32.34	0.046

VIB = vibration group; CON = control group; Tc = contraction time; Ts = sustain time; Tr = relaxation time; Dm = maximal displacement; Td = delay time.

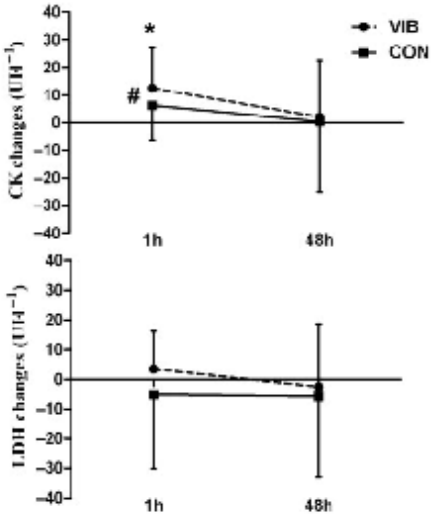

Figure 1. Changes respect pre-test on creatine kinase (A) and lactate dehydrogenase (B) levels 1 h and 48 h after intervention (mean ± SD).
*Significant inter-group differences ($p < 0.05$) measured by ANOVA test; #Significant intra-group differences ($p < 0.05$) measured by ANOVA test.

both groups but also in Dm for the VIB group and Tr in the CON group. Results also showed a significant increase in CK levels 1 h after intervention for the VIB group. In addition, analysis 48 h after exposure showed that CK returned to baseline levels in both groups. A significant group by moment interaction in CK was found 1 h after the intervention, while non-significant effects for LDH were reported.

Authors such as Križaj et al. (2008) indicated that TMG parameters are very sensitive to muscle fatigue and potentiation. Consistent with this statement several authors reported that Dm, Ts and Tr are the most accurate indicators (Dahmane et al., 2001, 2005; García-Manso et al., 2011; Valencic et al., 2001). Thus Dm, which could be equated to electrically evoked peak twitch torque, is determined by both the number and the type of muscle fibres recruited by the electrical stimulus, and could be considered as a measure of muscle belly stiffness (Pišot et al., 2008). In this sense, a decrease in Dm after an exercise may indicate an increase in muscle tone and greater muscle stiffness (Hunter et al., 2012). Another possible explanation to this response is the exercise-induced muscle damage, as some of the myofilaments became acutely stretched during the eccentric contractions and can no longer overlap due to inhomogeneities within the sarcomere (Proske & Allen, 2005). This process causes an increased tension in the passive cellular structures (Morgan & Proske, 2004) and consequently could lead to a Dm decrease (Hunter et al., 2012). Moreover, some authors have found an association between muscle fatigue and a decrease in Dm (Carrasco et al., 2011; García-Manso et al., 2011). However, this response is not consistent with our results due to other contraction time parameters such as Ts and Tr are needed to complement this response (Križaj et al., 2008). Thus, when the muscle fatigue appears, a decreased in Dm together with an increased in Tr and Ts can be observed (Križaj et al., 2008). In this sense, Simunic, Rozman, and Pisot (2005) Leer fonticamfound a decrease in all temporal outcomes after a non-fatiguing exercise; by contrast, when the exercise resulted in muscle fatigue these time parameters increased. In the current study, one may consider that the decrease in Dm, but also in some temporal parameters, could indicate greater muscle stiffness in VIB for RA but not a sign of local muscle fatigue.

Taken into account the above-mentioned responses, it would be interesting to hypothesise the possible link between TMG parameters and muscle damage biological markers. Indeed, in a recent study, Hunter et al. (2012) related a decrease in Dm with muscle damage measured with CK levels after an elbow flexor eccentric exercise. A similar response was observed in our study where the decreases in Dm were accompanied with significant increases in CK levels 1 h after the intervention in the VIB group. This is in agreement with Spitzenpfeil, Schwarzer, Fiala, and Mester (1999), who analysed the effect of a 21 days strength-training programme (36 sessions) on muscle response. When the strength training was combined with vibration (24 Hz and 2.5 mm) a greater increase in the CK levels was observed when comparing with the strength training alone. However, the total load used by Spitzenpfeil et al. (1999) was greater to the one applied in our current study and considering that these authors reported a short-term impairment in muscle function, although an adaptive long-term response, it may be considered that a greater WBV stimulus could lead to an increase in this muscle damage response. In this line, Gojanovica et al. (2011) showed an increase in CK levels after a WBV bout (26 Hz, 15 mm) measured between 24 and 72 h post-exercise. However, this response only was only observed in 25% of participants. Differences in WBV protocols and other methodological issues can explain these inconsistences.

A similar response to our study has been reported after different strength training protocols. Hurley et al. (2007) reported peak CK levels a few hours after performance of strengthening exercises, and it was also reported that after a passive recovery these

levels might be elevated up to 24 h (Brancaccio, Maffulli, Buonauro, & Limongelli, 2008). Resistance exercise protocols that involve exclusively eccentric muscle actions (Paschalis et al., 2007) cause more sustained muscle damage vs. traditional resistance exercise protocols that involve both concentric and eccentric muscle actions (Rodrigues et al., 2010). After eccentric exercises the enzymatic levels can be elevated even 72–96 h after the intervention (Zhou et al., 2011). For this reason, and taking into account the eccentric component of the WBV (Rittweger, Beller, & Felsenberg, 2000; Rittweger et al., 2003), we can speculate that our load (intensity or duration) was not enough to induce significant muscle damage 48-h post-exercise. As participants in this current study were physically active, this may have provided a protective effect or may result in muscle damage markers being permanently elevated (Kratz et al., 2002). It may be the case, therefore that the changes identified after exercise may be lower on trained subjects than on untrained subjects (Garry & McShane, 2000).

As a novelty in the current study we measured muscle damage by means of plasma LDH levels. To our knowledge this is the first study conducted to assess this response after a long bout of WBV. Only Gojanovica et al. (2011) evaluated the response of LDH after intermittent WBV protocol and neither observed changes in this biomarker. While this response is not apparent after WVB, different studies have analysed the relationship between LHD and strength training reporting statistically significant increases 24–72 h after intervention (Rodrigues et al., 2010). Normally, serum LDH activity has been shown to be elevated 24 h after bouts of exercise and is maintained for 48–72 hours (Bessa et al., 2008). In addition, serum CK activity increases to a greater extent vs. the serum activity of other muscle proteins such as LDH (Bessa et al., 2008). In fact, after a traditional strength training, CK levels tend to increase (Rodrigues et al., 2010), whereas LDH levels exhibit lower fluctuation (Rodrigues et al., 2010). This response is similar to that observed in the present study, where statistically significant changes were only observed for CK and not for LDH.

At this point one may wonder why previous studies recommended WBV for muscle damage prevention (Aminian-Far, Hadian, Olyaei, Talebian, & Bakhtiary, 2011) while our results indicate possible hazards effects. It must be noted that WBV increases muscle spindle activity and muscle pre-activation which results in greater background tension and less disruption to excitation–contraction coupling (Aminian-Far et al., 2011; Bakhtiary, Safavi-Farokhi & Aminian-Far, 2007). Theoretically, with an increase in muscle pre-activation, a greater number of motor units and muscle fibres would be recruited, which may reduce myofibrillar stress during repeated muscle contractions, leading to accelerate recovery (Kosar, Putland, & Candow, 2011). Thus, untrained adults who maintained a static half-squat position for 60 s on a WBV platform (35Hz, 5 mm) prior to performing 6 sets of 10 maximal voluntary isokinetic eccentric knee extensors contractions experienced a decrease in CK levels and soreness compared to participants who did not perform WBV before exercise (Aminian-Far et al., 2011). Furthermore, when the effects of vibration therapy (50 Hz for 60 s) are assessed prior to walking downhill in young adults, Bakhtiary et al. (2007) discovered that WBV resulted in a significant reduction in muscle soreness and subsequent decrease in plasma CK levels post-exercise compared to subjects who did not perform WBV. These results contrast with the finding reported in our study and suggest that WBV is an effective intervention to attenuate muscle damage following intense exercise training. However, it must be taken into account that in these studies the vibration stimuli was lower (60 s), which may explain the differences shown with our study (360 s); it appears that when the duration of the stimulus is higher the effects are totally opposite.

In conclusion, our results clearly show an elevation of CK activity 1 h after WBV in the VIB group and an immediate increase in muscle stiffness. However, attending to TMG analysis, we cannot confirm the presence of local muscle fatigue. Also, our intervention induced a transient effect on CK response so plasma levels of this enzyme returned to basal values 48 h after WBV exposure. Probably, higher intensity bouts of WBV (higher frequency and greater peak-to-peak displacement than those used in our study) could provoke remarkable muscle fatigue and muscle damage. In any case, our results can help professionals in the prescription of safe WBV protocols for a wide spectrum of population.

References

Aminian-Far, A., Hadian, M., Olyaei, G., Talebian, S., & Bakhtiary, A. H. (2011). Whole-body vibration and the prevention and treatment of delayed onset muscle soreness. *Journal of Athletic Training*, *46*, 43–49. doi:10.4085/1062-6050-46.1.43

Bakhtiary, A. H., Safavi-Farokhi, Z., & Aminian-Far, A. (2007). Influence of vibration on delayed onset of muscle soreness following eccentric exercise. *British Journal of Sports Medicine*, *41*, 145–148. doi:10.1136/bjsm.2006.031278

Bessa, A., Nissenbaum, M., Monteiro, A., Gandra, P. G., Nunes, L. S., Bassini-Cameron, A., … Cameron, L. C. (2008). High intensity ultraendurance promotes early release of muscle injury markers. *British Journal of Sports Medicine*, *42*, 589–593. doi:10.1136/bjsm.2007.043786

Brancaccio, P., Maffulli, N., Buonauro, R., & Limongelli, F. M. (2008). Serum enzyme monitoring in sports medicine. *Clinics in Sports Medicine*, *27*, 1–18. doi:10.1016/j.csm.2007.09.005

Brockett, C. L., Morgan, D. L., & Proske, U. (2004). Predicting hamstring strain injury in elite athletes. *Medicine & Science in Sports & Exercise*, *36*, 379–387. doi:10.1249/01.MSS.0000117165.75832.05

Cardinale, M., & Bosco, C. (2003). The use of vibration as an exercise intervention. *Exercise and Sport Sciences Reviews*, *31*, 3–7. doi:10.1097/00003677-200301000-00002

Carrasco, L., Sañudo, B., de Hoyo, M., Pradas, F., & da Silva, M. E. (2011). Effectiveness of low-frequency vibration recovery method on blood lactate removal, muscle contractile properties and on time to exhaustion during cycling at $\dot{V}O_{2max}$ power output. *European Journal of Applied Physiology*, *111*, 2271–2279. doi:10.1007/s00421-011-1848-9

Chapman, D. W., Newton, M., McGuigan, M., & Nosaka, K. (2008). Effect of lengthening contraction velocity on muscle damage of the elbow flexors. *Medicine & Science in Sports & Exercise*, *40*, 926–933. doi:10.1249/MSS.0b013e318168c82d

Cochrane, D. J., Stannard, S. R., Firth, E. C., & Rittweger, J. (2010). Comparing muscle temperature during static and dynamic squatting with and without whole-body vibration. *Clinical Physiology and Functional Imaging*, *30*, 223–229. doi:10.1111/j.1475-097X.2010.00931.x

Craig, C. L., Marshall, A. L., Sjostrom, M., Bauman, A. E., Booth, M. L., Ainsworth, B. E., … Oja, P. (2003). International physical activity questionnaire: 12-country reliability and validity. *Medicine & Science in Sports & Exercise*, *35*, 1381–1395. doi:10.1249/01.MSS.0000078924.61453.FB

Da Silva-Grigoletto, M. E., De Hoyo, M., Sañudo, B., Carrasco, L., & García-Manso, J. M. (2011). Determining the optimal whole-body vibration dose-response relationship for muscle performance. *Journal of Strength and Conditioning Research*, *25*, 3326–3333. doi:10.1519/JSC.0b013e3182163047

Da Silva-Grigoletto, M. E., Vaamonde, D., Castillo, E., Poblador, M. S., García-Manso, J. M., & Lancho, J. L. (2009). Acute and cumulative effects of different times of recovery from whole body vibration exposure on muscle performance. *Journal of Strength and Conditioning Research*, *23*, 2073–2082. doi:10.1519/JSC.0b013e3181b865d2

Dahmane, R., Valencic, V., Knez, N., & Erzen, I. (2001). Evaluation of the ability to make non-invasive estimation of muscle contractile properties on the basis of the muscle belly response. *Medical & Biological Engineering & Computing*, *39*, 51–55. doi:10.1007/BF02345266

Dahmane, R., Djordjevic, S., Simunic, B., & Valencic, V. (2005). Spatial fiber type distribution in normal human muscle: Histochemical and tensiomyographical evaluation. *Journal of Biomechanics*, *38*, 2451–2459. doi:10.1016/j.jbiomech.2004.10.020

Delagi, E. F., Perotto, A., Iazzetti, J., & Morrison, D. (1975). *Anatomic guide for the electromyographer*. Springfield, IN: Charles C Thomas Publisher.

García-Manso, J. M., Rodríguez-Ruiz, D., Rodríguez-Matoso, D., de Saa, Y., Sarmiento, S., & Quiroga, M. (2011). Assessment of muscle fatigue after an ultra-endurance triathlon using tensiomyography (TMG). *Journal of Sports Sciences*, *29*, 619–625. doi:10.1080/02640414.2010.548822

Gojanovica, B., Feihlh, F., Liaudeth, L., Gremiona, G., & Waeberh, B. (2011). Whole body vibration training elevates creatine kinase levels in sedentary subjects. *Swiss Medical Weekly*, *141*, w13222.

Garry, J. P., & McShane, J. M. (2000). Postcompetition elevation of muscle enzyme levels in professional football players. *Medscape General Medicine*, *2*, E4.

Hody, S., Rogister, B., Leprince, P., Wang, F., & Croisier, J. L. (2011). Muscle fatigue experienced during maximal eccentric exercise is predictive of the plasma creatine kinase (CK) response. *Scandinavian Journal of Medicine & Science in Sports* doi: 10.1111/j.1600-0838.2011.01413.x

Hunter, A., Galloway, S., Smith, I., Tallent, J., Ditroilo, M., Fairweather, M., & Howatson, G. (2012). Assessment of eccentric exercise-induced muscle damage of the elbow flexors by tensiomyography. *Journal of Electromyography and Kinesiology*, *22*, 334–341.

Hurley, B. F., Redmond, R. A., Pratley, R. E., Treuth, M. S., Rogers, M. A., & Goldberg, A. P. (2007). Effects of strength training on muscle hypertrophy and muscle cell disruption in older men. *International Journal of Sports Medicine*, *16*, 378–384. doi:10.1055/s-2007-973024

Kratz, A., Lewandrowski, K. B., Siegel, A. J., Chun, K. Y., Flood, J. G., Van Cott, E. M., & Lee-Lewandrowski, E. (2002). Effect of marathon running on hematologic and biochemical laboratory parameters, including cardiac markers. *American Journal of Clinical Pathology*, *118*, 856–863. doi:10.1309/14TY-2TDJ-1X0Y-1V6V

Kosar, A. C., Putland, J., & Candow, D. G. (2011). Potential beneficial effects of whole-body vibration for muscle recovery following exercise. *Journal of Strength and Conditioning Research*, *26*, 2907–2911. doi:10.1519/JSC.0b013e318242a4d3

Križaj, D., Simunic, B., & Zagar, T. (2008). Short-term repeatability of parameters extracted from radial displacement of muscle belly. *Journal of Electromyography and Kinesiology*, *18*, 645–651. doi:10.1016/j.jelekin.2007.01.008

McBride, J. M., Nuzzo, J. L., Dayne, A. M., Israetel, M. A., Nieman, D. C., & Triplett, N. T. (2010). Effect of an acute bout of whole body vibration exercise on muscle force output and motor neuron excitability. *Journal of Strength and Conditioning Research*, *24*, 184–189. doi:10.1519/JSC.0b013e31819b79cf

McHugh, M. P., Connolly, D. A., Eston, R. G., Kremenic, I. J., Nicholas, S. J., & Gleim, G. W. (1999). The role of passive muscle stiffness in symptoms of exercise-induced muscle damage. *American Journal of Sports Medicine*, *27*, 594–599.

Miyama, M., & Nosaka, K. (2007). Protection against muscle damage following fifty-drop jumps conferred by ten drop jumps. *Journal of Strength & Conditioning Research*, *21*, 1087–1092.

Morgan, D. L., & Proske, U. (2004). Popping sarcomere hypothesis explains stretch-induced muscle damage. *Clinical and Experimental Pharmacology and Physiology*, *31*, 541–645. doi:10.1111/j.1440-1681.2004.04029.x

Paschalis, V., Giakas, G., Baltzopoulos, V., Jamurtas, A. Z., Theoharis, V., Kotzamanidis, C., & Koutedakis, Y. (2007). The effects of muscle damage following eccentric exercise on gait biomechanics. *Gait & Posture*, *25*, 236–242. doi:10.1016/j.gaitpost.2006.04.002

Pilot, R., Narici, M. V., Simunic, B., De Boer, M., Seynnes, O., Jurdana, M., … Mekjavic, I. B. (2008). Whole muscle contractile parameters and thickness loss during 35-day bed rest. *European Journal of Applied Physiology*, *104*, 409–414. doi:10.1007/s00421-008-0698-6

Proske, U., & Allen, T. J. (2005). Damage to skeletal muscle from eccentric exercise. *Exercise and Sport Sciences Reviews*, *33*, 98–104. doi:10.1097/00003677-200504000-00007

Rey, E., Lago-Peñas, C., Lago-Ballesteros, L., & Casáis, L. (2012). The effect of recovery strategies on contractile properties using tensiomyography and perceived muscle soreness in profesional soccer players. *Journal of Strength and Conditioning Research*, *26*, 3081–3088. doi:10.1519/JSC.0b013e318247 0d33

Rittweger, J. (2009). Vibration as an exercise modality: How it may work, and what its potential might be. *European Journal of Applied Physiology*, *108*, 877–904. doi:10.1007/s00421-009-1303-3

Rittweger, J., Beller, G., & Felsenberg, D. (2000). Acute physiological effects of exhaustive whole-body vibration exercise in man. *Clinical Physiology*, *20*, 134–142. doi:10.1046/j.1365-2281.2000.00238.x

Rittweger, J., Mutschelknauss, M., & Felsenberg, D. (2003). Acute changes in neuromuscular excitability after exhaustive whole body vibration exercise as compared to exhaustion by squatting exercise. *Clinical Physiology and Functional Imaging*, *23*, 81–86. doi:10.1046/j.1475-097X.2003.00473.x

Ritzmann, R., Gollhofer, A., & Kramer A. (2012). The influence of vibration type, frequency, body position and additional load on the neuromuscular activity during whole body vibration. *European Journal of Applied Physiology*, *113*, 1–11. doi:10.1007/s00421-012-2402-0

Ritzmann, R., Kramer, A., Gruber, M., Gollhofer, A., & Taube, W. (2010). EMG activity during whole body vibration: Motion artifacts or stretch reflexes? *European Journal of Applied Physiology*, *110*, 143–151. doi:10.1007/s00421-010-1483-x

Ritzmann, R., Kramer, A., Gollhofer, A., & Taube, W. (2011). The effect of whole body vibration on the H-reflex, the stretch reflex, and the short-latency response during hopping. *Scandinavian Journal of Medicine & Science in Sports*, doi:10.1111/j.1600-0838.2011.01388.x

Rodrigues, B. M., Dantas, E., Salles, B. F., Miranda, H., Koch, A. J., Willardson, J. M., & Simao, R. (2010). Creatine kinase and lactate dehydrogenase responses after upper body resistance exercise with different rest intervals. *Journal of Strength and Conditioning Research*, *24*, 1657–1662. doi:10.1519/JSC.0b013e3181d8e6b1

Sale, D. (2002). Postactivation potentiation: Role in performance. *Exercise and Sport Sciences Reviews*, *30*, 138–143. doi:10.1097/00003677-200207000-00008

Simunic, B., Rozman, S., & Pisot, R. (2005). *Detecting the velocity of the muscle contraction*. Sarajevo: III International Symposium of New Technologies in Sport.

Spitzenpfeil, P., Schwarzer, J., Fiala, M., & Mester, J. (1999, July). Strength training with whole body vibration – Single case studies and time series analyses. In P. Parisi, F. Pigozzi, G. Prinzi (Eds.), *Sport Science in Europe*. Proceedings of the 4th annual conference of the European College of Sport Science, Rome, Italy.

Tillin, N. A., & Bishop, D. (2009). Factors modulating post-activation potentiation and its effect on performance of subsequent explosive activities. *Sports Medicine*, *39*, 147–166. doi:10.2165/00007256-200939020-00004

Tous-Fajardo, J., Moras, G., Rodríguez-Jiménez, S., Usach, R., Moreno, D., & Maffiuletti, N. A. (2010). Inter-rater reliability of muscle contractile property measurements using non-invasive tensiomyography. *Journal of Electromyography and Kinesiology*, *20*, 761–766. doi:10.1016/j.jelekin.2010.02.008

Valenčič, V., & Knez, N. (1997). Measuring of skeletal muscles dynamic properties. *Artificial Organs*, *21*, 240–242. doi:10.1111/j.1525-1594.1997.tb04658.x

Valencic, V., Knez, N., & Simunic, B. (2001). Tensiomyography: Detection of skeletal muscle response by means of radial muscle belly displacement. *Biomedical Engineering*, *1*, 1–10.

Varo, J. J., Martínez-González, M. A., De Irala-Estévez, J., Kearney, J., Gibney, M., & Martínez, J. A. (2003). Distribution and determinants of sedentary lifestyles in the European Union. *International Journal of Epidemiology*, *32*, 138–146. doi:10.1093/ije/dyg116

Zhou, Y., Li, Y., & Wang, R. (2011). Evaluation of exercise-induced muscle damage by surface electromyography. *Journal of Electromyography and Kinesiology*, *21*, 356–362. doi:10.1016/j.jelekin.2010.09.009