DEVELOPMENT OF AN EXERCISE BASED INJURY PREVENTION PROGRAMME FOR STRING PLAYERS

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DECLARATION

I, Adedayo Tunde Ajidahun, hereby declare that the work in this dissertation, unless where acknowledged, is mine. This work is submitted in fulfilment for the degree of Doctor of Philosophy, Faculty of Health Sciences, University of the Witwatersrand, Johannesburg, South Africa. It has not been submitted before for any degree or examination at this or any other University.

Signed at the University of the Witwatersrand, Johannesburg

On the 24th day of October 2017

DEDICATION

To God Almighty

To my parents: Peter Ajidahun and Folasade Ajidahun

To the best friends I have always had: Adeyinka, Adebola and Iyanuloluwa

PUBLICATIONS AND PRESENTATIONS FROM THIS THESIS

A. PUBLICATIONS

Ajidahun, A.T., Mudzi, W., Myezwa, H. and Wood, W.A., 2016. Upper extremity disability among string instrumentalists–use of the quick DASH and the NDI. Cogent Medicine, 3(1), p.1234535. https://doi.org/10.1080/2331205X.2016.1234535

Ajidahun, A.T., Mudzi, W., Wood, W.A. and Myezwa, H., 2017. Musculoskeletal problems among string instrumentalists in South Africa. South African Journal of Physiotherapy, 73(1), pp.7-pages. https://doi.org/10.4102/sajp.v73i1.327

B. PRESENTATIONS

Ajidahun, A.T., Mudzi, W, Woods, W. & Myezwa, H. 2014. Prevalence, distribution, severity of Playing Related Musculoskeletal Disorder among string instrumentalists in South Africa – A pilot study. Faculty Research Day, University of the Witwatersrand, Johannesburg

Ajidahun, A.T., Mudzi, W, Woods, W. & Myezwa, H. 2017. Postural demands of playing a string instrument – results of a Rapid Upper Limb Assessment Evaluation. World Confederation of Physical Therapy. Presented on 2nd of July 2017.

Ajidahun, A.T., Mudzi, W, Woods, W. & Myezwa, H. 2017. Conditioning the violinist to the demands of performance – an exercise based injury prevention approach. Accepted for presentation at the Performing Arts Health Symposium at the University of South Africa on 2nd of October 2017.

ABSTRACT

Background: The art of making music is an occupational risk factor for health-related problems. Musculoskeletal problems are the most common health problems experienced by musicians and the prevalence of musculoskeletal problems ranged from 37 – 77 %. The upper extremity, neck and back are the most commonly affected areas. In Africa, the prevalence of musculoskeletal problems is not well documented. Only a few studies have reported the presence of musculoskeletal problems with a relatively small sample size which is not often reflective of the population.

Several injury prevention strategies such as exercise, ergonomic and health education have been implemented to reduce the musculoskeletal problems in the developed countries. In South Africa, there is no documented evidence of an intervention to reduce musculoskeletal problems of musicians generally. Injury prevention strategies to prevent playing-related problems have been suggested and implemented most especially, health promotion, ergonomics and exercise. However, despite the exercise-based intervention, the prevalence of musculoskeletal problems in this population is still relatively high. It has been suggested that an exercise-based intervention should be developed based on the physical demands of playing a string instrument. Therefore, an exercise-based musculoskeletal injury prevention programme could reduce the incidence of musculoskeletal problems in string instrumentalists.

Aim: The aim of this study was to develop an exercise based injury programme for string instrumentalists. The specific objectives of the study were to:

- Establish the prevalence, severity and the anatomic distribution of musculoskeletal problems among string players in South Africa.
- Determine the biomechanical analysis associated with playing the string instrument and
- To adapt exercise programmes from existing studies patterned in line with the demands of playing a string instrument.

Methodology: The study was conducted in two phases using a mixed method approach. The aim of the first phase was to establish the burden of musculoskeletal problems among string players as well as evaluate the biomechanical risk associated with string instrument playing. The second phase was aimed at developing an exercise based injury prevention programme.

PHASE ONE

Study one: The first study in phase one was focussed on establishing the prevalence, severity, distribution of musculoskeletal injury among string instrument players in South Africa. This was done by conducting a cross sectional study. An injury profile questionnaire was modified from existing questionnaire to determine the prevalence, distribution, severity, symptoms of musculoskeletal problems among string players in South Africa. Disability associated with performance was also measured using the quick DASH and the NDI. String players aged 18 and above in orchestras in South Africa were invited to participate in the study.

Study two: The second study in phase one was focussed on evaluating the biomechanical risk factors associated with playing a string instrument. Inertial motion sensors, surface electromyography and rapid upper limb assessment was used to evaluate joint angles, muscle activity and postural loading respectively.

PHASE TWO

Study three: A scoping review of the exercise based intervention programme for musicians was conducted to explore the intervention pattern in musicians. The aim of the scoping review was to evaluate exercise based intervention programmes in the management of musculoskeletal problems among musicians.

Study four: A scoping review of exercise based intervention for work related musculoskeletal disorders was conducted. The aim of the scoping review was to extract reproducible exercises that can be adapted as a component of an exercise programme for string instrument players.

Study five: An integration of the anatomic affectation of musculoskeletal problems and the biomechanical risk factors was used to develop an exercise based injury prevention programme. Content and face validity of the exercise programme was conducted with sports physiotherapists and biokineticists. Possible implementation strategies were explored with musicians.

Results

Study one: A total of 114 string players participated in the study and the median (IQR) age of the participants was 28(20) years and 67 percent were females. The results of this study showed that the 77% of the string players have experienced musculoskeletal problems in one or more anatomic regions in the last one year. The low back (45.6%), upper back (44.7%), neck (41.2%), left shoulder (40.4%) shoulder and the right shoulder (35.1%) were the most commonly affected regions. Aching, soreness and tightening were the most common descriptors of musculoskeletal problems. Female string players were more likely to report problems in the neck, upper back, low back and left shoulder ($p<0.05$). Age showed significant association with musculoskeletal problems in the low back, left shoulder and left hand ($p<0.05$). The median (IQR) quick DASH score and NDI for the participants was 6.8(11.4) and 10(14) respectively. There was a significant association between quick DASH and NDI scores with current history of musculoskeletal problems and number of body regions affected ($p<0.001$).

Study two: Six string instrumentalists participated in the biomechanical analysis. The mean age of the string players was 26±5.7 years and three were females with 16.5±6.2 years of experience. The results showed that four out of the six string players showed positive signs of Hawkins and Kennedy test. Two of the six string players were hypermobile (≥5). Only one of the string players reported a current history of musculoskeletal problems. The mean RULA score was 4.2±1 and 3.8±0.4 for the right and left upper extremity respectively. The mean range of motion in the neck was 17.5º flexion and 3.5º left lateral flexion. In the right shoulder, the mean range of movement was 20º, 15.5º and 17.1º for flexion, internal rotation and abduction respectively. In the left shoulder, the mean range of movement was 26.4º, 10.9º and 3.7º for flexion, internal rotation and abduction respectively. Muscle activity was higher in the right upper trapezius (10.9±9.1), the left elbow flexors (6.9±9.9) and the left upper trapezius (5.8±3.9). Asymptomatic string players showed an increased muscle activity in the upper trapezius.

Study three: A scoping review of exercise based intervention for musicians was conducted and a total of 12 articles were included for the scoping review. The results showed that exercise was useful in reducing the risk of musculoskeletal problems among musicians. The exercise programme used was mainly strength and endurance training, core stabilisation exercises and stretching exercises. Only one study used a combination of strength and endurance, core stabilisation and proprioceptive exercises for professional orchestra musicians. With respect to string players, only one study included stretching exercises as part of a warm up and break programme. There was no specific exercise developed or adapted to prevent musculoskeletal problems among string players.

Study four: A scoping review of exercise based intervention for work related musculoskeletal disorders was conducted and a total of 78 articles were included for the review. Exercise programmes for cervical, shoulder, lumbar, forearm and wrists dysfunction were extracted.

The extracted exercise programme were categorised into – strength and endurance training, stabilisation exercises of the scapular and lumbo-pelvic regions as well as stretching exercises.

Study five: Extracted exercises were adapted to suit the biomechanical risk factors. Ten sports physiotherapists and biokineticists with a mean of 12.5 ± 7.3 years of experience participated in the validation process. The developed exercise programme was structured according to warm up, cool down and physical conditioning exercises. Neural mobilisation exercises were included by the experts. Possible implementation strategies with musicians showed that in as much as musicians believe that the exercise based intervention would be useful for them, time constraints was considered as a major restrictive factor. Teaching of the exercise programme to learners was suggested.

Conclusion

Musculoskeletal problems are high among string players in South Africa and the pattern of injury is mainly in the upper back, neck, low back and shoulders. The component of the developed exercise programme was aimed at improving the strength and endurance of the deep neck flexors and rotator cuff muscles. Stabilisation training exercises of the core and the scapular retractors were included in the exercise programme. Stretching exercises of the levator scapulae, upper trapezius, wrist extensors and flexors were included. Strengthening of the intrinsic muscles of the hand and neural mobilisation exercises of the median, radial and ulnar nerves were included in the exercise programme.

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LIST OF ABBREVIATIONS

ABBREVIATION	FULL
ACL	Anterior Cruciate Ligament
CINAHL	Cumulative Index to Nursing and Allied Health Literature
CTD	Cumulative Trauma Disorders
DASH	Disability of the Arms, Shoulder and Hand
EMG	Electromyography
ICC	Intra Class Coefficient
LSST	Lateral Scapular Slide Test
NDI	Neck Disability Index
PRHP	Playing Related Health Problems
PRMD	Playing Related Musculoskeletal Disorders
RSI	Repetitive Strain Injuries
SCM	Sternocleidomastoid
TRIPP	Translating Research into Injury Prevention Practice
VAS	Visual Analogue Scale
WHO	World Health Organisation
WRMD	Work Related Musculoskeletal Disorders
WRMDSD-UL	Work Related Musculoskeletal Disorders – Upper Limbs
PNF	Proprioceptive Neuromuscular Facilitation
MVC	Maximum Voluntary Contraction
RMS	Root Mean Square

“Music is a moral law. It gives soul to the universe, wings to the mind, flight to the imagination, and charm and gaiety to life and to everything”

Plato

CHAPTER 1

1. INTRODUCTION

1.1. Introduction to Chapter

This chapter explains the need and the justification for this study. The burden of musculoskeletal problems among string instrumentalists is highlighted. The need for research to be done locally to understand the musculoskeletal problems associated with playing the string instrument in a developing society like South Africa is also outlined. The chapter outlines the background of the research, problem statement, research question, aim, objectives, and significance of the study, theoretical and conceptual framework of the research as well as the methodological process of the research.

1.2. Background and Need

The art of making music is an occupational risk factor for health-related problems especially in the upper extremity and trunk (Zaza, 1998, Ramazzini, 2001, Bragge et al., 2006). In a Music Educators conference in 2008, neuro-musculoskeletal health, vocal health, hearing conservation and psychological health were considered as major areas of concern (Palac, 2008). Musculoskeletal problems are the most common health problems experienced by musicians regardless of the level of professionalism and the prevalence of musculoskeletal problems ranged from 37 – 77 % (Zaza, 1998, Brusky, 2010, Barnes et al., 2011, Paarup et al., 2011, Fotiadis et al., 2013).

Playing related musculoskeletal disorder (PRMD) is a multi-symptomatic problem that presents with pain, tingling, loss of flexibility and weakness occurring at one or more regions of the body (Bragge et al., 2006, Brusky, 2010). The anatomic body regions affected by PRMDs are mainly the upper extremities and the trunk (Allsop and Ackland, 2010, Leaver et al., 2011, De Sousa and Greten, 2015). There is a direct relationship between the instrument played and the distribution of musculoskeletal problems in the body and the demand of playing the specific instrument is considered as a major factor (Rigg et al., 2003, Allsop and Ackland, 2010, Brusky, 2010, Moraes and Antunes, 2012).

Musculoskeletal problems are a health concern for musicians worldwide due to their disabling capacity and negative impact on performance and quality of life (Bragge et al., 2006, Wu, 2007, Kenny et al., 2014, Lee et al., 2015). String musicians are considered the most vulnerable instrumentalists to developing PRMDs (Kivimäki and Jokinen, 1994, Steinmetz, 2015). Playing a string instrument is demanding as it involves static postural adaptation to support and hold the instrument while the upper extremities are used repetitively in producing sound (Moraes and Antunes, 2012).

Instrumentalists and athletes share several similarities such as the intense practice of motor skills and the demands of performance on the musculoskeletal structure (Dommerholt, 2009). These similarities allow for a sport oriented injury prevention model to be adopted in reducing PRMDs among musicians (Toledo et al., 2004, Dommerholt, 2009). Similar to an intervention programme for footballers, conditioning and preparation of the body of the athlete to the demands of the profession could be an important component in reducing the incidence of PRMDs (Longo et al., 2012, Steffen, 2013a, Steffen, 2013b). The use of specific tailored exercises in the reduction of musculoskeletal injuries has been reported in several work populations especially sports (Longo et al., 2012, Steffen, 2013a, Steffen, 2013b, Rasotto et al., 2015). Recently, the FIFA 11+ warm up injury prevention programme tailored to the demands of football playing was reported to reduce the incidence of musculoskeletal problems among soccer players (Daneshjoo et al., 2012, Gatterer et al., 2012). There was an improvement in proprioception and balance in professional soccer players after the two month FIFA 11+ intervention (Daneshjoo et al., 2012). The FIFA 11+ exercise programme showed positive results on the incidence of musculoskeletal problems when adapted for basketball players over a nine month basketball season (Longo et al., 2012).

The broad role of exercise in the management of PRMDs has been reported in literature, some studies reported marginal reduction in PRMDs (Brandfonbrener, 1997, De Greef et al., 2003). The components of the exercise programmes are physiotherapy exercises for specific body regions that are usually involved in playing and performance (Brandfonbrener, 1997, De Greef et al., 2003). The focus of the exercise programme was mainly to reduce perceived exertion thereby reducing injuries and not primarily to condition the musician to the demands of the profession (Brandfonbrener, 1997, Ackermann et al., 2002b, De Greef et al., 2003). Orchestral music is popular in South Africa. An analysis of the status of orchestras in South Africa by Burdukova (2010) identified four large professional orchestras in South Africa: namely the Johannesburg Philharmonic Orchestra, KwaZulu-Natal Philharmonic Orchestras, University of Pretoria symphony orchestra and the Cape Philharmonic Orchestra. Additionally there are other orchestras that were not included in the study by Burdukova (2010) and these are the Rand Symphony Orchestra, Eastern Cape Philharmonic Orchestra as well as youth orchestras. An understanding of the burden and the bio-psychosocial demands of playing the string instrument is important in developing an injury prevention strategy.

The burden of injury among instrumental musicians generally is not well established in literature, although, some studies with relatively small samples have reported the prevalence of injury in South Africa (Hohls, 2010, Barnes et al., 2011, Ajidahun and Phillips, 2013b). In South Africa, there is no literature on the management and prevention of PRMDs. Most of the national representative surveys were carried out in developed countries. The local studies conducted were not representative of the general population due to their small sample size (Hohls, 2010, Barnes et al., 2011, Ajidahun and Phillips, 2013b). Therefore, based on the different socio-cultural context and individual factors of a musician in South Africa, the burden of injury in a national representative sample in South Africa could be different. Previous exercise based injury prevention studies, did not evaluate the physical demands (biomechanical factors) of performance in developing the exercise programme (Brandfonbrener, 1997, Ackermann et al., 2002b, De Greef et al., 2003). The developed exercise programmes from literature were not focussed on specific instrument groups. Rather they were adapted according to playing music regardless of the instrument played. The theory of WRMDs identified the physical demands of work as an important factor in predisposing the worker to WRMDs.

The aims of this study was to establish the burden of musculoskeletal injury among string instrumentalists in South Africa and to evaluate the biomechanics associated with string instrument playing and subsequently develop an exercise based injury prevention strategy specifically for string instrumentalists.

1.3. Problem Statement

The burden of musculoskeletal problems is high among musicians and higher in string instrumentalists (Kivimäki and Jokinen, 1994, Steinmetz, 2015). Exercise programmes based on understanding the risk factors and the demand of playing have been employed in sports to reduce the incidence of common musculoskeletal problems in athletes (Soligard et al., 2008). Injury prevention among musicians has received considerable attention over the last three decades in developed countries in continents such as Australia, Europe and North America by exploring several injury prevention strategies in improving performance and reducing injuries (Brandfonbrener, 1997, Ackermann et al., 2002b, De Greef et al., 2003). The exercise based injury prevention programme in these studies was focussed on the injury pattern and the demands of performance in musicians but the specific demand of each instrument was not explored in all the studies published (Brandfonbrener, 1997, Ackermann et al., 2002b, De Greef et al., 2003). The pattern of injury and demands of performance varies for different musical instruments. In other studies, ergonomic adjustments, health promotion and psychological support have been used (Ackermann et al., 2002a, Zander et al., 2010, Burin and Osório, 2016). These intervention programmes have shown positive outcomes in reducing perceived exertion and eventual musculoskeletal injury in musicians. Despite these injury prevention programmes, musculoskeletal problems among string instrumentalists are high. There is no exercise based injury prevention programme for string instrumentalists in literature. Therefore, an instrument specific exercise based musculoskeletal injury prevention programme focussed on the pattern of injury, biomechanical and postural demands of playing could possibly contribute towards strategies aimed at reducing the incidence of musculoskeletal problems among string instrumentalists. In South Africa, a focus on the health of performing artists is relatively new and an exercise based injury prevention programme for string instrumentalists has the potential to contribute towards strategies that would reduce the incidence of musculoskeletal problems and associated disability. The developed exercise programme could be adapted by other instrument groups which would result in an improvement in the overall health of the musician and the orchestra.

1.4. Research Questions

- What is the burden of PRMDs among string instrumentalists (violinists, violists, cellists and double bassists) in South Africa?
- What are the movement patterns associated with string playing?
- What is the content and validity of a specialised exercise based injury prevention programme to reduce PRMDs among string instrumentalists in South Africa?

1.5. Aims and Objectives of the Study

The aims and objectives of this study were as outlined below.

Aim 1: To establish the burden of PRMDs among string instrumentalists in South Africa

The objectives for this aim were: To establish the prevalence (one week and one year), affected body regions, symptoms and severity of PRMDs, among professional and amateur string instrumentalists in South Africa.

- To determine the risk factors associated with PRMDs among string instrumentalists in South Africa.
- To determine the level of disability associated with PRMDs among string instrumentalists in South Africa.

Aim 2: To evaluate the biomechanics associated with playing a string instrument.

The objectives for this aim were to determine:

- The joint kinematics involved with playing a string instrument.
- The muscle activity in selected muscles during a performance by a string instrumentalist.
- The exposure of the string instrumentalists to ergonomic risk factors for musculoskeletal problem in the upper extremity

Aim 3: To develop and validate an exercise based injury prevention programme for the prevention of PRMDs among string instrumentalists.

The objectives for this aim were to:

- Establish the content and structure of an exercise based injury prevention programme for the prevention of PRMDs among string instrumentalists.
- Develop an exercise based injury prevention programme for the prevention of PRMDs among string instrumentalists.
- Establish the content and face validity of the injury prevention programme for string instrumentalists.

1.6. Significance of the Study

The aim of the study was to develop an exercise based injury prevention programme for string instrumentalists. To achieve this aim, the study was conducted in two phases. The first phase of the study explored the burden and risk factors associated with playing string instruments. The burden of PRMDs among string instrumentalists has been studied in developed countries mainly among full time professional orchestra and conservatories. Prior to this cross sectional study, there was no literature to provide data on the burden of PRMDs among string instrumentalists' nationally in South Africa. The theoretical underpinnings of work related injury posits that there is an inter-relationship of socio-cultural context, individual biological and physical factors, psychosocial and physical work demands (Karsh, 2006). The socio-cultural context and individual biological factors are not comparable to the countries where musculoskeletal problems of musicians have been extensively researched. Other studies from other countries have investigated the burden of PRMDs among musicians (Ackermann and Adams, 2003, Brusky, 2010, Ackermann et al., 2011, Leaver et al., 2011, Ackermann et al., 2012). However, there is a dearth of literature on the relationship between PRMDs and disability with respect to activity limitation and participation restriction, nationally and internationally. An understanding of the burden of PRMDs with its associated disability among the South African population would provide a baseline data for the estimation of musculoskeletal problems among string instrumentalists. The second phase of the study aimed to develop an exercise based injury prevention programme that would contribute towards the reduction of the burden of PRMDs and its associated disability among string instrumentalists in South Africa. It is postulated that an exercise based injury prevention programme would go a long way towards mitigating against predisposing factors for PRMDs.

1.7. Theoretical Framework of the Study

The modified translating research into injury prevention practice (TRIPP) theoretical framework was used in this study (Finch, 2006). This is a six stage injury prevention model modified from the four stage model originally developed by Van Mechelen (Van Mechelen et al., 1992).

This model utilises evidence based research methods to develop an injury prevention programme, assess its effectiveness and evaluates implementation (Van Mechelen et al., 1992). The TRIPP model by Finch (2006) involves injury surveillance, identification of injury mechanisms, development of injury prevention measures, recommendation of context specific implementation strategies and evaluation of effectiveness of the injury prevention measure. The scope of this study was to develop an exercise based injury prevention programme for string instrumentalists in South Africa. The first three stages of the TRIPP were used to guide the development of the exercise based injury prevention programme. Figure 1.1 illustrates the stepwise process of the TRIPP used in this study.

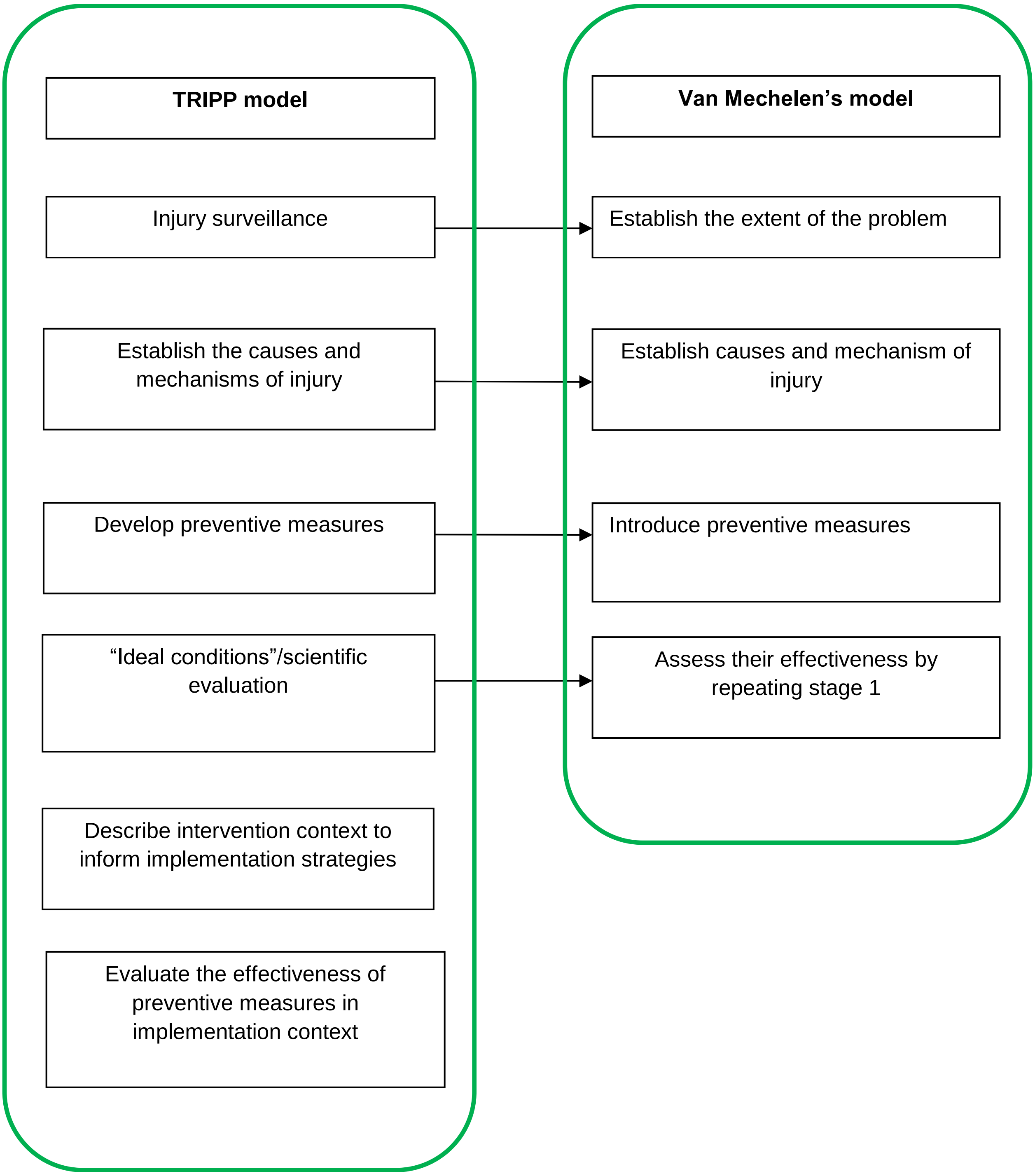


Figure 1.1: The Translating Research into Injury Prevention Practice (TRIPP) framework for research leading to real-world sports injury prevention (Finch, 2006).

1.8. Conceptual Framework of the Study

The conceptual framework of this study was based on the interaction between the epidemiology, anatomical and physiological demands of playing the various string instruments. A focus on all three areas justified the need and the appropriateness of specific exercise programmes targeted at the most commonly injured body regions, taking into consideration the intrinsic and extrinsic factors associated with string instrument playing. Figure 1.2 illustrates the conceptual framework of the study.

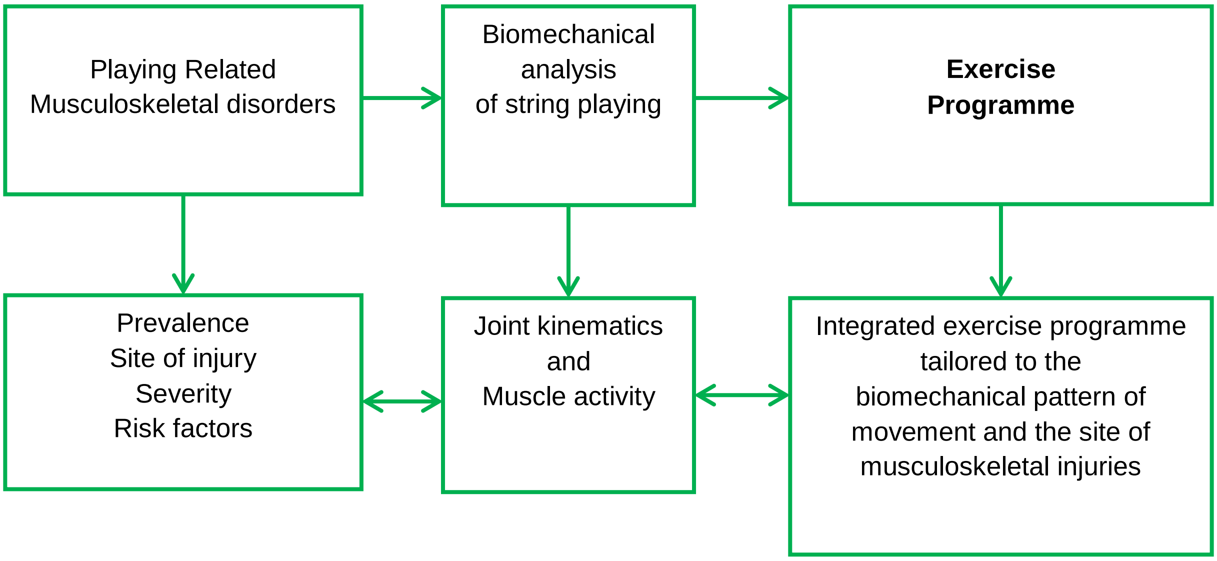


Figure 1.2. Conceptual framework of the exercise development process

1.9. Methodological Outline of Study

This study was divided into two phases. The first phase of the study established the burden of musculoskeletal injury among string instrumentalists and bio-mechanical analysis was conducted to evaluate joint movement and biomechanical interactions as risk factors for musculoskeletal injury. The second phase was the exercise programme development and its validation process. Figure 1.3 outlines the process of the overall study.

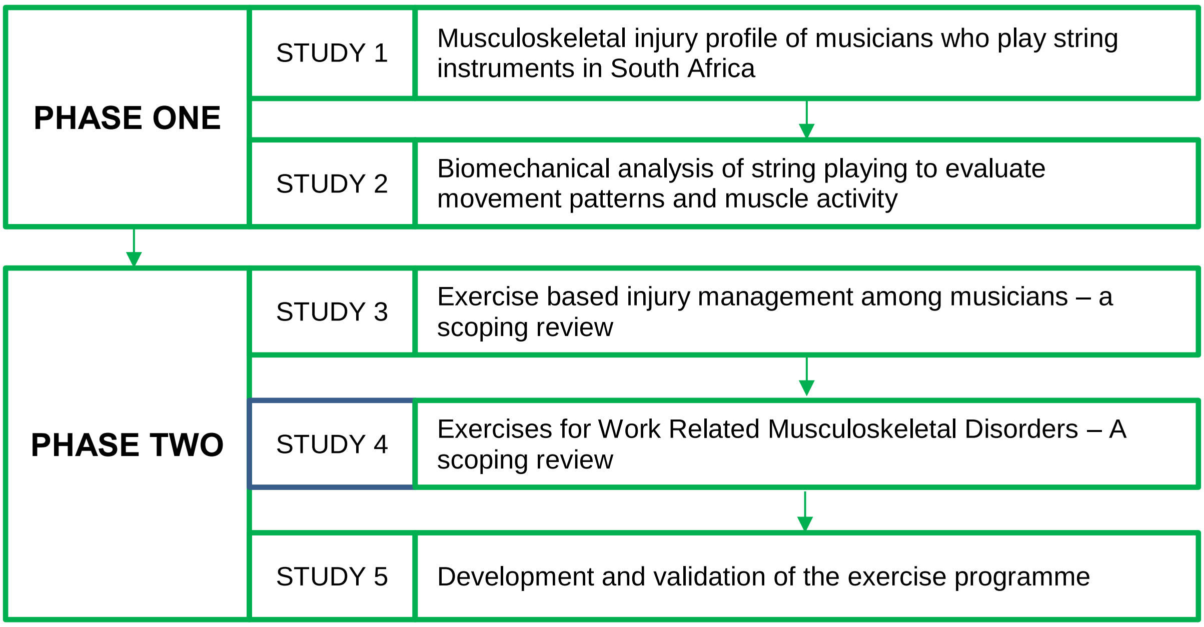


Figure 1.3: Flowchart of the research process

This thesis utilised the theory of Work Related Musculoskeletal Disorders (WRMD) to develop an exercise based injury prevention programme for string instrumentalists. The WRMD theory outlined the relationship between psychosocial work demand, physical work demand, individual factors, work, organisation and socio-cultural factors (Karsh, 2006). Prior to this study, exercise based interventions for musicians were focussed mainly on addressing symptoms of PRMDs in respective anatomic regions. This thesis is the first study in this field to evaluate the physical demands (biomechanical factors) of playing a specific instrument as well as patho-anatomical in developing exercise based injury prevention. Future injury prevention programmes could utilise evaluating biomechanical demands of performance when developing injury prevention programmes for musicians. This PhD provides a baseline for such an approach going forward. The general outline of the thesis is summarized in the next section.

1.10. General Outline of Thesis

Below is the summary of the general outline of the thesis:

Chapter 1: Background and need of study

Chapter 2: Literature review supporting the rationale for the study

Chapter 3: Instrumentation and outcome measures

Chapter 4: Study 1: Musculoskeletal injury profile of string instrumentalists in South Africa

Chapter 5: Study 2: Biomechanical analysis of string playing

Chapter 6: Study 3: Exercise based injury management among musicians – A scoping review

Chapter 7: Study 4: Exercises for Work Related Musculoskeletal Disorders (WRMDS) – A Scoping review

Chapter 8: Study 5: Development and validation of the exercise programme

Chapter 9: Conclusion and recommendations

1.11. Summary of Chapter

This chapter outlined the background of study and the objectives of the research. The conceptual framework for the justification of the research was outlined in this chapter. The overall methodological process of the research and the outline of the whole thesis were also included.

CHAPTER 2

2. LITERATURE REVIEW

2.1. Introduction to Chapter

This chapter focuses on the review of literature supporting the overall rationale of the study. The chapter is divided into three major sections. The first section is the review of literature explaining the burden of playing related health problems of musicians focussing on string instrumentalists and common diagnosis of playing related health problems (PRHPs) associated with playing the musical instrument.

The second section explains the pathophysiology of work related musculoskeletal disorders (WRMDs) using theories of work related musculoskeletal problems as it relate to musicians. The identified risk factors that predispose the musician to PRHPs are reviewed in relation to the integrated theory of work related musculoskeletal disorders.

The third section is a review of injury prevention strategies employed in reducing musculoskeletal problems among musicians. This section also includes the review of literature on exercise based injury prevention in general. The overall methodology of the narrative review is outlined in Section 2.2.

2.2. Methodology of Literature Review

Research databases with related topics of interest were accessed. These included Google scholar, PubMed, PEDro, Science direct, CINAHL, SPORTdiscus and Cochrane reviews. The Medical Problems of Performing Artists journal was searched to gather information on various areas of the research. Additionally, specific websites such as the World Health Organisation (WHO) and the Disability of the Arms, Shoulder and Hands (DASH) questionnaire were also searched to ensure as wide coverage on the literature on PRMDs as was possible. The flowchart of the literature review is outlined in Figure 2.1.

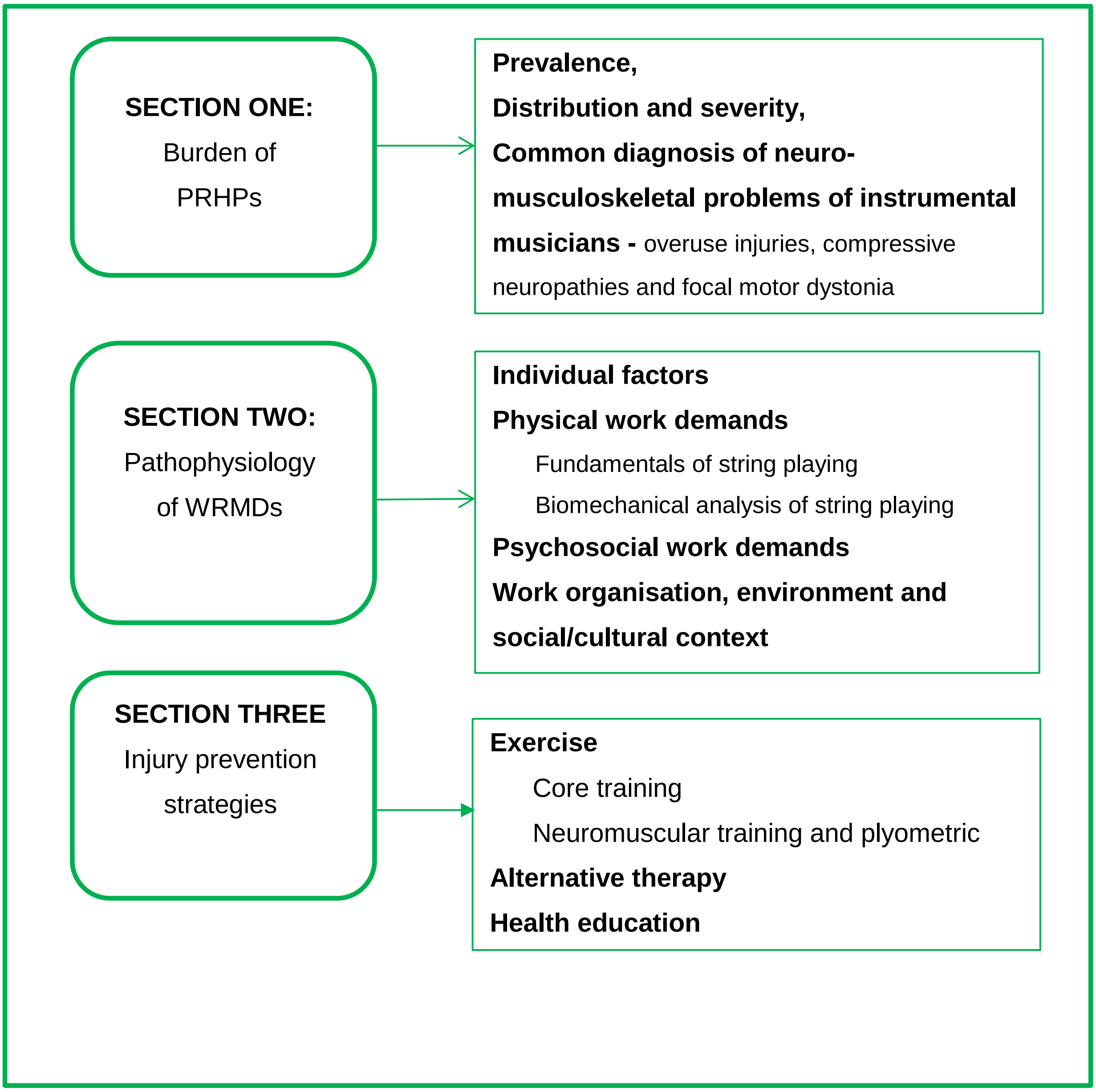


Figure 2.1: Flowchart of the outline of the literature review

A. SECTION ONE

This section is a narrative review of literature on the burden of playing related health problems among musicians that play instruments. The prevalence, distribution, severity and the common diagnosis of playing related problems are also explained.

2.3. Burden of PRHPs among Musicians

Playing a musical instrument predisposes the musician to playing related musculoskeletal problems and these problems are termed playing related musculoskeletal disorders (PRMDs), a derivative of the broad term for work related musculoskeletal disorders (WRMDs) (Bragge et al., 2006). The operational definition of PRMDs 'is the presence of ‘pain, weakness, lack of control, numbness, tingling, or other symptoms that interfere with your ability to play your instrument at the level you are accustomed to’ (Bragge et al., 2006). PRMD is often used in literature as an umbrella term that refers to musculoskeletal disorders associated with playing a musical instrument (Furuya et al., 2006, Ranelli et al., 2008, Sandell et al., 2009, Allsop and Ackland, 2010).

2.3.1. Prevalence and distribution of PRMDs among musicians

The incidence of overuse injury in two music schools in Australia was the first study to report musculoskeletal injury among instrumental musicians when 9.3% of the 1249 music students reported symptoms of overuse injury (Fry, 1987). A systematic review by Zaza (1998) reported the prevalence of PRMDs among professional and student musicians to range between 34% and 87%. Similarly, a national survey of the full-time professional orchestra in Australia showed that 84% of the instrumental musicians had experienced symptoms of PRMDs that had affected their playing and performance (Ackermann et al., 2012). This was further cemented by findings of a survey of professional orchestra in Britain which reported that 86% of the instrumental musicians had experienced pain mainly in the upper extremity and trunk over a period of 12 months (Leaver et al., 2011).

In South Africa, only three cross sectional studies with small samples of 20, 45 and 27 participants have reported the prevalence of problems associated with orchestral musicians (Hohls, 2010, Barnes et al., 2011, Ajidahun and Phillips, 2013b). Barnes et al (2011)’s study on a professional orchestra reported that 84.4% of the instrumental musicians had injuries associated with playing their musical instrument (Barnes et al., 2011). A survey of musculoskeletal problems at a music school reported a prevalence of musculoskeletal injuries of 82 % over a period of 12 months and 23.5 % over a period of one week (Ajidahun and Phillips, 2013b). Playing related musculoskeletal problems are evident among all musicians irrespective of the musical instrument played. A systematic review of PRMDs among pianists showed a prevalence of 26% to 93% (Bragge et al., 2006). In the systematic review conducted by Bragge et al. (2006), the lowest (26%) (Shields and Dockrell, 2000) and the highest (93%) (Blackie et al., 1999) prevalence was reported by piano students. In the study by Blackie et al. (1999) only 16 piano students participated in the study while 159 piano students participated in the study by Shields and Dockrell (2000). Percussionists reported a prevalence of 77% (Sandell et al., 2009) while the prevalence of PRMDs among wind instrumentalists ranged from 53-86% (Chesky et al., 2002, Brusky, 2010). In another study that looked at the prevalence of PRMDs among guitarists, 41.8% reported PRMDs over a period of 12 months (Rigg et al., 2003).

The anatomical distribution of PRMDs among orchestral musicians is dependent on the demands of the specific instrument on the body structures (Rigg et al., 2003, Allsop and Ackland, 2010, Brusky, 2010, Moraes and Antunes, 2012). The upper extremities and trunk are usually the most affected areas of injury. The fretting hand in the guitarists (Rigg et al., 2003), the fingers in the pianists (Allsop and Ackland, 2010) and the arms and wrists in the bassoonists (Brusky, 2010) were the commonly reported area of musculoskeletal problems.

2.3.2. Prevalence and distribution of PRMDs among string instrumentalists

String instrumentalists are the most vulnerable to musculoskeletal problems in comparison to other instrument groups such as the wind and percussion group (Davies and Mangion, 2002). The ratio of musculoskeletal problems is at least 2:1 between bowed string instrumentalists and other instrument groups (Zaza and Farewell, 1997, Hagberg et al., 2005).To show a consistently high prevalence of PRMDs among string instrumentalists, bowed string instrumentalists reported a prevalence of 68% in at least at one body region (Kaufman-Cohen and Ratzon, 2011). Table 2.1 outlines the musculoskeletal problems among string instrument players in the upper extremity and trunk. Sixty three percent of string instrumentalists in three orchestras in South Africa reported injuries in at least one body region (Hohls, 2010).

Table 2.1 outlines the musculoskeletal problems among string instrument players in the upper extremity and trunk.

Table 2.1. Summary of prevalence and location of musculoskeletal problems among string instrumentalists

Author	**Population**	**Prevalence**
Dawson (2001)	Upper string instrumentalists (violin and viola)	64.4% of upper string instrumentalists reported symptoms of musculoskeletal disorder
Paarup et al. (2011)	Professional symphony orchestra	33.3-57.3% of string instrumentalists perceived symptoms of PRMDs in the trunk and shoulders.
Kaufman-Cohen and Ratzon (2011)	Orchestral classical musicians	68% of string instrumentalists reported PRMD
Chan et al. (2000)	Violin players	79% of string instrumentalists reported PRMD over 12 months
Ranelli et al. (2008)	Young learners	0.66 and 0.7, prevalence proportion among upper string and lower string instrumentalists
Nawrocka et al. (2014)	Music school students	String instrumentalists report more symptoms in the shoulder (45%), neck (70%), upper back (50%), wrist and hands (52%). Severity of pain in the lumbar spine is high in wind and string instrumentalists
Abreu Ramos and Micheo (2007)	Professional level symphony orchestra	68% of PRMD is reported in string instrumentalists.
Fotiadis et al. (2013)	Professional symphony orchestra	String instrumentalists exhibited a higher prevalence of musculoskeletal problems in the shoulder and jawbone areas.
Vinci et al. (2015)	Professional symphony	30/45(66.7%) – Upper string 20/23 (87%) – lower string
Brandfonbrener (2009)	University students	63(86%) with pain history – string instrumentalists
Edling and Fjellman-Wiklund (2009)	Music teachers	77% reported musculoskeletal disorders during the preceding 12 months.

In string instrumentalists, the neck, upper back, wrist and hands were reported as the most common areas of pain among string instrumentalists in a music school (Zetterberg et al., 1998). The neck and shoulder were reported as the most frequently affected areas among upper string instrumentalists (Abreu Ramos and Micheo, 2007). A systematic review reported similar results identifying the neck, shoulder and the temporomandibular joints as the site of pain in violinists (Moraes and Antunes, 2012). In the various anatomic regions associated with playing related health problems among musicians, the common diagnoses are mainly musculoskeletal and neurological (Ostwald et al., 1994).

2.3.3. Common Diagnoses of Neuro-Musculoskeletal Problems of Instrumental Musicians

Musculoskeletal problems are the most common diagnosis of health-related problems of musicians. The location and pattern of the musculoskeletal problems is linked to the demands of playing the musical instrument (Rigg et al., 2003, Burkholder and Brandfonbrener, 2004, Ackermann et al., 2012, Moraes and Antunes, 2012). The upper extremity and trunk are mainly involved in music production and they are the most commonly affected region (Zaza, 1998, Bragge et al., 2006, Leaver et al., 2011). The most common diagnosis of playing related neuro-musculoskeletal problems among musicians are musculo-tendinous overuse injuries, compressive neuropathy and neurological problem of focal dystonia (Hoppmann and Patrone, 1989, Larsson et al., 1993b, Ostwald et al., 1994, Lederman, 2003).

2.3.3.1. Overuse Injuries

'Overuse injuries' which can also be referred to as cumulative trauma disorder (CTD) and repetitive strain injury (RSI) are umbrella terms that have been used in literature to describe an aggregation of common musculoskeletal symptoms of musicians that play instruments (Bragge et al., 2006). Newmark and Lederman (1987) categorised the following symptoms in amateur instrumentalists - focal pain or muscle spasm, paraesthesia, sore lips, incapacitating fatigue, soreness, re-injury and tendon snapping as overuse injury. Constant repetitive movement in the bowing arm is a probable cause of overuse injury in the upper extremities, especially the shoulder in violin players (Visentin and Shan, 2003). A classification of overuse related diagnoses was made by Dawson (2001), muscle-tendon strains, tendinitis, tenosynovitis, hypermobility and nerve compression syndromes were classified as overuse related diagnoses in instrumental musicians. An earlier study reported the prevalence of overuse injury among music students as 9.3% and 24% of those affected play the string instrument (Fry, 1987). Dawson (2001) reported a higher prevalence in a population of both professional and amateur instrumental musicians; 44.7% of the population reported overuse due to playing their musical instrument. The prevalence of overuse injury is higher among keyboard players followed by string instrumentalists (Dawson, 2001). However, professional string instrumentalists reported a higher prevalence of overuse injury than amateur string instrumentalists (Dawson, 2001). Overuse injuries are the most common musculoskeletal problems of instrumental musicians followed by compressive neuropathies (Ostwald et al., 1994).

2.3.3.2. Compressive Neuropathy

Compressive neuropathies or nerve compression syndromes are another common musculoskeletal problem diagnosed among musicians (Ostwald et al., 1994). Carpal tunnel syndrome and ulnar neuropathy are the most commonly diagnosed nerve compression syndromes among string instrumentalists (LeeParkYoon et al., 2013). In a study by Lederman (1993), 22% of musicians studied were diagnosed of entrapment neuropathies. Carpal tunnel and ulnar nerve neuropathies accounts for 24% and 20% of all the neuropathies diagnosed in this study (Lederman, 1993). Other entrapment neuropathies diagnosed were thoracic outlet syndrome (31.5%) and cervical radiculopathy (9.8%) (Lederman, 1993).

Carpal tunnel syndrome is the compression of the median nerve in the carpal tunnel in the wrist and it usually presents with nocturnal pain, paraesthesia, hypoesthesia and motor dysfunction in the distribution of the median nerve (Piazzini et al., 2007). It is the most common compressive neuropathy in the general population (Somaiah and Spence, 2008). Carpal tunnel syndrome can be managed surgically and conservatively, however, surgical management has shown better outcomes when compared with conservative management (Verdugo et al., 2003). A systematic review on conservative management of carpal tunnel syndrome concluded that steroids provide temporary relief and exercise therapy showed no significant effect in the amelioration of the syndrome (Piazzini et al., 2007).

Ulnar nerve neuropathy is another common compression neuropathy (Ostwald et al., 1994). The incidence of ulnar nerve neuropathy in the general population is 24.7 cases per 100,000 with a higher incidence in males than females (Mondelli et al., 2005). Increased pressure in the cubital fossa of the fingering arm (left hand) of string instrumentalists is a risk factor for ulnar nerve neuropathy (LeeParkYoon et al., 2013). The ulnar nerve is prone to entrapment in the elbow or the cubital tunnel (Charness et al., 1996). It usually presents with numbness in the distal distribution of the ulnar nerve, pain, tenderness and paraesthesia (Dawson, 1993). An exacerbation of paraesthesia with elbow flexion is a sign of ulnar nerve entrapment (Dawson, 1993). Both surgical and conservative management can be used in the treatment of ulnar nerve neuropathy (Amadio, 1993). Conservative management includes splinting the elbow in about 30-40 degrees flexion to relieve pressure on the cubital fossa and for musicians, rest is often suggested (Amadio, 1993). Surgical intervention which involves cubital tunnel release and medial epicondylectomy have shown better outcomes in the management of ulnar nerve neuropathy (Amadio, 1993). Charness et al. (1996), reported a diagnoses of compressive neuropathy in one-third of musicians with focal dystonia where focal dystonia is neurological problem which involves an involuntary, painless movement of the limb (Fahn, 1991). Although, the relationship between focal dystonia and compressive neuropathy is not clear from literature, it is possible that focal dystonia and compressive neuropathies are two separate pathologies (Newmark and Hochberg, 1987, Karp, 2004).

2.3.3.3. Focal Motor Dystonia

Focal motor dystonia is an involuntary painless movement of the limb (Newmark and Hochberg, 1987, Fahn, 1991). A retrospective study over a five-year period at a general hospital in the United States of America reported a prevalence of 12.7 % of musicians with symptoms of focal motor dystonia (Newmark and Hochberg, 1987). The lack of control in the upper extremity is the most common focal motor dystonia in woodwind instrumentalists (Schuele and Lederman, 2003). The involuntary movement associated with focal dystonia usually affects the muscles involved in playing the musical instrument, in the hand in most instrument groups and facial muscles in brass players (Brandfonbrener, 1995). Focal dystonia has resulted in the early retirement of several musicians. Drug therapy (antiparkinsonian drugs) and botulinum injections (muscle relaxant) as well as ergonomic training and specific exercises to reduce tension have been used to manage focal dystonia (Jabusch et al., 2005). The interventions have shown positive results in reducing symptoms in 52 % of the patients (Jabusch et al., 2005). However, long-term treatment has not shown effectiveness in returning the musician to optimal playing and performing (Jabusch et al., 2005, Altenmüller and Jabusch, 2010).

The burden of playing health related problems is high among musicians and the pattern of injuries is commonly associated with the demands of playing a musical instrument (Burkholder and Brandfonbrener, 2004, Barton et al., 2008, Ackermann et al., 2012) . An understanding of the risk factors associated with playing a musical instrument is explained in the next section based on the integrated theory of work related musculoskeletal disorders (Karsh, 2006).

2.3.4. Disability Associated with PRMDs

The burden of neuro-musculoskeletal problems among musicians impedes performance and can further impede on activities of daily living and eventual disability. Verbrugge and Jette (1994) defined disability as difficulty in doing activities in any domain of life due to a health or physical problem.

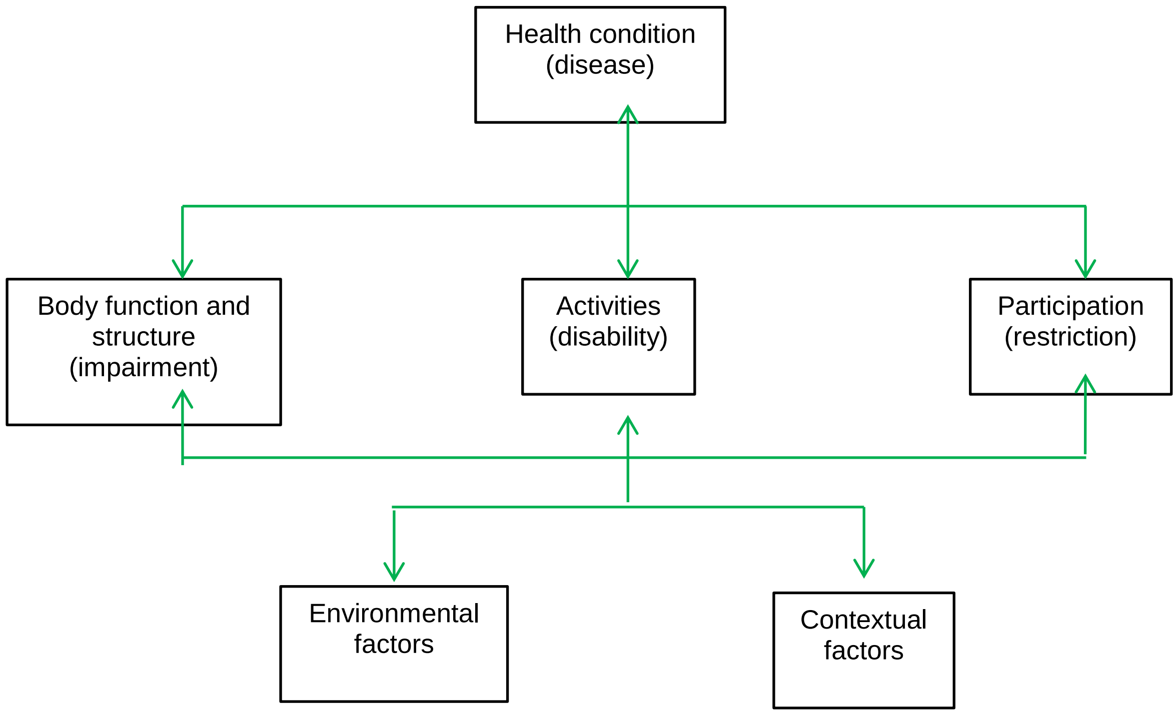


Figure 2.2. ICF bio-psychosocial approach to functioning and disability (World Health Organisation, 2005).

In 2005, the World Health Organisation (WHO) developed a construct to explain disability as the primary impact of a dysfunction on a body structure which results into activity limitation and participation restriction as illustrated in Figure 2.2 above (World Health Organisation, 2005). Functional limitation is usually associated with musculoskeletal injury and the severity of the limitation is usually dependent on the severity of the injuries (WuEdgar et al., 2007, Angst et al., 2011).

B. SECTION TWO

2.4. Pathophysiology of Work Related Musculoskeletal Disorders

Several theories have been proposed to predispose the worker to work related musculoskeletal problems. The earliest framework was developed by Armstrong et al. (1993), this model hypothesized that work related musculoskeletal problems would occur due to an interaction between exposure and the dose of the work on the anatomic regions involved in executing the task. Armstrong et al. (1993), explained exposure as the extrinsic factors such as the ergonomic arrangement of the instrument required for the job description that would alter the anatomy and physiology of the worker. Factors that alter the state of the body are referred to as dose (Armstrong et al., 1993). The body adaptations could be mechanical, physiological and psychological changes (Armstrong et al., 1993). Shortening and lengthening of contractile structures is an example of mechanical adaptation, electrolyte imbalance and tissue damage are examples of physiological adaptation while an example of psychological adaptation is anxiety, electrolyte imbalance (Armstrong et al., 1993, Buckle and Devereux, 2002).

Based on the initial conceptual framework by Armstrong et al. (1993), several other models have been developed with the goal of understanding the pathophysiology of WRMDs (Armstrong et al., 1993, Hagberg et al., 1995, Feuerstein, 1996, Sauter and Moon, 1996, National Research Council, 1999, Carayon and Smith, 2000, Kumar, 2001). Karsh (2006) reviewed the seven concepts and theories of the potential cause of work related musculoskeletal disorders and an integrated theory was hypothesised as shown in Figure 2.3. All the conceptual models are based on the relationship between physical exposures, dose and the response of the body structures (Karsh, 2006). Three of the models reviewed included psychosocial stressors as contributing factors (Feuerstein, 1996, Sauter and Moon, 1996, Carayon and Smith, 2000). The work-style model by Feuerstein (1996) identified psychosocial and ergonomic stressors as key predisposing factors to WRMDs. Figure 2.3 shows the model and the basic components of the models.

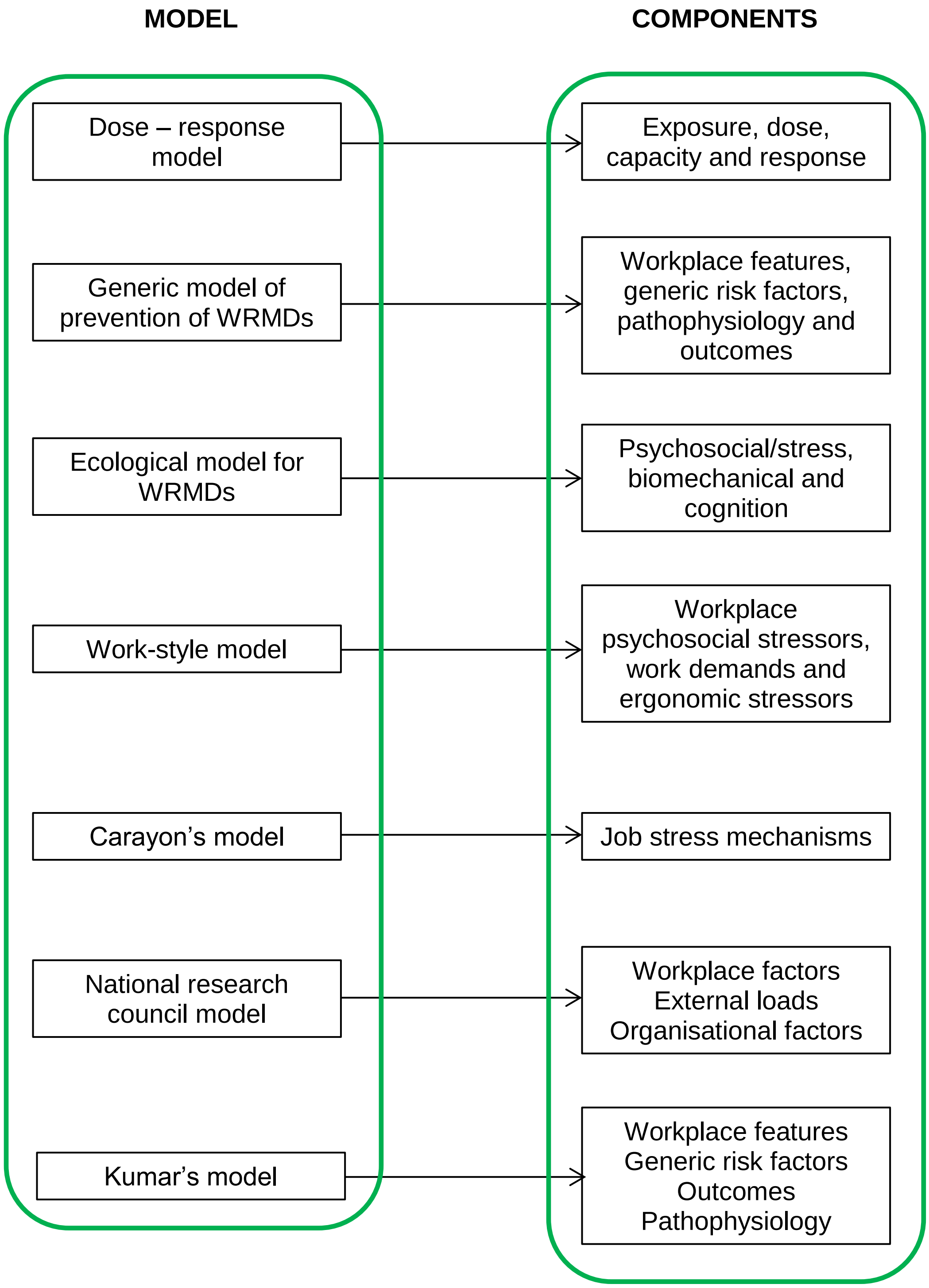


Figure 2.3. Theories of work related musculoskeletal disorders and their components (Karsh, 2006)

The integrated model for the theory of work related musculoskeletal disorders by Karsh (2006), outlined the interaction of four factors that can predispose the human to WRMDs - individual factors, psychological work demands, physical work demands, work organisation, environment and social/cultural context. Figure 2.4 illustrates the interaction and relationship between the four factors.

As illustrated in Figure 2.3, the physical work demands of the job directly results into physical strain by increasing the load on contractile structures which would eventually result into physiological changes such as fatigue, overuse and deformation (Karsh, 2006). Similarly, the psychosocial demands of the job results into anxiety and stress which increases the likelihood of developing work related symptomatic stressors which would eventually result into a work related musculoskeletal problem (Karsh, 2006). Individual factors of the worker such as gender, age, individual capacity and genetic factors, modulate the risk of the worker to the psychosocial and the physical demands of the work (Karsh, 2006). The individual resultant effects of individual factors, psychosocial and physical work demands or a combination of the three eventually affect the quality of the work performed (Karsh, 2006).

The burden of PRMDs among instrumentalists has been associated with several risk factors. The integrated theory of the mechanism of WRMDs as illustrated in Figure 2.4 categorised the risk factors into four inter-related components namely - individual factors, physical work demands, psychological work demands and work organisation / environment / socio-cultural factors (Karsh, 2006). The predisposing factors for PRMDs among string instrumentalists was reviewed according to specific components of the integrated model by Karsh (2006).

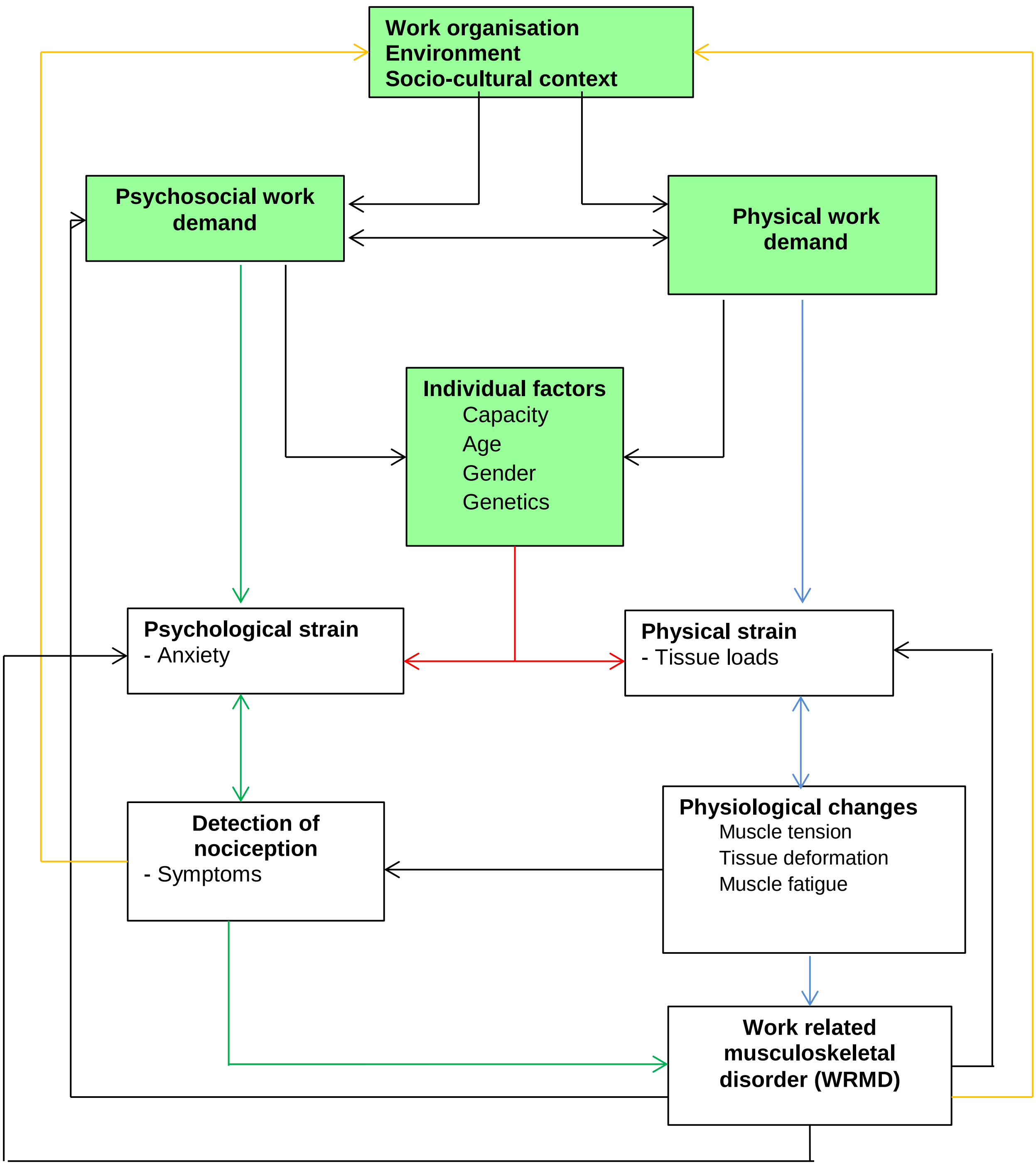


Figure 2.4. Integrated theory of work related musculoskeletal disorders model (Karsh, 2006)

Key:

(red line)	Individual factors
(blue line)	Physical work demand
(green line)	Psychosocial work demand
(yellow line)	Work organisation, environment and social/cultural context

2.4.1. Individual Factors

The anatomic and physiologic structure of the individual is considered as an important component that predisposes the individual to work related musculoskeletal problems (Karsh, 2006). Karsh (2006) hypothesized that individual factors such as age, genetics, capacity and gender modulates the physical and psychological demands of the work which consequently results into symptoms of work related musculoskeletal problems. Individual factors such as socio-demographic characteristics (age and gender) (Ranelli et al., 2008, Kenny et al., 2014, Steinmetz, 2015), capacity (level of competence and practice habits) (Kaufman-Cohen and Ratzon, 2011) and hypermobility (Larsson et al., 1993a, Grahame, 2007) have been reported in literature to predispose musicians to musculoskeletal problems.

2.4.1.1. Socio-Demographic Characteristics

Age: Age is a risk factor associated with musculoskeletal problems in the general population (Anderson and Loeser, 2010, Cross et al., 2014). Older people are prone to develop arthritis when compared to younger ones and the erosion of the articular cartilage is a major predisposing factor to osteoarthritis (Bi et al., 2006, Nelson et al., 2006) . However, among instrumental musicians, there is contradictory evidence to suggest that age has a direct influence on the development of PRMDs (Ranelli et al., 2008). Ranelli et al. (2008) in their study with young learners showed that older musicians will more likely report musculoskeletal problems than young learners. Age is not considered a predictor of PRMDs among instrumental musicians. However, knowledge and understanding of PRMDs increases with age, which is directly associated with an increase in years of experience (Ranelli et al., 2008).

Gender: Musculoskeletal problems in the general population are higher among females than males (Ekman et al., 2000, Anderson et al., 2001, Brandfonbrener, 2002). Variation in joint laxity (Brandfonbrener, 2002), smaller body frame (Ekman et al., 2000) and hormonal influences (Anderson et al., 2001) have been reported in literature to predispose females to musculoskeletal problems. In the broad category of instrumental musicians, the female gender has been reported as a risk factor for PRMDs (Zaza, 1992, Zaza and Farewell, 1997, Yeung et al., 1999). Female string instrumentalists have been reported in literature to be more likely to develop PRMDs than their male counterparts (Davies and Mangion, 2002) . Similarly, Zaza (1992) found that being female is a predictor of playing related health problems among instrumental musicians. A study on the predictors of musculoskeletal injury among musicians in Germany reported that both the female gender and stage fright are strong predictors of musculoskeletal problems (Steinmetz, 2015). The female gender is at a higher risk of developing musculoskeletal problems and the increased risk is mostly a genetic variation (Ekman et al., 2000, Anderson et al., 2001, Brandfonbrener, 2002).

2.4.1.2. Level of Competence and Practice Habits

Competence level and practice habits such as warm-ups, taking breaks and playing hours have been identified in literature are associated to PRMDs (Kaufman-Cohen and Ratzon, 2011). Adequate warm-up prior to a physical activity reduces the risk of musculoskeletal injury (Soligard et al., 2008, Daneshjoo et al., 2012, McCrary, 2016). Warm-up normally involves stretching and joint range of movements and practise of the activity at an easier pace. However, instrumental musicians often perform musical warm-ups which involves playing a scale at a graduated pace (Wu, 2007). Kaufman-Cohen and Ratzon (2011), reported that half of musicians perform warm-ups and normally for a period of 10 minutes. The nature of the warm-up was not reported in the study by Kaufman-Cohen and Ratzon (2011). In a music school in Spain, 90 % of the students do not warm-up (exercise) before playing, however in the education and implementation of a warm-up exercise programme that comprises of stretching exercises, 90 % of the students performed a correct warm-up exercise before playing (López and Martínez, 2013). Lack of warm-up and playing related stress was found to be a predictor of musculoskeletal problems among professional instrumental musicians (Davies and Mangion, 2002). Lack of warm-up exercises prior to playing has been reported to predispose the instrumental musician to PRMDs (Davies and Mangion, 2002, De Greef et al., 2003, Yoshimura et al., 2008, Kaufman-Cohen and Ratzon, 2011). Instrumental musicians practise and play for an average of five to nine hours per week (Newmark and Lederman, 1987, Yoshimura et al., 2008, Kaufman-Cohen and Ratzon, 2011). A significant increase in practice hours increases the development of playing related problems among amateur instrumentalists (Newmark and Lederman, 1987). Similarly, Zetterberg et al. (1998) reported that higher practice hours among female music students is associated with pain in the hand. The development of problems such as pain are linked to physiological and anatomical changes that occur due to repetitive strain and overuse (Shan et al., 2004).

2.4.1.3. Joint Hypermobility

'Joint hypermobility is defined as excessive range of joint movement caused by genetic abnormality in the connective tissue' (Grahame, 1999, Grahame, 2008). Joint hypermobility has been reported as a predisposing factor to musculoskeletal problems in adolescents and children (El-Metwally et al., 2004, Smits-Engelsman et al., 2011, Tobias et al., 2013). In the general population, females have an increased joint hypermobility in comparison to males (Rikken-Bultman et al., 1997, Jansson et al., 2004). A study of 1,039 musicians showed that 34% and 39% of female string instrumentalists and pianists with joint laxity also report pain (Brandfonbrener, 2002). This is similar to an earlier study that evaluated joint hypermobility in musicians treated at a medical program over two years, 34% of the 128 patients managed were hypermobile with upper extremity problems (Brandfonbrener, 2000). Instrumentalists with joint laxity are more likely to complain of joint pain and symptoms of overuse injuries (Brandfonbrener, 2000, Brandfonbrener, 2002). An earlier study by Larsson et al. (1993a) suggested that laxity in joints used for repetitive movements are less likely to report pain in comparison to joints used for support during performance. The individual factors as explained by Karsh (2006) can result into both psychological and physical strain. The physical work demands of performance are influenced by the individual factors which can result into increased physical strain and psychological strain (Karsh, 2006).

2.4.2. Physical Work Demands

Anatomical changes associated with playing a musical instrument are considered as important risk factors that predispose the musician to musculoskeletal problems throughout their entire career (Eijsden-Besseling et al., 1993, Edling and Fjellman-Wiklund, 2009, Ramella et al., 2014). The art of playing the string instrument requires the body to hold, support and produce sound (Rolland et al., 1986) This synergy of movements involves postural adaptation, muscle tension, joint movement through various angles and rapid repetition of movements (Shan and Visentin, 2003, Shan et al., 2004, de Araújo et al., 2009). The learning of how to play a string instrument is usually acquired at an early age (Ranelli et al., 2008). This results in alteration of the body of the young learner at an early age to accommodate the instrument played (Gabor, 2013).

Bowed string instrumentalists have been reported to be more predisposed to PRMDs than other instrument groups (Zetterberg et al., 1998, Hagberg et al., 2005). This is probably as a result of the asymmetric abnormal posture required to play the string instrument (Moraes and Antunes, 2012). A study conducted in a music conservatory to evaluate postural disorders among music students reported that 66.2% of the students have an abnormal posture with or without the musical instrument (Ramella et al., 2014). Another study to evaluate postural stabilisation systems among musicians showed that 93 % of professional musicians assessed had postural stabilisation impairment in the lumbo-pelvic region and scapular (Steinmetz et al., 2010). Chronic pain was reported to be a determinant predisposing factor to postural stabilisation dysfunctions (Steinmetz et al., 2010).

Overuse injury is the most common musculoskeletal problem of musicians (Newmark and Lederman, 1987, Dawson, 2001, Bragge et al., 2006). A study by Shan et al. (2004) with the objective of understanding the association between joint kinematics and repetitive strain injury showed a positive correlation between increased muscle activity and overuse injury indicating an increase in the physical effort during performance is probably the possible cause. The body requirements and demands to play a string instrument are directly associated to the anatomic distribution and incidence of musculoskeletal problems (Leaver et al., 2011). The fundamental principles and the biomechanical analysis of string playing are explained below.

2.4.2.1. Fundamentals of string playing

The violin family comprise the violin, viola, cello and the double bass and they make up about two thirds of a modern orchestra. The violin and the viola are classified as upper string instruments while the double bass and the cello are classified as lower string instruments (Guptill et al., 2000, Wilke et al., 2011, Cooper et al., 2012). The basis of classification is not entirely clear but the position of the violin and viola over the collarbone and left shoulder in comparison to the cello and double bass which are held in front of the player supported by the ground is a possible defining factor (Cooper et al., 2012, Hamann and Cooper, 2016). Sound is produced during string playing by the modulation of frequency with the bow contact on the string. This is done by a combination of movements which mainly involves - ballistic, slow controlled, circular and repetitive movements (Rolland et al., 1986). Optimal performance requires a balance between the three components – the right hand, left hand and the trunk as well as the instrument (Rolland et al., 1986).

The right hand/extremity: The right upper extremity which is the bowing arm, functions mainly in the production and modulation of sound (Askenfelt, 1986). The principle of the functions of the bowing arm is explained by the Newton's third law of motion which states that, "to every action there is an equal and opposite reaction". Bowing involves fine coordinated movement of the right upper arm, forearm and hand in string instrumentalists (Shan and Visentin, 2003, Baader et al., 2005). The agonist and the antagonist of the elbow flexors and extensors contract simultaneously to modulate the speed and the force generated during the bowing action (Rolland et al., 1986). There are four components of bowing action and this includes – bow position, bow velocity, bow force and bow bridge distance (Askenfelt, 1986). The bow force and bow velocity increases dependent on the musical performance (Askenfelt, 1986). There are two types of bowing action which includes ballistic movements and slow controlled movements. The ballistic movements involve sharp, fast thrusts of the agonists while the antagonist's controls the movement (Rolland et al., 1986). However, during slow controlled movements, the antagonists act all through the range of motion to control the movement (Rolland et al., 1986). The quality of sound production is controlled independently by the players left and right hand (Askenfelt, 1986).

The left hand/extremity: The left upper extremity functions mainly in the support of the in upper string (Shan and Visentin, 2003) and tone manipulation in all the string instrumentalists in general by an action referred to as shifting (Visentin et al., 2015). Shifting requires swift movement from one string to the other in order to manipulate the tone of the sound produced by the action of the bowing arm (Monosoff and Walls, 1985, Visentin et al., 2015). The neck is used to hold the body of the instrument in between the chin and the left shoulder while the balance effect of the trunk in the neutral position is used to reduce tension and maintain stability during performance (Rolland et al., 1986, Wilke et al., 2011, Moraes and Antunes, 2012). A conceptual framework developed by Wilke et al. (2011), analysed the consequences of string playing in relation to the playing technique and the body region affected. The playing technique outlined involves – holding and stabilisation of the instrument, bowing action, prolonged sitting and 'shifting' (Wilke et al., 2011). Table 2.2 shows the conceptual framework for the development of PRMDs among string instrumentalists.

Table 2.2: Conceptual framework for the development of PRMDs among string instrumentalists by Wilke et al. (2011).

Playing technique	Location affected	Consequence
Upper string instruments (violin and viola)		
Stabilising the instrument	Lateral inclination of the spine	Muscular stiffness Bony deformation
Holding and playing the instrument	Asymmetrical exposure of the spine	Pain in the thoracic spine
Prolonged sitting during rehearsals or performances	Lumbar spine	Pain in the lumbar spine
Holding and stabilising the instrument	Externally rotated shoulder	Pain in rotator cuff Impingement syndrome
	Supination of the left arm	Pain in the rotator cuff Tennis elbow
Grasping of the strings	Flexion of the left hand	Heavy exposure of the tendons of the extensor musculature
Moving the bow back and forth	Right shoulder in abducted position	Rotator cuff disorders Impingement syndrome Biceps tendinitis
Low string instruments (cello and double bass)		
Holding and playing the instrument	Entire body and upper limb	General back pain
Grasping the strings at high pitched notes Moving the bow over the strings	Forward bend of the upper body	Back complaints in the thoracic and lumbar spine
Holding the instrument in an upright position	Lateral posture of the cervical spine	Tenseness of the neck musculature and cervical spine
Grasping the strings at the upper end of the instrument neck	Left shoulder in an abducted and elevated position(overhead work in double bassists)	Rotator cuff complaints Impingement syndrome Biceps tendinitis
Grasping the strings	Pronation of the left arm	Pain in the rotator cuff
Moving the bow over the high strings (farthest away from the bow) Moving the bow over the strings at both ends (moving the bow from the frog to the head over the strings between the bridge and the fingerboard)	Strong pronation of the right arm	Pain in the rotator cuff

2.4.2.2. Biomechanical Analysis of String Playing

Biomechanical analysis movement have been analysed mainly in studies by using camera-based system to measure kinematics (Barris and Button, 2008, Muro-de-la-Herran et al., 2014) and electromyography to measure muscle activity (Duc et al., 2005, Escamilla et al., 2006, Zebis et al., 2012). Biomechanical analysis has been used as an outcome measure in rehabilitation, in objective assessment of treatment methods and in understanding movement for injury prevention and management (Colby et al., 2000, Visentin and Shan, 2003, Scarvell et al., 2004, WuChen et al., 2007). In string instrumentalists, biomechanical analysis of performance has been used mainly to measure bowing parameters and muscle activity patterns as it relates to performance related injury (Visentin and Shan, 2003, Fjellman-Wiklund, 2004a, Fjellman-Wiklund, 2004b, Kelleher et al., 2013, Verrel et al., 2014). Biomechanical evaluation of bowing in string playing has been used as an objective outcome measure in motor skill acquisition and coordination (Visentin and Shan, 2003, von Hasselbach et al., 2011).

A scoping review of biomechanical research on string instrumentalists by Kelleher et al. (2013) showed that a number of studies have utilised either electromyography and or camera based kinematics to objectively evaluate the pattern of string playing among musicians especially the violin and viola players. The specific muscle activities measured were involved in bowing and shifting action of the right and left upper extremity as well as neck muscles used in supporting the violin or the viola (Kelleher et al., 2013). Muscle activity in the upper trapezius has been associated with injury pattern among the upper string instrumentalists (violin and viola) (Reynolds et al., 2014, Steinmetz et al., 2015).

Muscle activity and repetition of movement predisposes the string instrumentalist to overuse injury (Shan et al., 2004) and postural impairments due to the abnormal postures assumed during performance also puts an immense demand on the musician. An earlier study by Eijsden-Besseling et al. (1993), reported postural disorders in 22% of conservatory students. A comparison between postural problems among medical students and music students showed that music students had more abnormal antero-position of the head, kyphosis, scoliosis, swayback and shoulder asymmetry (Eijsden-Besseling et al., 1993). In a study by Steinmetz et al. (2010) conducted among specialised instrumental musicians with a history of PRMDs, 49% presented with impairments in the lumbo-pelvic and scapula anatomical region as well as upper crossed syndrome. String instrumentalists showed a higher swayback posture and abnormal antero-position of the head when compared with other instrument groups (Eijsden-Besseling et al., 1993). The adaptability of the anatomical structure of children and adolescents to excessive load, stress and abnormal body posture increases the risk of developing postural adaptations to the demands of the instrument played and this increases with years of playing experience (Ramella et al., 2014). An analysis of postural flaws among violinists reported excessive flexion of the radio-carpal joint when bowing and lateral deviation of the head (de Araújo et al., 2009).These abnormal postural flaws often result in an increase in the load on the joints and muscles which leads to an eventual pathology of these anatomical structures (de Araújo et al., 2009). A study by Edling and Fjellman-Wiklund (2009) reported an increase in physical workload in music teachers with postural asymmetry when compared with music teachers without asymmetry.

Karsh (2006), integrated theory of work related musculoskeletal disorders showed that the physical work demand can result into an increase in tissue load which results in musculoskeletal problems. Physical work demand also can influence the psychological state of the player which can also result into performance related anxiety which would eventually result into musculoskeletal problems (Karsh, 2006).

2.4.3. Psychological Work Demands

Psychosocial problems such as, anxiety, fear and increased psychosocial stress has been reported to contribute to the development work related problems (Wesner et al., 1990, Van Kemenade et al., 1995, Kenny and Ackermann, 2015) . A study to determine the occurrence of performance anxiety among music students in the United States showed that 16.5% and 21% of the students had anxiety and distress that negatively affected their performance (Wesner et al., 1990). Davies and Mangion (2002) identified playing related stress as a significant factor that predisposes the instrumental musician to PRMDs. Kivimäki and Jokinen (1994) reported an association between increased psychosocial stress and high prevalence of PRMDs among string instrumentalists when compared with other instrument groups. Related to this finding, in the general population, low job satisfaction has been found to be associated with an increase in stress (Johnson et al., 2005).

Performance anxiety is considered as a major risk factor of PRMDs (Fehm and Schmidt, 2006, Nagel, 2010, Ackermann et al., 2011). Britsch (2005) reported a prevalence of performance anxiety in 75 % of music students. In an orchestra performance, wind players show more symptoms of performance anxiety than string instrumentalists (Kivimäki and Jokinen, 1994). More frequent solo performance and general exposure on stage has been suggested as predisposing the wind players to performance anxiety when compared to string instrumentalists (Kivimäki and Jokinen, 1994). Muscle tension, sweating hands, rapid heart rate and tremor are the most common symptoms associated with performance anxiety (Kivimäki and Jokinen, 1994).

2.4.4. Work Organisation, Environment and Social/Cultural Context

The work environment of musicians involves practice and break schedule and musicians often have to practice long hours to perfect their skills (Kaufman-Cohen and Ratzon, 2011, Bailey and Penhune, 2012). Practice usually involves repetition of movements and abnormal postures for long periods. Awkward postures, postural and technical flaws as well as practice habits have been perceived by musicians and their health care providers as predisposing the musician to injuries (Ackermann and Adams, 2004). A study by Rickert et al. (2013), showed that musicians perceive that work organisational and socio-cultural aspects of playing music in an orchestra result in an increased psychosocial stress, especially lack of autonomy in the intensity of practice as well as professional scrutiny. A coordinated injury prevention strategy with an understanding of these work organisation stressors has been suggested (Zaza, 1993, Rickert et al., 2013).

One major behavioural norm among orchestral musicians is injury concealment (Spahn et al., 2002, Rickert et al., 2014a). Orchestral culture suggests that it is a norm to play through pain and injury which also results into a poor help-seeking behaviour (Rickert et al., 2014a). Recently, health promotion in music schools have incorporated education on playing related injuries as well as basic prevention and management strategies to reduce the likelihood of musicians concealing injuries, and positive results has been reported (Barton and Feinberg, 2008, Zander et al., 2010). In a study by Ranelli et al. (2008) to determine the prevalence of musculoskeletal problems among children learning how to play a musical instrument it was shown that older children with more experience are more likely to report symptoms of musculoskeletal problems in comparison to younger children.

The interface of the human to its work environment is an important risk factor to work related musculoskeletal problems (Drinkaus et al., 2003, David, 2005, Motamedzade et al., 2011). The postural alignment of the musician with the instrument requires that the body perform synchronously as much as possible with as little tension as possible (Foxman and Burgel, 2006).

The risk factors for work related musculoskeletal problems are multi-factorial and a combined effect of physical and psychological work demands as well as the work and behavioural organisation of the profession predisposes the worker to work related problems (Karsh, 2006, Rickert et al., 2013). Therefore, injury prevention programmes with a holistic approach which considers the multi-factorial component of the injury development and impact on performance may be effective in reducing work related problems (Rickert et al., 2013, Rickert et al., 2014a, Rickert et al., 2014b).

C. SECTION THREE

2.5. Injury Prevention Strategies

Understanding the risk factors and pathophysiology of health-related problems of instrumental musicians has been the focus of several studies (Fry, 1987, Zaza and Farewell, 1997, Zaza et al., 1998, Zetterberg et al., 1998, Tanaka et al., 2001, Furuya et al., 2006). Over the last two decades, an aggregation of these epidemiology studies has resulted in the proffering of several injury prevention strategies to reduce and manage PRHPs among instrumental musicians (Brandfonbrener, 1997, Medoff, 1999, De Greef et al., 2003, Chan et al., 2013a, Baadjou et al., 2014, Chan et al., 2014). Despite the injury prevention strategies adopted, a recent systematic review reported the prevalence of PRMDs as still high among professional instrumental musicians (Kok et al., 2015).

The involvement of medical practitioners in the holistic health management of instrumental musicians has been suggested (Milanese, 2000). However, medical practitioners will need to familiarize themselves with the philosophy and the concept of music education and training in order to offer workable injury prevention strategies (Guptill et al., 2000, Andersen et al., 2013). A recent study of onsite management of musculoskeletal problems by physiotherapists in Australia has shown positive results in the acute management of PRMDs among professional instrumental musicians (Chan et al., 2013c).

In 2008, the International Foundation for Music Research identified four key areas that require injury prevention and management strategies – neuro-musculoskeletal health, vocal health, hearing conservation and psychological health (Palac, 2008). Injury prevention strategies employed and adapted to manage vocal, hearing and psychological health problems of instrumental musicians have been reported in several studies (Raeburn, 1999, Raeburn, 2000, Laitinen, 2005, Santucci, 2009, Zander et al., 2010). Neuro-musculoskeletal health management have been the focus of some studies and a key component in injury prevention of neuro-musculoskeletal problems is exercise (Soligard et al., 2008, Longo et al., 2012).

2.5.1. Exercise

Exercise has been a major intervention strategy in health promotion (Cancelliere et al., 2011, Thompson et al., 2013). Exercise therapy has been an adjunct or the main intervention in the management of several diseases such as obesity, back pain, sports related injury and in general rehabilitation (Martinez-Silvestrini et al., 2005, Sjögren et al., 2006, Pillastrini et al., 2009, Peterson et al., 2011, Sihawong et al., 2013, Østerås et al., 2014, Rasotto et al., 2015). Several studies have reported the use of exercise programmes to prevent and manage PRMDs among musicians (Brandfonbrener, 1997, De Greef et al., 2003, Kava et al., 2010, Chan et al., 2014). A scoping review of exercise based intervention for musicians is discussed in Chapter six. Exercise based injury prevention programmes are primarily comprised of core training, neuromuscular training, plyometric and agility training (F-MARC, 2005). These three main components of exercise injury prevention programmes have been used in various studies depending on the functional activities required (Soligard et al., 2008).

2.5.1.1. Core Training

The core is comprised of muscles that support the lumbo-pelvic-hip complex with the aim of stabilising the spine and pelvis during functional movements (Fredericson and Moore, 2005). The core plays a pivotal role in musculoskeletal injury prevention and in ensuring smooth movement (Peate et al., 2007, Lederman, 2010).

Local muscles	**Global muscles**
Multifidi Psoas major Transversus abdominis Quadratus lumborum Diaphragm Internal oblique (posterior fibres) Iliocostalis and longissimus (lumbar portions)	Rectus abdominis External oblique Internal oblique (anterior fibres) Iliocostalis (thoracic portion)

Figure 2.5. Muscles of the lumbar spine

As illustrated in Figure 2.5 above, both local and global muscles play a significant role in the stabilisation of the spine (Akuthota and Nadler, 2004). The local muscles are involved mainly in segmental stabilisation rather than in the gross movement of the spine (Hodges and Richardson, 1996, Hodges and Richardson, 1999). In normal function, the local muscles anticipate and react to rapid multidirectional limb and trunk movement by early activation (Heller, 2008). The global muscles function mainly as prime movers and are activated for functional movement to occur (Heller, 2008). Both global and local muscles work synergistically in maintaining stability during movement (Panjabi, 1992).

The core stability is maintained by a combination of intra-abdominal muscle activity, axial load and the lumbo-pelvic muscle activity (McGill, 2001, Daggfeldt and Thorstensson, 2003). It has been reported that an increase in the intra-abdominal pressure, increases global trunk stiffness which decreases the axial load on the spine during movement (McGill, 2001, Daggfeldt and Thorstensson, 2003).

The spinal stability system hypothesised by Panjabi (1992) consists of three subsystems which are the control subsystem, passive subsystem and the active subsystem which acts in synergy to stabilise the spine during movement as shown in Figure 2.6.

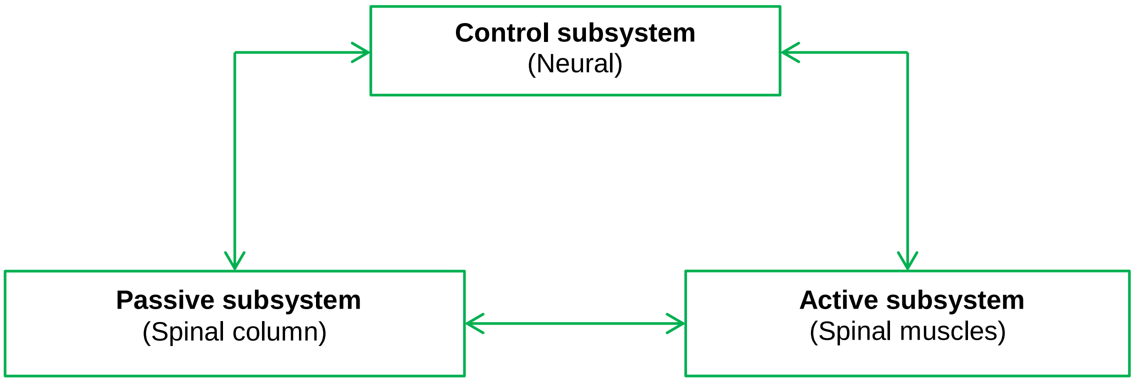


Figure 2.6. The spinal stability system (Panjabi, 1992)

The passive subsystem which consist of the spinal column (the capsules, ligaments and vertebrae) functions in the spinal stability system towards the end of range of motion by providing reactive forces to prevent excessive movements of the spine (Panjabi, 1992). The active subsystem which consists of the muscles and the tendons functions in force generation and dynamic stability of the spine while the neural control subsystem regulates the action of both the passive and the active subsystem (Panjabi, 1992). Injury, degeneration and disease of the passive and active sub-systems would result in dysfunction of the spinal stabilising system (Hodges and Richardson, 1999, França et al., 2010). The neural control compensates for the pathology in the passive and active subsystems by attempting to re-establish the stability of the spinal system (Panjabi, 1992).

2.5.1.2. Neuromuscular and Plyometric Training

Early musculoskeletal injury prevention programmes focussed mainly on improving strength, endurance, flexibility and power until recently when joint stability has become an important component of injury prevention programmes through enhancement of neuromuscular control mechanisms (Griffin, 2003). Neuromuscular training can be defined as “training enhancing unconscious motor responses by stimulating both afferent signals and central mechanisms responsible for dynamic joint control” (Risberg et al., 2001). Neuromuscular training is the neural activation of the muscles to control joint motion and this requires complex interaction in the sensorimotor system (Riemann and Lephart, 2002a, Riemann and Lephart, 2002b).

This includes muscle actions, muscle activation and coordination. The sensorimotor system is a representation of the composite of the physiological systems of the complex neurosensory and neuromuscular process as shown in Figure 2.7 (Riemann and Lephart, 2002a, Riemann and Lephart, 2002b).

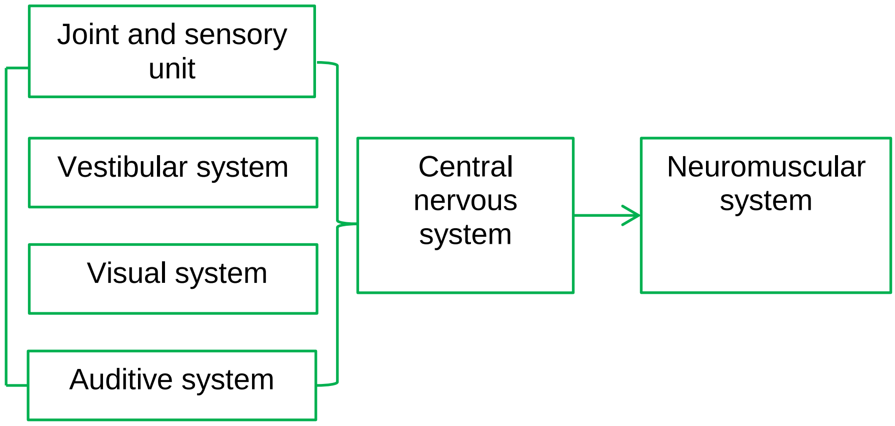


Figure 2.7. The sensorimotor system (Riemann and Lephart, 2002a, Riemann and Lephart, 2002b).

Plyometric training is focussed on improving the ability of muscles to produce power in dynamic movements within a short period of time (Rimmer and Sleivert, 2000). It is mainly used in the rehabilitation and injury prevention in sports that require muscle power and speed (Rimmer and Sleivert, 2000, Fergenbaum and Marino, 2004, Thomas et al., 2009).

2.5.2. Alternative Therapies

'Alexander technique is a psychophysical method that uses enhanced kinaesthetic awareness and voluntary inhibition to prevent non-beneficial movement patterns (Klein et al., 2014). It involves conscious awareness by easing muscle tension and thereby improving co-coordination of movement and breathing (Kenny, 2005, Klein et al., 2014). The fundamental principle of Alexander technique is in three stages, firstly, an understanding of the body's physical state in space, secondly, conscious inhibition of habitual movement patterns, thirdly, organisation of the body to create and maintain a balance (Mayers and Babits, 1987). Alexander technique have been shown to reduce performance anxiety (Hoberg, 2008, Burin and Osório, 2016) and improve skill as well as improve body awareness (Valentine et al., 1995). One method to teach Alexander technique is Feldenkrais method which uses a form of somatic education. The somatic education involves a gentle movement directed at improving human movement in order to enhance functioning (Feldenkrais, 1972).

2.5.3. Health Education

In 2006, health promotion that focussed on prevention education for music students was recommended by the Health Promotion in Schools of Music (HPSM) and the four key areas identified were to: adopt a health promotion framework, develop an undergraduate occupational health course, educate students about hearing loss and active engagement with healthcare resources (Chesky et al., 2004). Barton and Feinberg (2008) implemented an educational programme in health promotion and injury prevention among music students. The results of the six weeks educational programme showed that the music students had a better understanding of injury prevention strategies but it took a much longer time for behaviours to change (Barton and Feinberg, 2008). Recently, in South Africa, there have been suggestions for the inclusion of a health promotion approach in the prevention of performance related problems among music students (Devroop, 2014, Rennie-Salonen and de Villiers, 2016).

2.6. Summary of Chapter

This chapter reviewed relevant literature with regards to the prevalence and burden of musculoskeletal problems of instrumental musicians and the pathophysiology of musculoskeletal problems. Common diagnoses of musculoskeletal problems among instrumental musicians and injury prevention programmes were covered in this chapter. The chapter also reviewed the components of neuromuscular exercise training.

The literature review showed that the focus of research in the health of performing artists has shifted towards a more preventative approach. The role of exercise in the prevention of musculoskeletal problems has been documented and it points to the need for an exercise based injury prevention programme to prevent PRMDs among string instrumentalists in South Africa.

PRMDs are common among string instrumentalists and the risk factors associated with PRMDs are a combination of both intrinsic factors and extrinsic factors. The components of exercise programmes are usually tailored to meet the demands of the job. Therefore, it would be important to consider the biomechanical demands of playing in developing an exercise based injury prevention exercise programme. The next chapter explains the overall methodology of the development of the exercise based injury prevention programme and the outcome measures and instruments used in this study.

CHAPTER 3

3. INSTRUMENTATION AND OUTCOME MEASURES

3.1. Introduction to Chapter

The outcome measures and instruments used for data collection are discussed in this chapter. The research methodology was divided into five studies. The study design, aim and outcome measures of each study are outlined below. Outcome measures require the use of valid, reliable and responsive measurement procedures and in this chapter, the reliability and the validity of the various instruments used are also discussed.

3.2. Overall Methodology

In this thesis, a mixed method approach was used in achieving the overall aim of the study. The research was conducted in five main studies. The aim and methodology used for each study is explained in detail in the following chapters.

3.3. Study 1: Injury Surveillance

The aim of Study 1 was to establish the burden of PRMDs among string instrumentalists in South Africa. The study design, outcome measures and instruments are discussed in this section.

3.3.1. Study design

A cross sectional study design method was used to collect information from participants. A cross sectional study design involves the description of a population at a particular point in time (Levin, 2006) and it was most suitable for the purpose of this study. Table 3.1 shows the outline of the instruments and outcome measures in Study 1.

Table 3.1: Outline of the instruments, outcome measures and the relationship with the specific objectives.

Study 1	Injury surveillance: Establish the extent of injury	
Objective	**Instruments**	**Variables**
To determine the prevalence, distribution, symptoms and severity of PRMDs associated risk factors.	Modified self-administered questionnaire indicating the presence of PRMDs	**Outcome:** PRMDs **Independent:** Age, gender, instrument, practice hours, playing position and years of experience.
To determine the level of disability associated with PRMDs	The Quick DASH Neck disability index (NDI)	**Outcome:** Disability scores **Independent:** Age, gender, instrument, practice hours, playing position and years of experience.

3.3.2. Outcome measures, validity and reliability of the instruments

Objective 1: To evaluate the burden of PRMDs among string instrumentalists in this study, a self-administered questionnaire was modified from three studies that measured the occurrence of musculoskeletal pain among instrumental musicians internationally. The modified questionnaire measures the lifetime and point prevalence, distribution, symptoms and the severity of PRMDs among instrumental musicians. The 17-item questionnaire was divided into three sections – demographics, playing experience and occurrence of musculoskeletal injury (Appendix A). The questionnaire was piloted using the online survey and adjustments were made as recommended by professional musicians. One questionnaire with regards to previous debilitating musculoskeletal injury was added to the demographic questionnaire. Test – retest reliability of the modified questionnaire was done and the result of the test – re-test reliability is reported in Chapter 4.

Objective 2: To determine the level of disability associated with PRMDs
The quick Disability of the Arms Hands and Shoulders (DASH) and the Neck Disability Index (NDI) questionnaire are the two instruments selected to measure disability associated with PRMDs in this study.

a) The Quick Disability of the Arms Hands and Shoulders (DASH)

The DASH is a Likert self-reported questionnaire with 30 items which measure physical functions and symptoms of people with musculoskeletal disorders in the upper limbs. The 11- item quick DASH was classified into the three ICF model constructs – activity limitation, impairment and participation limitation using earlier studies (Drummond et al., 2007, Dixon et al., 2008) as outlined in Table 3.2. The DASH was developed as an outcome measure to evaluate region specific disorders of the upper extremity and it records symptoms as well as activity performance (Hudak et al., 1996). The DASH includes two optional modules relating to work or sports/performing arts (Appendix C) and it can be completed in about 10 minutes. The 30-item DASH was shortened to an 11-item quick DASH questionnaire by Beaton et al. (2005). Table 3.2 below categorised the quick DASH questionnaire according to the three ICF categories – activity limitation, participation restriction and impairment.

Table 3.2: Linking DASH with ICF categories (Drummond et al., 2007, Dixon et al., 2008)

	Activities	Participation	Impairment
1	Open a tight or new jar	Recreational activities in which you take some force or impact through your arm, shoulder or hand.	Arm, shoulder or hand pain
2	Do heavy household chores (e.g., wash walls, floors)	To what extent has your arm, shoulder or hand problem interfered with your normal social activities with family, friends, neighbours or groups?	Tingling in your arm, shoulder or hand.
3	Carry a shopping bag or briefcase.	Were you limited in your work or other regular daily activities as a result of your arm, shoulder or hand problem?	During the past week, how much difficulty have you had sleeping because of the pain in your arm, shoulder or hand?
4	Wash your back	Doing your usual work because of arm, shoulder or hand pain?	
5	Use a knife to cut food	Playing your musical instrument or sport because of arm, shoulder or hand pain?	
6	Recreational activities in which you take some force or impact through your arm, shoulder or hand.	Spending your usual amount of time practising or playing your instrument or sport?	
7	During the past week, were you limited in your work or other regular daily activities as a result of your arm, shoulder or hand problem?		
8	Using your usual technique for your work		
9	Doing your work as well as you would like?		
10	Spending your usual amount of time doing your work?		
11	Using your usual technique for playing your instrument or sport?		
12	Playing your musical instrument or sport because of arm, shoulder or hand pain?		
13	Playing your musical instrument or sport as well as you would like?		
14	Spending your usual amount of time practising or playing your instrument or sport?		

Validity and reliability: Kitis et al. (2009), reported the test-retest reliability of the DASH measured with ICC of 0.92 and 95% CI as 0.88 – 0.95. The quick DASH and the 30 item DASH questionnaire have shown similar reliability (Gummesson et al., 2006). The quick DASH is a valid tool in measuring dysfunction of the upper extremity (WuEdgar et al., 2007, Fan et al., 2008, Angst et al., 2011).

b) The Neck Disability Index (NDI)

The Neck Disability Index is a self-administered instrument developed from the Oswestry Index for Back Pain and the Pain Disability Index (Vernon and Mior, 1991). It is used to assess neck pain complaints and it is the most commonly used self-report instrument in evaluating neck pain in clinical research (Pietrobon et al., 2002). It has 10 sections, with a total of 5 possible scores for each section making a maximum total score of 50 which is then transformed to a percentage (Vernon and Mior, 1991) (Appendix B).

Validity and reliability: The test-retest reliability of the NDI measured with ICC of 0.5 and 95% CI was 0.75-0.90 (Cleland et al., 2008).

3.4. Study 2: Biomechanical analysis of string playing

The aim of this study was to evaluate the biomechanics of playing the string instrument during a music performance. The study design, outcome measures and instruments are discussed in this section.

3.4.1. Study design

A cross sectional observational study design was used to collect information. Table 3.3 outlines the objectives, instruments and the outcome measures in Study 2.

Table 3.3: Outline of the instruments and outcome measures and the relationship with the objectives of the study

Objectives	Instruments	Variables
To evaluate musculoskeletal integrity of the string instrument players	The Janda approach (Page et al., 2010)	Muscle imbalance: Upper crossed syndrome
	Activation of the transversus abdominis (TrA) and multifidus (Hides et al., 2000, Steinmetz et al., 2010).	Lumbo-pelvic stabilisation
	Serratus anterior assessment Kendall et al. (2005)	Scapular stabilisation
	Saehan DHD-3 SH1003 (South Korea) digital hand dynamometer	Hand grip strength to measure gross upper extremity strength.
	Kibler's test	Scapular dyskinesia
	Beighton's hypermobility test	Joint hypermobility
	Neer's test Empty can test Hawkins-Kennedy test	Assessment for shoulder impingement
To evaluate exposure of the string players to ergonomic causes of PRMDs	Rapid upper limb assessment (RULA)	Postural load during performance
To determine the upper extremity and trunk joint angles when playing	Inertial motion unit sensor using the MVN BIOMECH® Xsens	Neck, upper extremity and trunk joint range of movement
To determine the muscle activity in selected muscles during a performance of a string instrument	Eight channel EMG with wireless electrode	Amplitude of muscle activation in selected muscles – upper trapezius, right and left middle fibre of the deltoid, right and left elbow extensors, right and left elbow flexors, right and left wrist extensors, right and left wrist flexors and erector spinae.

3.4.2. Musculoskeletal integrity assessments

Objective 1: To determine the musculoskeletal integrity of the string players.

Subjective postural evaluation, gross muscle strength, shoulder impingement assessment, lumbo-pelvic stabilisation and hypermobility tests were conducted.

a) Subjective postural evaluation

Subjective postural observation was conducted to evaluate shoulder symmetry, kyphosis, lordosis and pelvic tilt. These observation procedures are basic postural tests used in clinical practice to evaluate posture. This evaluation was done by a qualified physiotherapist (with 10 years of experience).

b) Gross upper limb muscle strength

Muscle strength of the upper limb was evaluated by measuring the hand grip strength. Hand grip strength is often used as an outcome measure to evaluate general physical strength especially in the upper extremity (Boissy et al., 1999, Rantanen et al., 1999, Massy-Westropp et al., 2004, Harris and Eng, 2007). The Saehan DHD-3 SH1003 (South Korea) digital hand dynamometer was used to measure the grip strength in this study. Muscle shtrength was measured with the participant seated and the elbow placed at 90 degrees. The dynamometer was calibrated for male and female separately according to the guideline of the instrument. The unit of measurement used in this study was kilogram (Kg). Participants were asked to grip the dynamometer as much as possible using the second rung. Three trials were recorded and the mean of the three trials was finally recorded for analysis.

c) Muscle imbalance

The Janda approach was used to measure upper crossed syndrome (Page et al., 2010). The inhibition and facilitation of upper crossed syndrome was measured with three assesments which includes – cervical flexion, push up and shoulder abduction tests (Page et al., 2010). The procedure for the measurement of upper crossed syndrome followed the procedure outlined by Steinmetz et al. (2010). The test is positive for upper crossed syndrome if there was dysfunctional pattern in executing the movements (Page et al., 2010, Steinmetz et al., 2010). The specific procedure for the upper crossed syndrome test is outlined in Appendix E. Figure 3.1 illustrates the facilitated and the inhibited muscles in upper crossed syndrome (Page et al., 2010) .

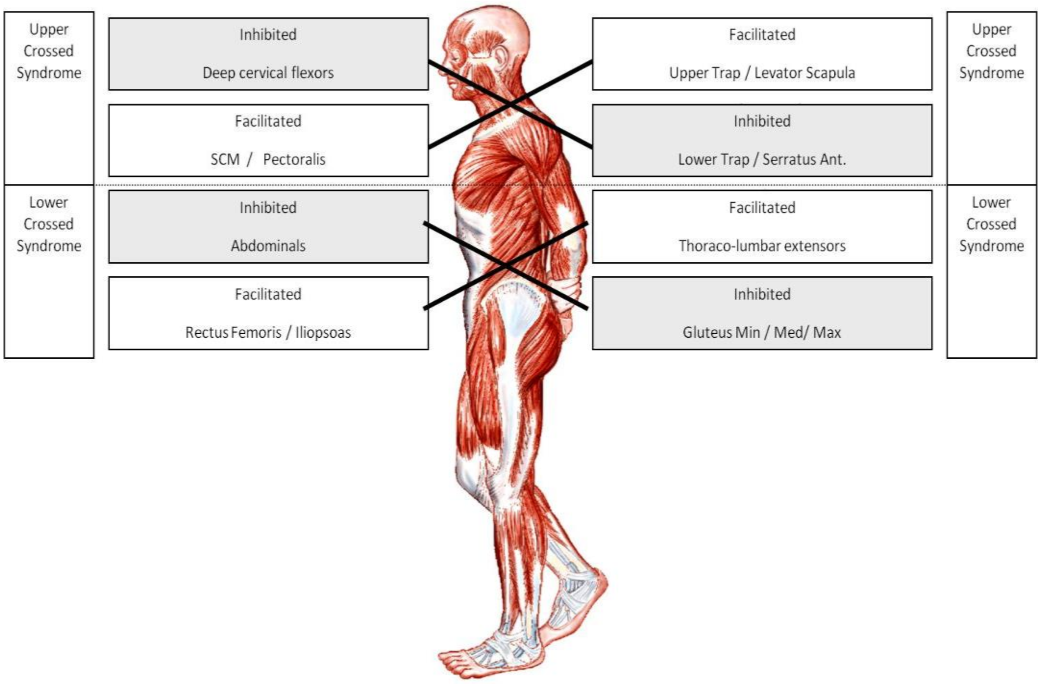


Figure 3.1: Muscle imbalance – the Janda approach

Validity and reliability: The clinical tests to measure upper crossed syndrome using the Janda approach have been found to be valid in measure upper extremity crossed syndrome among musicians (Steinmetz et al., 2010). The reliability of the upper crossed syndrome test has shown strong intra-rater reliability and moderate inter-rater reliability, k was 0.97 and 0.52 respectively (Niemier et al., 2009).

d) Lumbo-pelvic stabilisation

The modified lumbo-pelvic stabilisation palpation test described by Steinmetz et al. (2010) was used in this study. To assess the Transversus abdominis (TrA) patient in supine lying, assessor palpates the insertion of the abdominal muscles on the anterior superior iliac spine. The patient is instructed to suck in the abdomen and a gentle deep tension should be felt under the fingers equally on each side. A change to the tension indicates increased activation of the superficial and global rather than independent contraction of the TrA. To assess the MF, the assessor places one in the vertebrae and the participants were asked to press their spine against the hand of the assessor. The examiner positions one hand as described on the anterior superior iliac spine. The test is also positive if the patient loses the resting lumbar lordosis.

Validity and reliability: The inter rater and intra rater reliability of the lumbo-pelvic stabilisation test described by Steinmetz et al. (2010) was 0.82 and 0.74 respectively.

e) Scapular stabilisation

The method described by Kendall et al. (2005) was used to evaluate the stabilising system function of the serratus anterior in this study. Patients stand in front of a wall, arms elevated at 90 degrees, extended elbow and pushes against a resistance. Normally the scapular should adduct. A weak serratus anterior results in the scapula sliding medially on the thorax which results in scapula winging. Test is positive if the scapula loses contact with the chest wall.

f) Shoulder dysfunction tests

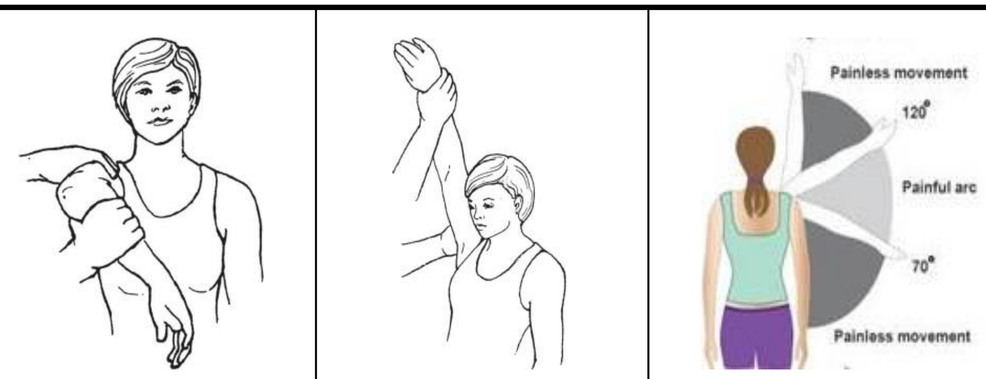
Shoulder dysfunction was evaluated by using a combination of three clinical tests – Neer's test, Hawkins and Kennedy test, and O'Brien's test. These tests are done to determine the integrity of the shoulder complex.

i) **Neer's test:** The Neer's test is commonly used to indicate subacromial impingement syndrome. The patients scapula is stabilized by the examiner while the arm is flexed to about 180 degrees with internal rotation. Pain in this position is considered a positive test for subacromial impingement syndrome. The sensitivity and the specificity of the Neer's test in diagnosisng subacromial impingement syndrome is 72 % and 60 % respectively (Hegedus et al., 2012).

ii) **Hawkins-Kennedy test:** The Hawkins-Kennedy test is commonly used to diagnose subacromial impingement syndrome. However, it has been used with other tests as differential diagnosis for bursitis and rotator cuff pathology. The procedure for the Hawkins-Kennedy test involves the examiner to place the testing arm in 90 degrees of shoulder flexion with 90 degrees of elbow flexion and passive internal rotation of the arm. Pain on internal rotation is considered a positive sign for the test. The sensitivity and the specificity of the Neer's test in diagnosisng subacromial impingement syndrome is 92.1 % and 25 % respectively (Çalış et al., 2000).

iii) **Painful arc test:** The painful arc test is used to diagnose subacromial impingement syndrome (Kenyon and Kenyon, 2009). The test can be performed in sitting or in standing, patient is instructed to abduct the arm and to report if there was pain around the glenohumeral region (Kenyon and Kenyon, 2009). If there is pain, the patient is asked to continue till about 120 degree abduction. Pain should normally subside at 120 degree (Kenyon and Kenyon, 2009). A positive test is considered when the patient reports pain betweeen 60 and 120 degrees which subsides in the range after 120 degrees (Kenyon and Kenyon, 2009).

Summary of the importance of the clinical tests: The sensitivity and specificity of Hawkins-Kennedy and Neer's test together in diagnosing bursitis is 70.8 % and 50.8 % and rotator cuff pathology is 83.3 % and 55.7 % (MacDonald et al., 2000). Figure 3.2 is an illustration of the shoulder impingement tests.



Hawkins and Kennedy test | Neer's test | Painful arc test

Figure 3.2: Shoulder impingement tests

(Photo source: http://www.aidmyrotatorcuff.com/shoulder-tendon-muscle-injury/shoulder-impingement-syndrome.php and http://aibolita.com/surgical-treatment/54031-provocative-examinations.html)

g) **Scapula dyskinesia:** Scapular dyskinesis was measured by using the lateral scapula slide test (LSST). This test was developed to measure scapula imbalance at three difference positions of shoulder abduction in the coronal plane at 0, 45 and 90 degrees; measurements between the inferior angle of the scapula and the closest spinous process. An indication of shoulder dysfunction is noted if the difference between the two sides is ≥1.5cm. Figure 3.3 shows the ilustration of the LSST.

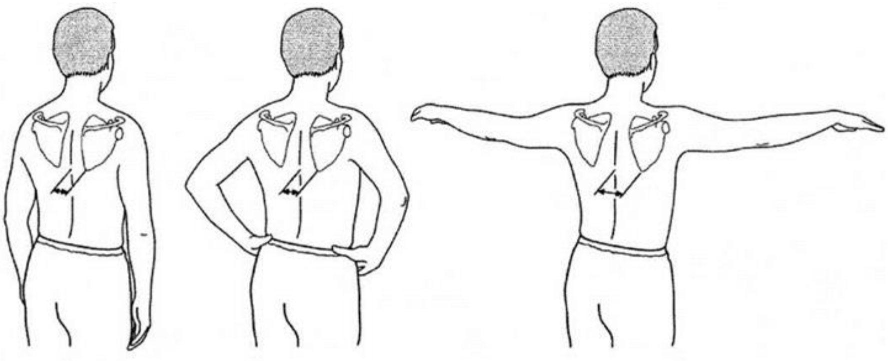


Figure 3.3: Lateral scapular slide test

(**Photo source**: http://aibolita.com/surgical-treatment/54031-provocative-examinations.html)

Validity and reliability*:* Intra rater reliability of the LSST was high ranging from 0.91 and 0.97. However, the sensitivity and the specificity of this test in evaluating assymetry associated with shoulder dysfunction is low (Odom et al., 2001). Therefore, scapular assymetry using the Kibler's test is not necessarily due to shoulder dysfunction. Other factors such as hand dominance and occupation might be responsible for the assymetery. Interpretation of the results should be with caution due to its low sensitivity and specificity in diagnosing shoulder dysfunction in asymptomatic people (Gibson et al., 1995). Contrastingly, Curtis and Roush (2006) reported a moderate to strong test-retest reliablity of the LSST using a scoliometer to measure shoulder assymetery in males with and without shoulder pathology. The ICC ranged from 0.62 – 0.95 for the three test positions. Therapists in this study were more experienced with an average year of practice of 22 years while the therapist in the earlier study had an average of 5 years experience (Curtis and Roush, 2006). The scoliometer might be a more accurate tool in measuring LSST when compared to the tape rule (Curtis and Roush, 2006).

The Kibler's test is a valid tool in measuring scapula assymetery, however, there is conflicting evidence with regards to its reliability in measuring assymetry associated with shoulder pathology. This test is suitable for this research due to its importance, validity and moderate to strong reliability in measuring scapular assymetery, irrespective of shoulder pathology (Koslow et al., 2003, Curtis and Roush, 2006).

h) Hypermobility test

Joint laxity was measured by using the hypermobility assessment method modified from the early method by Carter and Wilkinson (1964). It involves the measurement of joint range of motion in five movements in both the upper and lower extremity. The range of motions measured are – passive dorsiflexion of the fifth metacarpophalangeal joint, passive hyperextension of the elbow, passsive hyperextenstion of the knee and forward flexion of the trunk. The score from the five movements is summed up and the maximum and minimum possible score is 9 and 0 respectively (Beighton et al., 1973). Hyermobility is considered when a participants scores ≥ 5 (Smits-Engelsman et al., 2011). Table 3.4 below outlines the specific joint movement measurement and its indication for joint hypermobility.

Table 3.4: Beighton's hypermobility test (Beighton et al., 1973)

	Movement	**Indication**
I	Passive dorsiflexion of the 5th metacarpophalangeal joint (bilateral testing)	Positive if ≥ 90 degrees
II	Passive hyperextension of the elbow (bilateral testing)	Positive if ≥ 10 degrees
III	Passive hyperextension of the knee (bilateral testing)	Positive if ≥ 10 degrees
IV	Passive apposition of the thumb to the flexor side of the forearm (bilateral testing)	Positive if the whole thumb touches the flexor side of the forearm
V	Forward flexion of the trunk with the knees straight	Positive if the hand palms rest easily on the floor

Validity and reliability: The Beighton hypermobility test is a valid tool in measuring hypermobility in the general population irrespective of age and gender (Rikken-Bultman et al., 1997, Seçkin et al., 2005, Hirsch et al., 2007, Smits-Engelsman et al., 2011). Boyle et al. (2003) reported an excellent intrarater and interrater reliability scores with rho values of 0.86 and 0.87 respectively.

3.4.3. Rapid Upper Limb Assesment

Objective 2: To evaluate exposure of the string players to ergonomic risk of PRMDs.

Biomechanical and postural load demands of performance was evaluated by using the RULA. The upper extremity, neck and trunk were evaluated based on the postural demands during performance and the sum of the scores are calculated as shown in the Figure 3.4 below to generate a single score that can be used to evaluate the level of risk for musculoskeletal disorders (McAtamney and Corlett, 1993). The RULA scoring worksheet is attached in Appendix F.

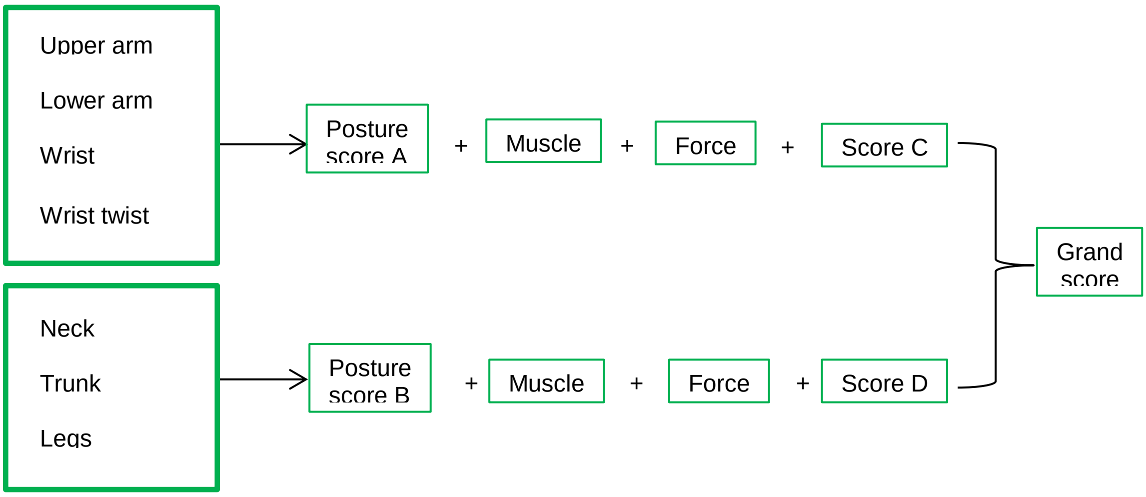


Figure 3.4: RULA method scoring sheet (McAtamney and Corlett, 1993)

Table 3.5 below outlines the grand scores category and the risk of exposure to musculoskeletal disorders.

Table 3.5: Level of musculoskeletal disorder (MSD) risk (Middlesworth, n.d.).

Score	Level of musculoskeletal disorder (MSD) risk
1-2	Negligible risk, no action required
3-4	Low risk change may be needed
5-6	Medium risk, further investigation, change soon
6+	Very high risk, implement change now

As shown in Table 3.5 above, the RULA score is categorised according to the level of MSD risk. A score of 1 shows negligible risk and no action is required while a score of 6+ shows a very high risk and change is required immediately (Middlesworth, n.d.).

Validity and reliability: The RULA is a valid tool in measuring postural load during work (McAtamney and Corlett, 1993). The inter-rater reliability of the RULA using Kendall's coefficient of concordance was statistically significant, Kendall's W = 0.773, $X^2 = 27.82$, $p < 0.001$ (Laeser et al., 1998).

3.4.4. Electromyography (EMG) of selected muscles during performance

Objective 3: To determine the muscle activity in selected muscles during moderately difficult instrumental performance.

Surface electromyography (sEMG): Surface electromyography was used to measure the amplitude of muscle activity in selected muscles of the upper extremity, cervical and lumbar region (upper trapezius, right and left middle fibre of the deltoid, right and left elbow extensors, right and left elbow flexors, right and left wrist extensors, right and left wrist flexors and erector spinae) during performance. The EMG signal was measured by using the Labchart® version 7.0; Adinstruments, Colorado Springs, Colorado.

Validity and reliability: the instrument has been shown to be valid in measuring muscle activity in several studies (Reyes et al., 2014, Gallina et al., 2017). The Labchart® instrument has shown moderate to strong reliability (ICC: 0.69-0.88) in stroke survivors (Phadke et al., 2012). In healthy individuals, the Labchart® intra-session reliability of the Labchart® showed strong reliability measuring the amplitude of muscle activity in the extensor carpi radialis and first dorsal interosseous, 0.77-0.99 and 0.90 – 0.99 respectively (Bastani and Jaberzadeh, 2012).

3.4.5. Joint angles measurement during performance

Objective 4: To determine the upper extremity and trunk joint angles when playing

Xsens 3D motion tracking: An inertial sensor based motion analysis used to measure movement was used to determine the joint angles in the upper extremity and trunk during performance by using the Xsens MVN BIOMECH® system (Xsens Technologies BV, Enschede, Netherlands). The system uses a modelled biomechanical algorithm to estimate 3D joint kinematics (Roetenberg et al., 2009).

Validity and reliability: Validity of Xsens inertial motion sensor to measure angular kinematics showed similar results with flexion and extension but abduction / adduction and internal rotation / external rotation showed weak correlation with camera based systems (Zhang et al., 2013). The intra-session reliability of the Xsens inertial motion sensor was conducted in this study.

3.5. Study three: Exercise based injury management among musicians – A scoping review

Objective: To establish the content and structure of an exercise based injury prevention programme for the prevention of PRMDs among string instrumentalists.

Methodology: Scoping review of studies with the objectives of evaluating developing an exercise based injury prevention programme for musicians was reviewed. The stepwise methodology of the scoping review process by Arksey and O'Malley (2005) is explained in Chapter 6.

3.6. Study four: Exercise for Work Related Musculoskeletal Disorders (WRMDS) – A scoping review.

Objective: To extract reproducible exercise based intervention for the prevention and management of work related musculoskeletal problems.

Methodology: Scoping review of studies with the aim of extracting reproducible exercises from studies focussed on the management of work related musculoskeletal problems in the general population was conducted. The stepwise methodology of the scoping review process by Arksey and O'Malley (2005) is explained in Chapter 7.

3.7. Study five: Development and validation of the exercise programme.

Objective 1: To develop an exercise based injury prevention programme for string instrumentalists.

Methodology: The exercise programme was developed based on the integration of the injury pattern as well as biomechanical demands of playing a string instrument by utilising the clinical and theoretical rationale of exercise development.

Objective 2: To establish the content and face validity of the developed exercise programme

Methodology: The content and face validity of the exercise programme was conducted by consultations with sports/neuro-musculoskeletal system physiotherapists and bio-kineticists.

Objective 3: To explore the developed exercise implementation strategy with musicians.

Methodology: Focus group discussions were conducted with string players and music tutors to explore the implementation strategy of the developed exercise programme with musicians.

The stepwise methodology of the exercise development process, validation and focus group discussion are explained in Chapter 8.

3.8. Ethical Considerations

This research was approved by the University of the Witwatersrand Human and Research ethics committee (Appendix H). Verbal and written (Appendix I) permission to approach the string instrumentalists in the various orchestras was received. Written project information was explained to the participants and they consented to participate in the study. Attached are the information documents and the informed consent forms (Appendix J). Participants were allowed to drop out of the study at any stage of the date collection process without any negative consequences on them.

3.9. Summary of Chapter

This chapter explains the outcome measures and the instruments used in collecting information. The validity and the reliability of the instruments used were reported. A pilot study of the data collection procedure was conducted and the reliability of the modified outcome measures was reported in the next chapter.

CHAPTER 4

4. THE BURDEN OF MUSCULOSKELETAL PROBLEMS AMONG STRING PLAYERS IN SOUTH AFRICA

4.1. Introduction to Chapter

This chapter presents the results of the cross-sectional study aimed at establishing the burden of PRMDs among string players in South Africa. The chapter is outlined into five major sections, the background of the study, aim and objectives, methodology (pilot study and the main study), results and discussion.

4.2. Introduction

Musculoskeletal problems are the most common health related problems of string instrumentalists especially in the upper extremity and trunk (Leaver et al., 2011, Moraes and Antunes, 2012). Several risk factors such as practice hours, posture, years of experience and instrument played have been associated with musculoskeletal problems of string instrumentalists internationally (Kaufman-Cohen and Ratzon, 2011, Leaver et al., 2011, Moraes and Antunes, 2012). However, in South Africa, the studies that have reported injuries of instrumental musicians generally have been with small samples (Barnes et al., 2011, Ajidahun and Phillips, 2013b). There is still a dearth of literature with regards to musculoskeletal problems of string instrumentalists in South Africa. Therefore, the study was designed to evaluate the burden of musculoskeletal problems of string instrumentalists in South Africa.

This information on prevalence, distribution and severity is important in order to develop exercise programmes as an injury prevention strategy. This chapter explains the methodology, results and the inferences from the results of the study.

4.3. Aim and Objectives

Aim: the overall aim of this study was to evaluate the burden of PRMDs among string instrumentalists in South Africa

Objectives:

- To establish the prevalence, affected body regions, symptoms and severity of PRMDs among string instrumentalists in South Africa.
- To determine the risk factors associated with PRMDs among string instrumentalists in South Africa.
- To determine the level of disability associated with PRMDs among string instrumentalists in South Africa.

4.4. Methodology

4.4.1. Study design

A cross sectional study design was used to collect data on prevalence, distribution, symptoms and severity of PRMDs among string instrumentalists in South Africa.

4.4.2. Sampling and sample size

A consecutive sampling technique was used in accordance with the inclusion criteria. An estimated sample size of 87 with a margin of error of 0.1, confidence interval of 95 % and an estimated prevalence of 65 % as reported by (Kok et al., 2015) was used for this study.

Sample size formula: $n=Z^{2} P (1-P) \div e^{2}$

Where n is sample size, P is estimated prevalence, e is margin of error and Z^2 is the confidence interval.

4.4.3. Study participants

The study participants were string instrumentalists in both amateur (youth) and professional orchestra in South Africa.

4.4.4. Inclusion criteria

The following inclusion criteria were used in inviting participants for the study

- Aged 18 and above
- Play any of the following bowed string instruments – violin, viola, cello and double bass

4.4.5. Measuring instruments

Self-administered questionnaires were used to collect information in this study. The questionnaire was divided into three sections: demographics and history of musculoskeletal problems (Appendix A), the Neck Disability Index (NDI) (Appendix B) and the quick DASH (Appendix C). The outcome measures and the instruments used in this study are outlined in Table 4.1 below.

Table 4.1: Aim, outcome measures and instruments for study one

Study one	**Injury surveillance: Establish the extent of injury**	
Aim	**Instruments**	**Variables**
To determine the prevalence, distribution, symptoms and severity of PRMDs and associated risk factors.	Modified self-administered questionnaire indicating the presence of PRMDs	**Outcome:** PRMDs **Independent:** Age, gender, instrument and practice habits
To determine the level of disability associated with PRMDs	The Quick DASH Neck disability index (NDI)	**Outcome:** Disability scores Independent: Age, gender, instrument and practice habits

4.5. Pilot study of Study 1

The pilot study for this cross-sectional study was aimed at evaluating the use of the internet based questionnaire in collecting data on prevalence, distribution, severity and disability with regards to PRMDs among string instrumentalists in South Africa with the following objectives:

- To determine if the participants understand the question and the questions answer the objectives of the research.
- To determine the amount of time taken to complete the survey.
- To evaluate the participant recruitment process.
- To determine unforeseen eventualities that may occur in the process of data administration.

Study design: A cross sectional quantitative study was conducted. Data were collected over a period of one month.

Sample size: Thirty string instrumentalists in South Africa were selected and contacted via email to participate in the study. Out of the 30 invited, only 14 responded to the electronic questionnaire.

Measuring instruments: The self-administered questionnaire, the DASH and the NDI were created as an electronic questionnaire using Survey Monkey®. The participants were asked to complete the questionnaire and give comments with regards to the questionnaire.

Key recommendations: The pilot study provided valuable information in preparation for Study 1. Recommendations were made to include a history of musculoskeletal problems not associated with playing the musical instrument. The demographic question, 'Which is your bowing arm?’ was suggested to be removed due to the standard pattern of playing which involves the right and left arm as the bowing and fingering arm respectively. The 30-item full length DASH questionnaire was replaced with the shorter 11-item quick DASH questionnaire to reduce time. The quick DASH has similar use with the full length DASH in measuring disability associated with upper extremity disorders (Gummesson et al., 2006).

In addition, this pilot study revealed potential difficulties in the process of data collection:

- Participants were more likely to respond to surveys from a known person, therefore, the study design was modified such that, the manager of the orchestra was contacted and he/she thereby forwards the survey to the string instrumentalists in the group.
- Online surveys usually report a lower response rate; therefore alternative recruitment methods were considered using paper questionnaires if the sample size was not met in the specified period.
- The pictorial diagram of the distribution and severity of the PRMDs could not be uploaded in the Survey Monkey questionnaire. Therefore, it was suggested that the narrative version as shown in Appendix A be used.

<u>Test-retest reliability of the modified questionnaire</u>: Music students at the University of the Witwatersrand were recruited to establish the test-retest reliability of the modified questionnaire. The students completed the questionnaire in the department twice with an interval of 24 hours (Paiva et al., 2014). The correlation coefficient of the test-retest reliability of the continuous variables of the modified questionnaire showed moderate to strong correlation (r_s=0.42-1.00, $p<0.05$). In the categorical variables, the measure of agreement (Cohen’s Kappa) ranged from (k=0.63 – 1, $p<0.05$). All the respondents understood the questions. On completion of these modifications, the main study was conducted

4.6. Main study

4.6.1. Data collection procedure

The survey was conducted using an online survey system and a paper based questionnaire. The instruments and outcome measures for this study are explicitly discussed in Chapter 3. The management of philharmonics and youth orchestras in all the nine provinces in South Africa were invited to participate in the study. A total of 16 organisations were invited to participate in the study and reminders were sent every two weeks for a period of six months. After six months of using the online survey, non-respondents to the online survey were invited to participate in a paper based questionnaire format. Questionnaires were handed out to the string instrumentalists in orchestras and sent by post to the orchestra manager who handed out the questionnaires to the string instrumentalists, collected and posted back to the researcher. Orchestra who participated in the online survey were excluded from participating in the paper based survey. The overall data for this study was collected over a period of one year and two months from July 2014 to September 2015.

4.6.2. Response rate

The total response rate for this study was 40.9% and as shown in Table 4.2, the response rate of the participants is reported according to the mode of survey and questionnaire as well as the total number of participating orchestras and number of returned questionnaires per mode of survey

Table 4.2. Response rate

Mode of survey	Number of orchestra	Mode of questionnaire return	Total number of questionnaires returned	Response rate, %
Online	6	Survey Monkey	52	33.3
Paper	7	Post	15	15
		Site	62	100
Total	13			40.9%

Of the 16 orchestras invited to participate in the study, 13 participated in the study. Six completed the online survey while seven completed the paper based questionnaire. A total of 129 respondents completed the surveys from six of the nine provinces in South Africa. Sixteen participants were excluded because they were younger than 18 years.

The response rate of the questionnaires administered at the rehearsal venue was 100% (62/62) and by post was 15% (15/100). A total of 129 respondents participated in the study with an overall response rate of 40.9%, although only 114 respondents met the inclusion criteria

4.6.3. Data management

Out of the 129 respondents, three were below age 18 and they were removed from the sample. Twelve cases with generalised blank questionnaires were removed from the sample. A total of 114 respondents remained. Recoding of new variables was done to categorise string instruments into upper and lower string. The presence of PRMDs on the body chart was recoded as a dichotomous variable. Fourteen cases had missing data mainly in the distribution of PRMDs segment (Question 16). It was assumed that since the preceding question of point prevalence was 'No', the respondents did not have symptoms of PRMDs within the last seven days, so the 16 cases were considered as 'No symptoms'.

Twelve cases reported symptoms of PRMDs only in the areas where they had symptoms and left the remaining part of the body chart as blank. Where nothing was indicated, the interpretation was that they had ‘no symptoms of PRMDs’ on the blank part of the body chart. The other missing data were coded as missing.

4.6.4. Normality of data

The normality of data was tested by using the Kolmogorov-Smirnov and Shapiro-Wilk tests for normality. These are the two commonly used statistical tests to determine the distribution of a continuous variable in a dataset (Ghasemi and Zahediasl, 2012). Table 4.3 shows the results of the Kolmogorov-Smirnov and Shapiro-Wilk tests for normality of data for age and years of experience.

Table 4.3. Test for normality of dataset using the Kolmogorov-Smirnov and the Shapiro-Wilk test

	Kolmogorov-Smirnov			**Shapiro-Wilk**		
	Statistic	df	**Sig.**	**Statistic**	**df**	**Sig.**
Age	0.18	111	<0.001	0.86	111	<0.001
Years of experience	0.17	111	<0.001	0.90	111	<0.001

The Kolmogorov-Smirnov and Shapiro-Wilk tests showed that the data were not normally distributed using age and years of experience ($p<0.001$). Therefore, non-parametric tests were used to determine the association between the dependent and independent variables (Kitchen, 2009, Ghasemi and Zahediasl, 2012). The Figure 4.1 below shows the graphical llustration of the normality curve of the age distribution of the study participants.

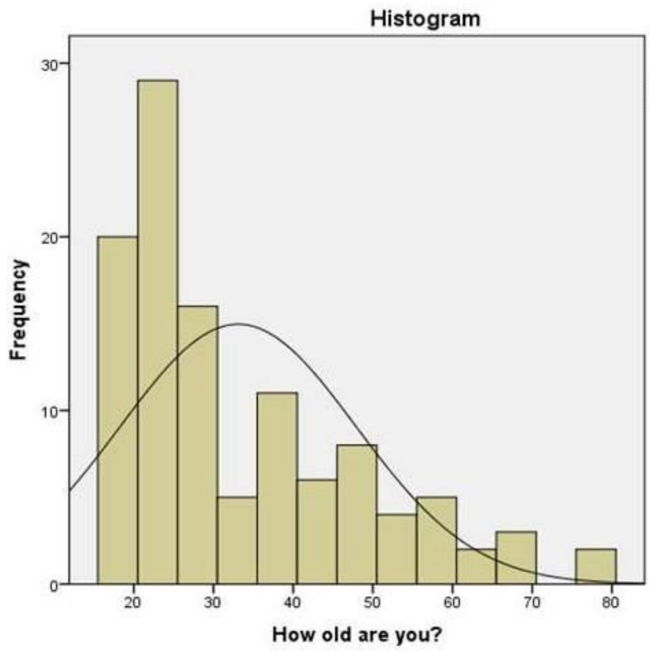


Figure 4.1. Graphical illustration of the normality curve

Figure 4.1 above showed that the data were positively skewed (skewed to the right). This implies that the mean of the age distribution was on the right. In positively skewed dataset, the mean is larger than the median (Doane and Seward, 2011). Therefore, reporting the median would be a better representation of the description of the population (Hozo et al., 2005).

4.6.5. Data analysis

Data were exported to Microsoft Excel and all analysis was done using IBM SPSS 22.0. Descriptive statistics of median, interquartile range (IQR) and frequency were used to analyse demographics, symptoms, distribution and severity of PRMDs. Association between the dependent and the independent variable were analysed by using Fischer's exact and the Mann-Whitney U tests. Predictors of PRMDs were analysed using logistic regression analysis.

4.7. Results

The results of this study are reported in the following sections – socio-demographic characteristics, history of musculoskeletal problems and disability and finally the inferential statistics of the findings.

4.7.1. Socio-demographic characteristic of the participants

Table 4.4 outlines the socio-demographic profiles of the study participants which include age, gender, and instrument played, years of experience, education, practice hours, race, playing position, dominant arm and province.

Table 4.4: Demographic information and playing habits of participants (n = 114)

Variables (N=114)	**Overall**
Age, Median(IQR) years	28(20)
Gender n (%)	
Male	38(33)
Female	76(67)
Instrument n (%)	
Violin	70(62)
Viola	16(14)
Cello	22(20)
Double bass	5(4)
Education n (%)	
Postgraduate	32(29)
Bachelors	23(21)
Conservatory diploma	11(10)
Matriculation certificate	39(35)
Others	6(5)
Practice hours / week Median(IQR)	9(21)
Years of experience, Median(IQR)	16(25)
Dominant arm n (%)	
Right	97(87)
Left	7(6)
Both	8(7)
Playing position n (%)	
Standing	28(25)
*Low sitting	41(37)
*High sitting	43(38)
Race n (%)	
White	67(59.3)
Black	38(33.6)
Coloured	6(5.3)
Asian	2(1.8)
Province n (%)	
Gauteng	56(49.1)
Free State	22(19.3)
KwaZulu-Natal	18(15.8)
Western Cape	7(6.1)
Eastern Cape	7(6.1)
Limpopo	4(3.5)

*Low sitting – sitting on a low chair / stool (Hamann and Cooper, 2016)

*High sitting – elevated sitting on chair / stool (Hamann and Cooper, 2016)

Majority of the participants in this study were females (n=76; 66.7%), have completed at least Bachelor's degree (n=55; 49.5%), are white (n=67; 59.3%) and play the violin (n=70; 61.9%). The median (IQR) age of the respondents was 28(20) years and with a median (IQR) of 16(25) years of experience. Sitting (75%) was the most common posture assumed by the string instrumentalists during a music performance as shown in Table 4.4.

4.7.2. Prevalence of PRMDs

The prevalence of PRMDs among the respondents was 77% and 35% over the last 12 months (lifetime) and seven days (point) respectively. Figure 4.2 shows the lifetime and point prevalence of musculoskeletal problems among string instrumentalists in South Africa.

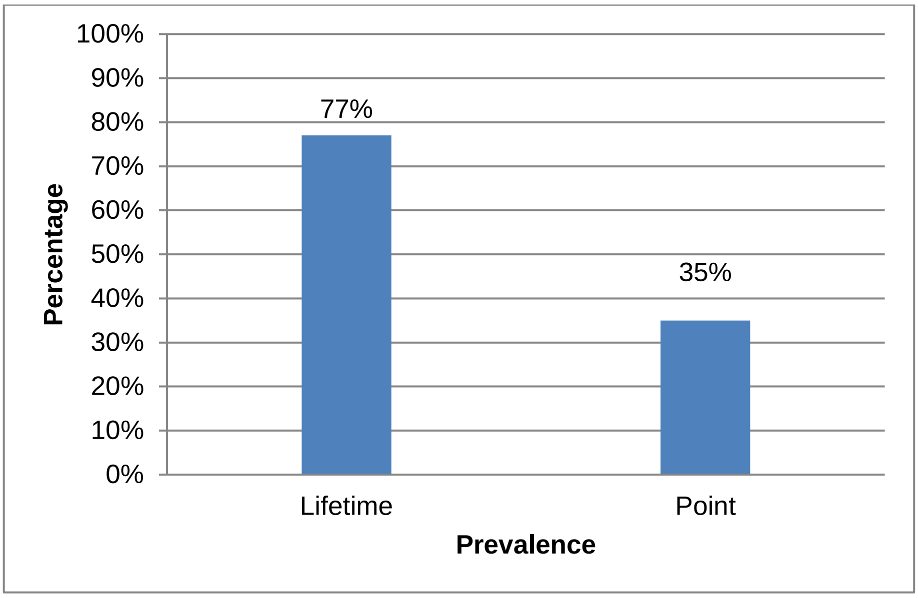


Figure 4.2: Prevalence of PRMDS (N=114)

Figures 4.3 and 4.4 illustrate the lifetime and point prevalence of musculoskeletal problems among the study participants according to gender and instrument group respectively.

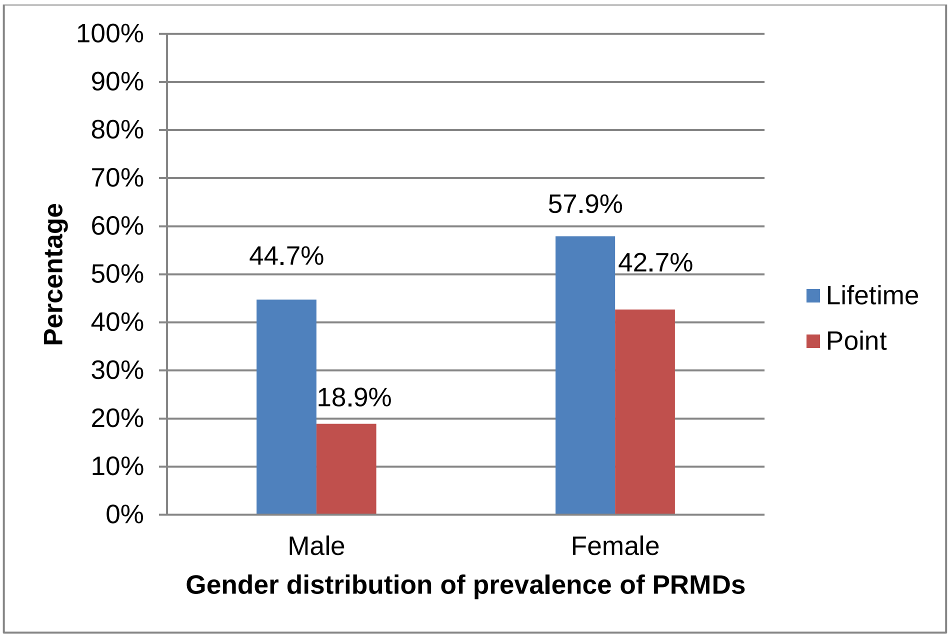


Figure 4.3: Gender distribution of the prevalence of musculoskeletal problems among string instrumentalists in South Africa (N=114)

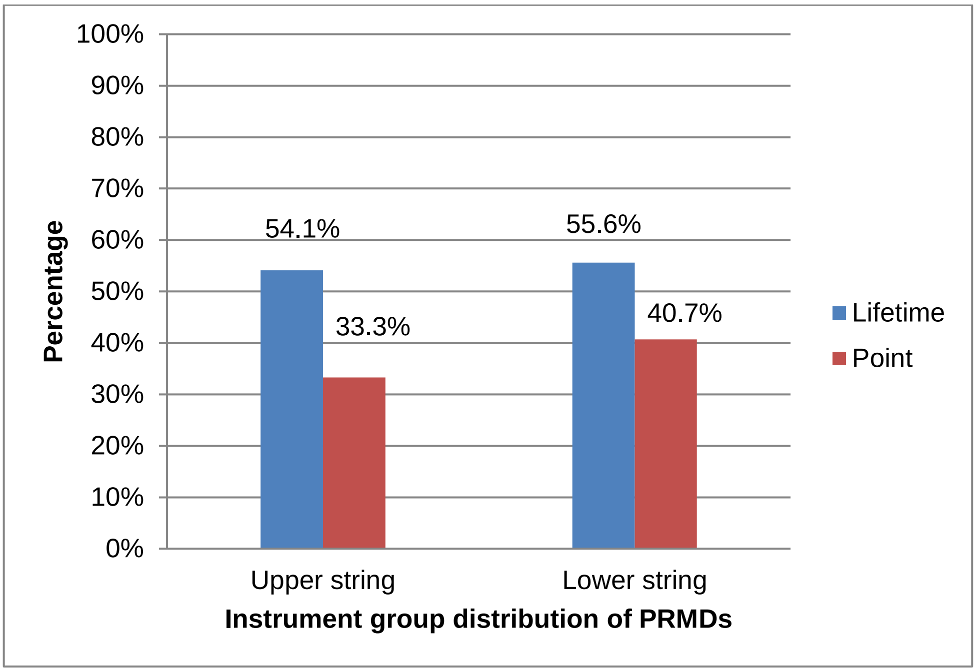


Figure 4.4: Instrument group distribution of the prevalence of musculoskeletal problems of string instrumentalists in South Africa (n=113)

Table 4.5: Prevalence of PRMDs according to race

	Lifetime			Point		
Race	**N**	**%**	**p**	**N**	%	**p**
White	41	62.1	<0.001	24	36.9	0.29
Black	12	31.6		10	26.3	
Mixed	5	83.3		3	50	
Asian	1	100		2	100	

In this sample, 77 % reported musculoskeletal problems in one or more anatomical regions with 35 % experiencing problems that have interfered with their performance over the last seven days. The prevalence of musculoskeletal problems was higher among females (lifetime=57.9%; point=42.7%) as shown in Figure 4.3 and the low string instrumentalists (lifetime=55.6%; point=40.7%) as shown in Figure 4.4. As outlined in Table 4.5 above, 62.1% of the white race reported PRMDs while the black race reported a 31.6% prevalence of PRMDs. The difference in the lifetime prevalence of PRMDs between the white and black community was significant, p <0.001.

4.7.3. Distribution of PRMDs

Figure 4.5 shows the overall distribution of the musculoskeletal problems in specific anatomical regions of the upper extremity and trunk over a period of 12 months.

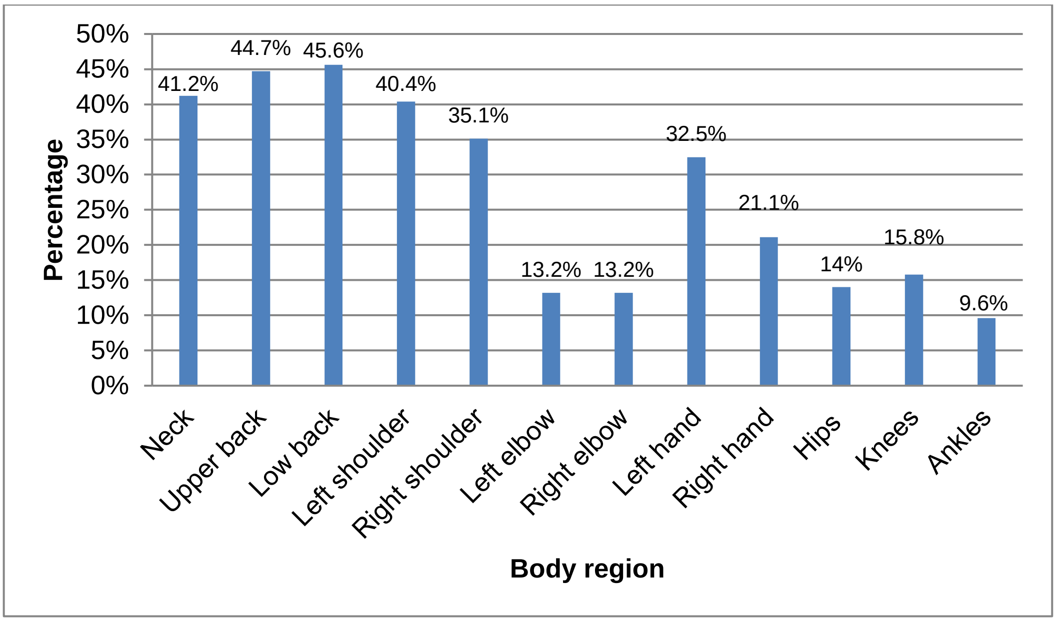


Figure 4.5. General anatomic distribution of musculoskeletal problems among string instrumentalists (N=114)

In the 12-anatomic body regions surveyed, the low back, upper back, left and right shoulder, neck and the left hand were the most common regions of musculoskeletal problems with a >30% prevalence of musculoskeletal problems.

Figure 4.6 below illustrates the prevalence of PRMDs among upper string instrumentalists (viola and violin players) in specific anatomic regions of the upper extremity, neck and trunk.

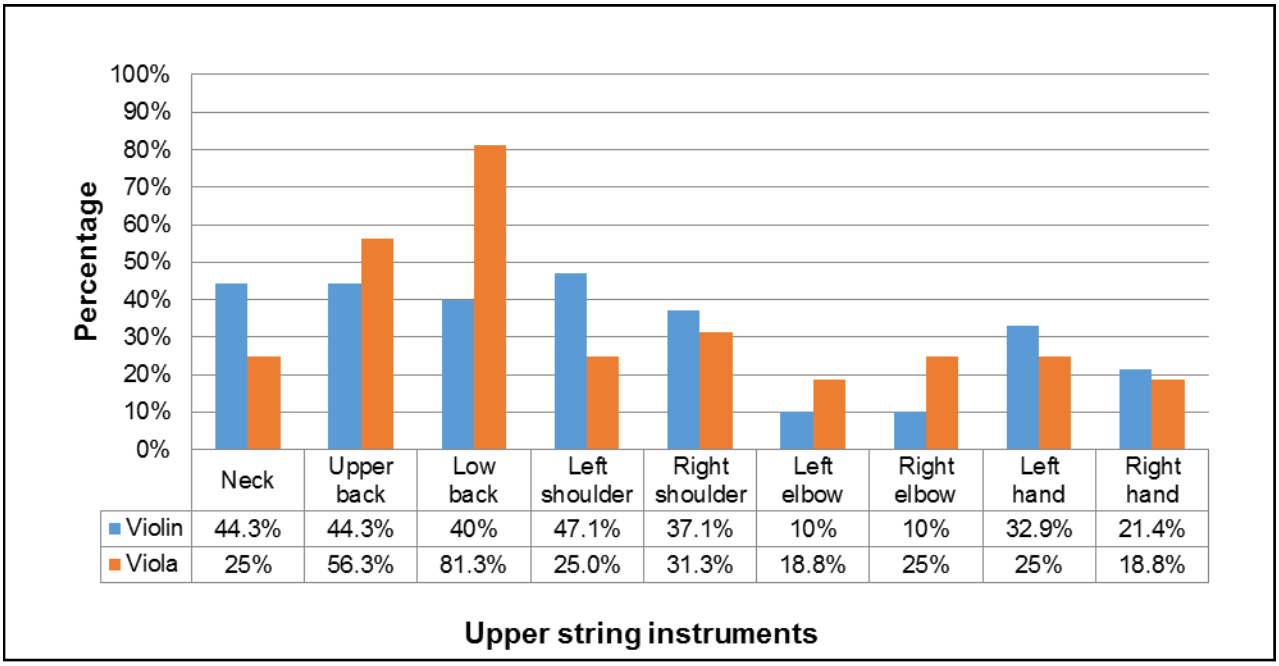


Figure 4.6: Distribution of musculoskeletal problems in the nine anatomic regions in upper string instrumentalists (n=86)

Viola players showed a higher prevalence of musculoskeletal problems in the low back (81.3%), upper back (56.3%), the right (25%) and left elbows (18.8%) while the violin players showed a higher prevalence of musculoskeletal problems in neck (44.3%), left (47.1%) and right shoulders (37.1%), left (32.9%) and right hand (21.4%) as shown in Figure 4.6.

Figures 4.7 below illustrate the prevalence of PRMDs among low string instrumentalists (cellists and double bassists) in specific anatomic regions of the upper extremity, neck and trunk.

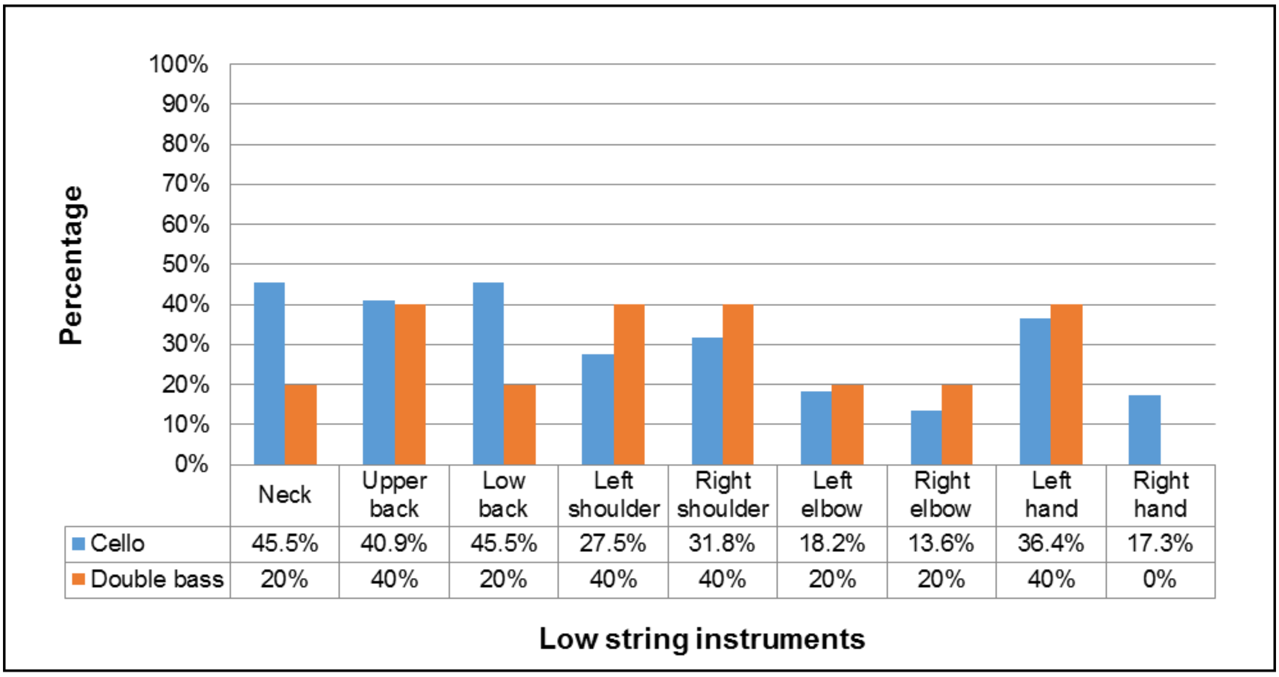


Figure 4.7: Distribution of musculoskeletal problems in the nine anatomic regions in low string instrumentalists (n=27)

Cello players showed a higher prevalence of musculoskeletal problems in the neck, upper back, low back and right hand while the double bass players showed a higher prevalence of musculoskeletal problems in left and right shoulders, right and left elbows left and right hand as illustrated in Figure 4.7.

Table 4.6 below outlines the distribution of musculoskeletal problems according to the race of the participants

Table 4.6: Distribution of musculoskeletal problems according to race

Anatomic region	White, n (%)	Black, n (%)	Mixed, n (%)	Asian, n (%)
Neck	31(52.2)	12(31.6)	3(50)	-
Upper back	34(50.7)	12(34.2)	3(50)	-
Low back	32(47.8)	16(42.1)	3(50)	1(50)
Left shoulder	26(38.8)	14(36.8)	3(50)	1(100)
Right shoulder	25(37.3)	12(31.6)	2(33.3)	1(50)
Left elbow	8(11.9)	4(10.5)	2(33.3)	1(50)
Right elbow	7(10.4)	5(13.2)	2(33.3)	1(50)
Left hand	18(26.9)	12(36.8)	3(50)	2(100)
Right hand	12(17.9)	9(23.7)	2(33.3)	1(50)

As shown in Table 4.6 above, the distribution of musculoskeletal problem was <50% in the neck and upper back among whites while 31.6% and 34.2% of the black string instrumentalists reported PRMDs in the neck and upper back. The presence of PRMDs in the low back was 47.8% and 42.1% in the white and black race respectively.

Musculoskeletal problems were commonly reported in the low back, upper back, left and right shoulder, neck and the left hand irrespective of the specific instruments played. The common descriptors of the reported musculoskeletal problems are explained in the next section.

4.7.4. Symptoms of PRMDs

The most common symptoms used to describe PRMDs in this population were aching (54%), soreness (42.2%), fatigue (40.9%) and tightening (39.4%) as shown in Figure 4.8.

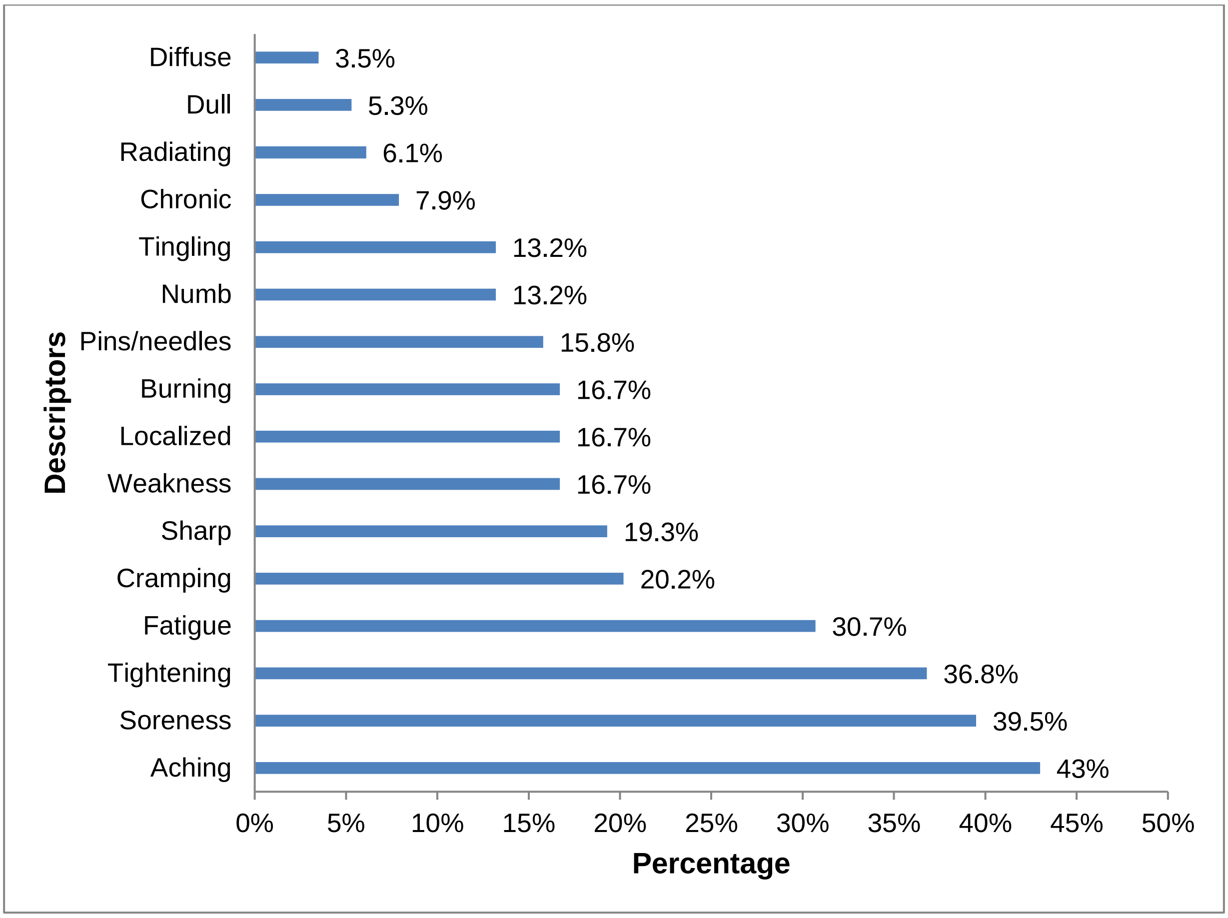


Figure 4.8: Reported symptoms of PRMDs (N=114)

The descriptors of PRMDs among string instrumentalists were multi-symptomatic as shown in the Figure 4.8 above. The frequency of musculoskeletal problems in one or more anatomic regions is reported in the next section.

4.7.5. Frequency of musculoskeletal problems in relation to number of body regions affected

Table 4.5 outlines the frequency of musculoskeletal problems in relation to number of body regions affected.

Table 4.7: Frequency of musculoskeletal problems in relation to number of body regions affected (N=114)

Number of anatomic regions	n (%)
0	26(23.2)
1	12(10.7)
2	13(11.6)
3	17(15.2)
≥ 4	44(39.3)

Sixty-six percent of the respondents reported musculoskeletal problems in two or more anatomic regions as shown in Table 4.5 above. The severity of musculoskeletal problems among the respondents is reported in the next section.

4.7.6. Severity of lifetime prevalence of PRMDs

The severity of PRMDs in the respondents with a history of musculoskeletal problems was mainly reported as mild in the upper back (24.6%), low back (28.1%), right shoulder (20.2%) and left hand (21.9%) and moderate to severe in the neck (21%) as illustrated in Figure 4.9.

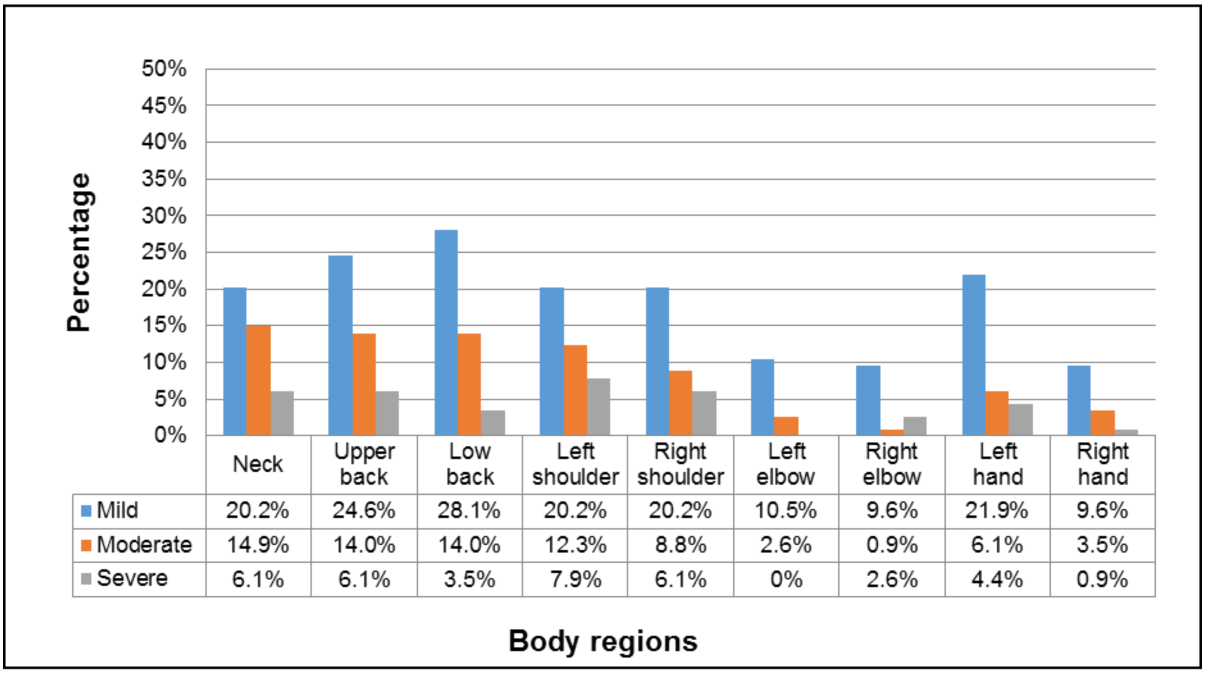


Figure 4.9: Severity of PRMDs in nine anatomic regions

4.7.7. Risk factors associated with PRMDS

Table 4.6 below shows the association between musculoskeletal problems and risk factors such as age, gender, string instrument, practice hours and playing experience. Non-parametric statistical tests of Fischer's exact for categorical variables and Mann-Whitney U for categorical and continuous variables were used to measure the association. The level of significance was set at $p<0.05$.

Table 4.8: Association between musculoskeletal problems and risk factors

	Fischer's Exact Test		**Mann-Whitney U Test**		
	Gender p-value	**Instrument p-value**	**Age U(p-value)**	**Practice hours/week U(p-value)**	**Playing experience U(p-value)**
Prevalence	0.02*	0.61	963 (0.36)	958(0.78)	1055(0.66)
Body regions					
Neck	0.00**	1.00	1320.5(0.36)	1309(0.63)	1420.5(0.53)
Upper back	0.01*	0.82	1376(0.44)	1320(0.53)	1512(0.80)
Low back	0.01*	0.66	1078.5(0.01)*	1101(0.04)	1210(0.04)*
Right shoulder	0.10	1.00	1025(0.02)*	1134(0.18)	1196(0.14)
Left shoulder	0.04*	0.26	1112.5(0.03)*	1238.5(0.35)	1177.5(0.04)*
Right elbow	0.38	0.75	543.5(0.14)	588(0.40)	569.5(0.18)
Left elbow	0.77	0.34	564(0.33)	573(0.47)	560(0.15)
Right hand	0.46	0.79	957.5(0.59)	914.5(0.54)	1012(0.76)
Left hand	0.40	0.64	891(0.01)*	1237.5 (0.88)	953.5 (0.01)*

*p-value <0.05, **p-value<0.01

Fischer's exact test showed a significant relationship between gender and the presence of musculoskeletal problems (p<0.05) in the neck, upper back, low back and left shoulder as shown in Table 4.6. Using Mann-Whitney U test, age (U=963, p>0.05), practice hours (U=958, p>0.05), instrument played (p>0.05) and playing experience (U=1055, p>0.05) showed no significant association with the presence of musculoskeletal problems. In as much as the prevalence of musculoskeletal problems is not significantly associated with age, the presence of musculoskeletal problems in the low back, right and left shoulder and left hand is significantly associated with age as shown in Table 4.6. Likewise, years of playing are significantly associated with musculoskeletal problems in the low back, left shoulder and left hand.

Table 4.7 below shows the strength of association between the presence of musculoskeletal problems in specific regions and gender of the respondents. Binary logistic regression was used to measure the strength of association. Unadjusted and adjusted (adjusted for age and years of experience) association between gender and the anatomic regions were reported.

Table 4.9: Unadjusted and adjusted binary logistic regression between anatomical regions affected and gender

	Unadjusted		Adjusted	
Anatomical regions	**OR (95%CI)**	**p-value**	**OR(95%CI)**	**p-value**
Neck	0.16(0.06-0.43)	0.00**	0.12(0.04-0.37)	0.00**
Upper back	0.31(0.13-0.72)	0.01*	0.38(0.16-0.93)	0.03*
Low back	0.29(0.12-0.69)	0.01*	0.29(0.12-0.73)	0.01*
Right shoulder	0.46(0.19-1.10)	0.08	0.42(0.16-1.08)	0.07
Left shoulder	0.40(0.71-0.94)	0.04*	0.41(0.17-1.00)	0.05
Right elbow	0.46(0.12-1.76)	0.26	0.46(0.12-1.81)	0.27
Left elbow	0.71(0.21-2.39)	0.57	0.44(0.11-1.81)	0.26
Right hand	0.61(0.22-1.70)	0.35	0.69(0.24-1.98)	0.49
Left hand	0.66(0.28-1.56)	0.34	0.53(0.20-1.37)	0.19

*p-value <0.05, **p-value<0.01

Unadjusted odds ratio using binary logistic regression showed that males are less likely to report musculoskeletal problems in the neck, upper back, low back and left shoulder when compared with females ($p<0.05$). When adjusted for years of experience and age, males were less likely to report musculoskeletal problems in the neck, upper back and low back ($p<0.05$). The results show that being female is a predictor of musculoskeletal problem in the neck and trunk while age and years of experience are likely predictors of musculoskeletal problems in the upper extremity. The association between the presence of musculoskeletal problems and disability is reported in the next section.

4.7.8. Disability associated with PRMDs

A total of 99 respondents completed the disability measurements and the demographic questionnaire. The median (IQR) age, years of experience practice hours of the respondents was 28(20.5), 16(23.5) and 9(19) respectively.

4.7.9. Characteristics of the disability measurements of respondents

Table 4.8 shows the overall disability scores for the quick DASH and the NDI. The quick DASH scores were presented with respect to the ICF constructs of activity limitation, impairment and participation restriction.

Table 4.10: Quick DASH and the NDI scores (n=99)

Disability Measures	Median (IQR)
Quick DASH	6.8(11.4)
Activity limitation	10.4(14.6)
Participation restriction	12.5(18.8)
Performing arts module	6.8(11.4)
Neck disability Index	10(14)

The median (IQR) overall quick DASH score and the neck disability score was 6.8(11.4) and 10(14) respectively. The median (IQR) disability score was higher in the participation restriction domain 12.5(18.8) than the activity limitation domain, 10.4(14.6) as shown in Table 4.8.

4.7.10. Distribution of the disability scores in relation to the socio-demographics

Table 4.9 shows the comparison of the disability scores with socio-demographic of age, gender, instrument and number of affected anatomic regions.

Table 4.11: Comparison of the disability scores with socio-demographics (n=99)

Disability outcome measure	**Quick DASH** Median(IQR)	**Activity limitation** Median(IQR)	**Participation restriction** Median(IQR)	**Performing arts module** Median(IQR)	**Neck disability index** Median(IQR)
Age					
18-29	9.1(14.8)	11.5(19.3)	15.6(29.7)	9.1(14.8)	12(12)
30-49	6.8(8.0)	8.3(8.3)	12.5(12.5)	6.8(8.0))	5(14)
≥50	8.3(24.8)	4.2(25)	12.5(25)	8.3(24.8)	8(18)
Gender					
Male	6.8(6.8)	6.3(10.4)	12.5(12.5)	6.8(6.8)	6.0(18)
Female	9.1(15.3)	11.5(17.7)	12.5(23.4)	9.1(15.3)	10(14)
Instrument					
Upper string	7.2(13.6)	10.4(14.6)	12.5(18.8)	7.2(13.6)	10(14)
Lower string	6.8(11.4)	8.3(16.7)	12.5(18.8)	6.8(11.4)	10(16)
Number of affected regions					
0	4.6(4.6)	8.3(8.3)	6.3(12.5)	4.6(4.6)	2(12)
1	5.9(9.1)	4.2(8.3)	6.3(7.8)	5.9(9.1)	4(8.5)
2	6.8(27.3)	8.3(34.4)	18.8(50)	6.8(27.3)	8(13)
3	5.7(9.1)	8.3(11.5)	12.5(12.5)	5.7(9.1)	7.0(10.5)
≥4	13.6(21.1)	18.8(26)	25(40.6)	13.6(21.1)	14(12)

The overall disability score and in all the domains was higher among females except in the participation restriction domain as shown in Table 4.9. Respondents with problems in four or more anatomical regions have higher disability scores 13.6(21.1) generally and in all the domains measured as shown in Table 4.8.

4.7.11. Quick DASH score

Figure 4.10 illustrate the median score of the specific activity limitation, participation restriction and impairment measured with the quick DASH instrument in the respondents with and without PRMDs.

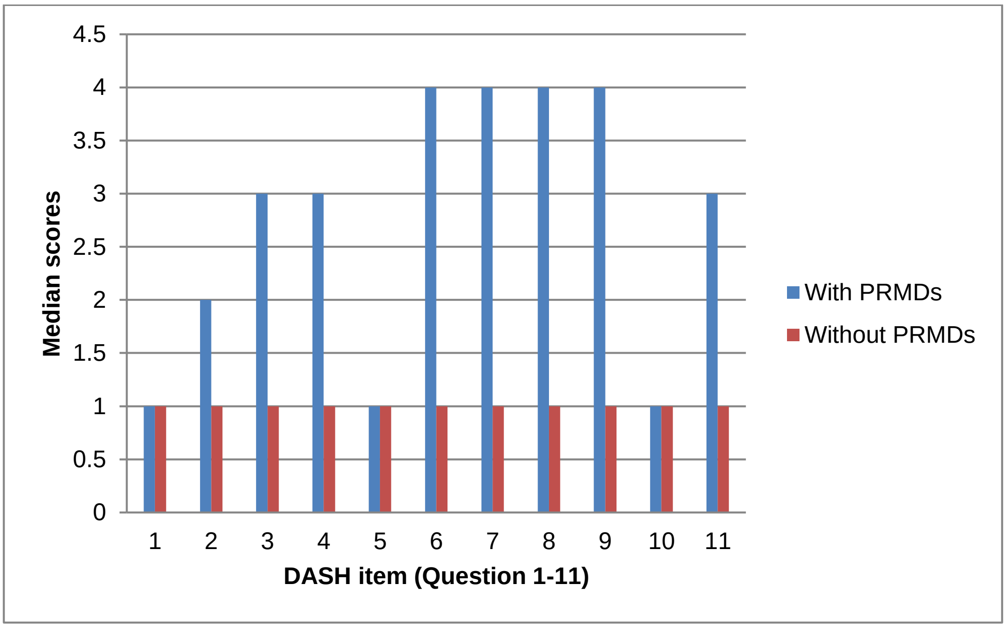


Figure 4.10: Median question specific DASH scores of the string instrumentalists with and without PRMDs (n=99)

The median quick DASH scores were higher for questions related to impairment and symptoms of upper extremity problems as shown in Figure 4.10 above.

Figure 4.11 below illustrates the median score of the specific activity, participation and impairment measured with the performing arts module of the quick DASH instrument in string instrumentalists with and without PRMDs.

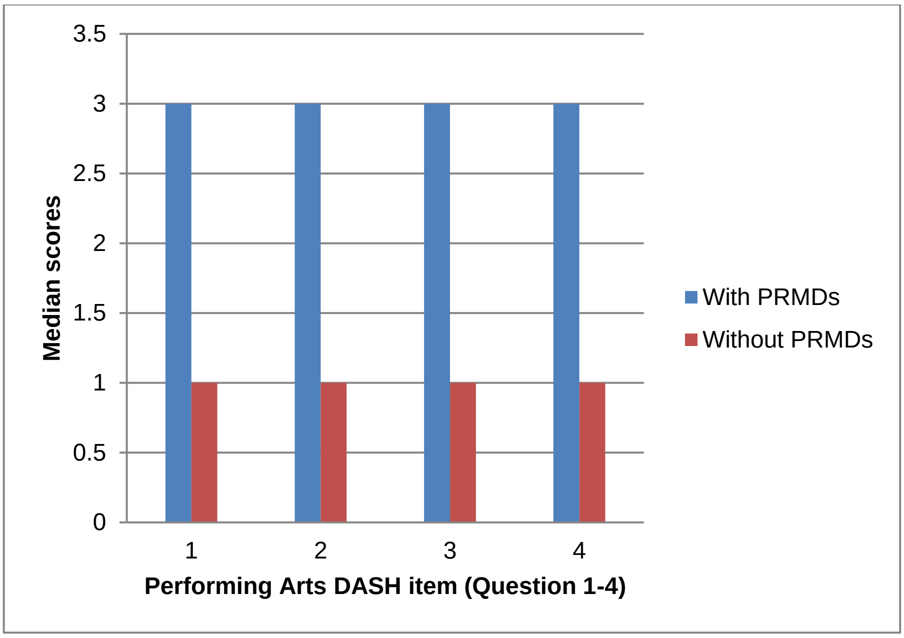


Figure 4.11: Question specific performing arts DASH scores for the respondents with and without PRMDs (n=99)

String instrumentalists with PRMDs reported higher quick DASH scores in the performance related sections. The median score was higher in all the questions as shown in Figure 4.11.

4.7.12. Neck disability index scores

Figure 4.12 illustrates the median score of the specific activity, participation and impairment measured with the NDI in the respondents with and without PRMDs.

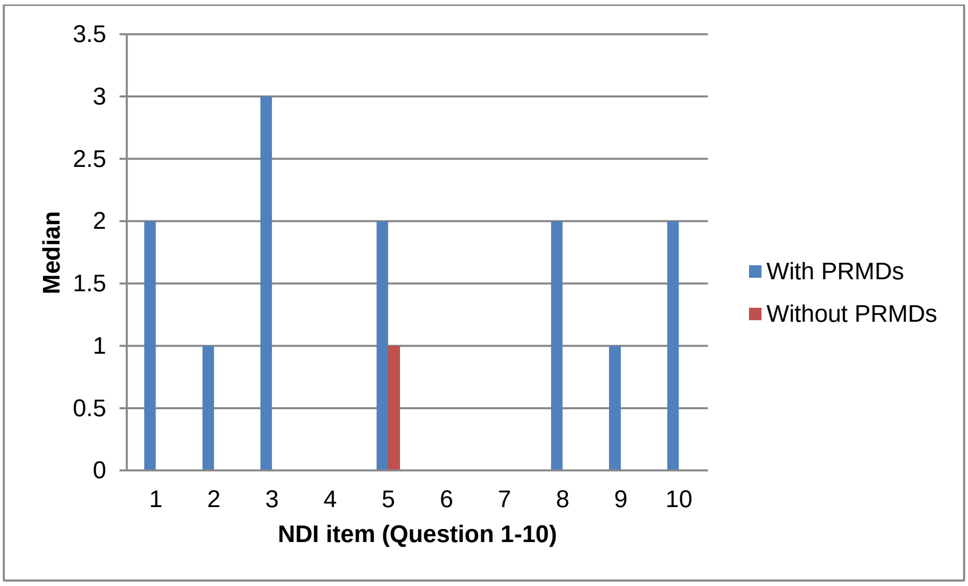


Figure 4.12: Question specific NDI scores for string instrumentalists with and without PRMDs (n=99)

Respondents with PRMDs had a higher score in all the questions when compared with respondents without PRMDs as shown in Figure 4.12.

4.7.13. Association of risk factors and outcome measures of disability

Table 4.10 below shows the result of the associations between the identified risk factors and disability. The association between the independent variables (disability outcome measures) and the dependent variables (socio-demographics) was measured using the Spearman correlation analysis for continuous variables. Mann-Whitney U test was used to measure the association between dependent categorical variables of gender, string instrument and history of musculoskeletal problems and independent variables (disability outcome measures).

Table 4.12. Association of risk factors and outcome measures of disability

	Quick DASH		NDI
	General	**Music**	
Socio-demographic			
Age, r_s(p)	-0.11(0.27)	-0.11(0.27)	-0.22(0.05)
Gender, U(p)	849.5(0.19)	849.5(0.19)	679(0.57)
Practice and playing habits			
Years of experience, r_s(p)	-0.11(0.28)	-0.11(0.28)	-0.20(0.08)
Practice hours/week, r_s(p)	0.05(0.60)	0.05(0.60)	-0.08(0.48)
String instrument, U(p)	721.5(0.37)	721.5(0.37)	588.5(0.76)
Musculoskeletal injury			
Current injury, U(p)	298(0.00)**	298(0.00)**	255(0.00)**
History of injury, U(p)	462.5(0.06)	462.5(0.06)	260(0.04)*
Number of affected body regions, r_s(p)	0.39(0.00)**	0.39(0.00)**	0.47(0.00)**

*p<0.05, **p<0.001

As shown in Table 4.10 above, quick DASH score and the NDI showed significant weak association with the point prevalence of musculoskeletal injury, r_s=0.39 and r_s=0.47 respectively. The neck disability index showed a significant association with the history of musculoskeletal problems (p<0.05). Socio-demographic characteristics, practice and playing habits showed no significant association with outcome measures for disability (p>0.05).

Non-parametric statistical test of Mann-Whitney U was used to determine the association between categorical (presence of musculoskeletal problems in the anatomic regions) and continuous variables (disability scores). The level of significant was set at $p<0.05$. Table 4.11 below shows the associations between disability scores and the severity of musculoskeletal problems in the nine anatomical regions.

Table 4.13: Association between disability scores (quick DASH and NDI) and the severity in the anatomic regions

	Quick DASH, r_s(p)		NDI, r_s(p)
Anatomic regions	**General module**	**Performing arts module**	
Neck	0.36(0.00)**	0.36(0.00)**	0.49(0.00)**
Upper back	0.31(0.00)**	0.31(0.00)**	0.29(0.01)*
Low back	0.08(0.45)	0.08(0.45)	0.27(0.02)*
Right shoulder	0.40(0.00)**	0.40(0.00)**	0.43(0.00)**
Left shoulder	0.42(0.00)**	0.42(0.00)**	0.24(0.03)*
Right elbow	0.35(0.00)**	0.35(0.00)**	0.39(0.00)**
Left elbow	0.25(0.01)*	0.25(0.01)*	0.28(0.01)
Right hand	0.10(0.31)	0.10(0.31)	0.11(0.32)
Left hand	0.34(0.00)**	0.34(0.00)**	0.24(0.03)*

*p<0.05, **p<0.001

There is a moderate positive significant association between the general DASH disability scores and the severity of musculoskeletal problems in the right shoulder (r_s=0.4) and left shoulder (r_s=0.42) as shown in Table 4.11. The NDI scores shows moderate significant association with the severity of musculoskeletal problems in the neck (r_s=0.49) and right shoulder (r_s=0.43).

4.8. Discussion

The key outcomes from the results of this study showed a high prevalence of musculoskeletal problems among string instrumentalists which mainly affects the upper extremity and trunk. Although the severity of musculoskeletal problems in this study was generally reported as mild to moderate, the measurements of disability showed a weak - moderate relationship between musculoskeletal injury and disability scores. Gender, years of playing experience and age showed significant association with musculoskeletal problems.

a. Prevalence, distribution, severity and symptoms of PRMDs

The prevalence of musculoskeletal problems among the string instrumentalists in this study was 77%, with 35% currently experiencing problems that interfere with their performance. The result of this study is consistent with other studies that have reported a high lifetime prevalence of musculoskeletal problems among string instrumentalists (Chan et al., 2000, Abreu Ramos and Micheo, 2007). Over a 12 month period, 79% of string instrumentalists reported PRMDs (Chan et al., 2000). In the study by Abreu Ramos and Micheo (2007), 68% of string instrumentalists reported symptoms of PRMDs. A prevalence of work related musculoskeletal problems greater than 60% has been reported as high in several studies (Janwantanakul et al., 2008, Hayes et al., 2009, Widanarko et al., 2011). In this study, females reported a higher prevalence of musculoskeletal problems than males. An increased prevalence of musculoskeletal problems among female string instrumentalists is similar to previous studies (Davies and Mangion, 2002). Female string instrumentalists are generally more prone to musculoskeletal injuries than their male counterparts; body frame and the adaptation of the body structure of the females has been suggested as possible predisposing factors. Risk factors such as joint laxity (Brandfonbrener, 2002), hormonal differences (Anderson et al., 2001) and smaller body frame (Ekman et al., 2000) have been identified in literature as contributing factors to the higher injury reported in females than males. It has been reported that females are more predisposed to reporting illnesses when compared to males (Van Wijk and Kolk, 1997, Barsky et al., 2001).

This study showed a significant difference in the lifetime prevalence of PRMDs between the white and black race. White string instrumentalists reported a higher prevalence of PRMDs in the neck (52.2%) and upper back (50.7%) in comparison to Black string instrumentalists. The neck and the upper back are mainly involved in the postural stability of supporting the upper string instruments (Moraes and Antunes, 2012). Studies have shown morphology differences between ethnic groups (Aloia et al., 2000, Silva et al., 2010). Silva et al. (2010) reported a lifetime difference in skeletal muscle between ethnic groups. Their study showed that Blacks have a higher skeletal muscle mass in comparison to Whites and Asians (Silva et al, 2010). This study suggests that morphologic differences are associated with musculoskeletal injury among string instrumentalists and these differences should be explored in identifying potential risk factors for developing injury prevention programmes for musicians.

Problems found as a result of playing string instruments can be categorised according to the ICF, where injuries at body part levels are described as impairment and the resulting activities and participation restrictions (World Health Organisation, 2001b, World Health Organisation, 2005). This study found that impairments associated with playing the string instrument were predominantly in the neck, upper back, low back, right and left shoulders, and left and right hands. These reported body locations are similar to what has been established before (Leaver et al., 2011, Paarup et al., 2011). It therefore follows that the body regions commonly used in playing the musical instrument are the most injured anatomical regions. The physical demands of playing a string instrument predispose the player to musculoskeletal problems and impairments (Wilke et al., 2011). Among string instrumentalists, the left upper extremity is usually used for support and fingering, the right upper extremity is the bowing and or the plucking arm and the trunk is usually the major postural support region (Paarup et al., 2011, Moraes and Antunes, 2012). It is therefore not surprising that musculoskeletal problems are common in these anatomical regions. However, the interesting finding in this study was the increased prevalence of musculoskeletal problems in the low back among viola players in comparison to the violin players. Playing the viola and the violin is similar in terms of support and playing pattern and hence it was not expected to have a different injury distribution pattern (Moraes and Antunes, 2012). It should however be noted that the viola is a heavier, wider and longer instrument and that could predispose the violist to increased postural demand (Turner-Stokes and Reid, 1999, Castleman, 2002).

The symptoms of musculoskeletal problems among string instrumentalists in this study are consistent with the common symptoms of overuse injuries in other studies (Dawson, 2001). Overuse injuries are the most common musculoskeletal problem of instrumental musicians and they are normally due to a direct consistent loading of the neuro-musculoskeletal structures involved in performing an activity (Hawkins and Metheny, 2001).

The severity of musculoskeletal problems in the affected anatomical regions was reported as mild to moderate. Steinmetz (2015) showed similar results among professional orchestra musicians and the average pain score using the numeric pain rating score in the affected body regions was between 3.9 and 4.7. It is noteworthy to highlight the relatively higher severity of musculoskeletal problems in the neck, upper back and the right and left shoulders when compared to the other affected anatomical regions. Prolonged neck flexion and the static abnormal posture of the left shoulder could be responsible for the increased severity in the upper trunk and left shoulder (Moraes and Antunes, 2012). The right shoulder is involved in the repetitive bowing activity and this could result in musculoskeletal injury in the right shoulder (Turner-Stokes and Reid, 1999). The results of this study are consistent with earlier studies which have shown that postural imbalance is common among string instrumentalists; and that postural structures are often the most injured body regions in the string instrumentalist (Barczyk-Pawelec et al., 2012, Moraes and Antunes, 2012). The implication is that correct ergonomics could be an important factor in reducing musculoskeletal problems among upper string instrumentalists. It therefore follows that an understanding of the demands on these structures could help proffer solutions to reducing the presence and severity of musculoskeletal problems and resultant disability emanating from the regions affected. Disability is defined using the ICF and is an interaction between impairment, activity limitation and participation restriction (World Health Organisation, 2001b). As such disability was measured in this study using the Quick DASH and the NDI.

b. Disability

The disability scores in string instrumentalists with PRMDs in this study were higher than those without PRMDs. Musculoskeletal problems of string instrumentalists in this study were associated with disability. PRMD is a multi-symptomatic disorder that usually affects more than one anatomic region (Zaza, 1998, Bragge et al., 2006). In this study 76.7 % of the respondents reported symptoms in two or more anatomic regions and disability scores were increased proportionately with an increase in the number of affected body regions. The median quick DASH disability score of 6.8(11.4) in this study is relatively smaller to the mean DASH score in the study by Barton et al. (2008) with college string instrumentalists reporting a mean DASH score of 11.8(11.7). The presence of musculoskeletal problems in the upper extremity or neck is often associated with an increase in quick DASH disability scores (Fan et al., 2008, Niekel et al., 2009). In this study, only 35% of the respondents reported PRMDs over the last seven days and the severity was mild – moderate and the level of severity accounts for the relatively quick DASH scores. An increase in disability scores is often associated with morbidity of musculoskeletal problems (Wong et al., 2007). String instrumentalists reported a higher quick DASH score in participation restriction and activity limitation. This suggests that the mild-moderate severity of PRMDs is associated with limitation in participation and activity which can result in an eventual reduction in activities of daily living which could eventually negatively impact on the ability to earn a living. Other studies have only reported disability associated with playing a musical instrument (Barton et al., 2008, Kaufman-Cohen and Ratzon, 2011). This study was the first study to explore the relationship between PRMDs and the components of the ICF model for disability – activity limitation and participation restriction.

The median (IQR) NDI score in the string instrumentalists with a current history of PRMDs was 10(14). In respondents with PRMDs, the median (IQR) was higher in all the NDI item questions. The neck disability index has been used in several studies in clinical settings to measure disability associated with neck dysfunction (Vernon, 1996, Kaale et al., 2005, Pool et al., 2007). The median (IQR) NDI score in symptomatic string instrumentalists 10(14) was lower when compared with other studies in patients with a clinical diagnosis of neck pain attending outpatient clinics for management, the mean NDI scores ranged from 32.2(11.6) – 35.7(9.8) (Cleland et al., 2008). This is not surprising as a higher neck disability index score is often associated with the severity of musculoskeletal problems (Sterling et al., 2006). Musculoskeletal problems of instrumental musicians are mainly mild to moderate (Steinmetz,

2015) and this probably accounts for the lower NDI scores when compared with studies with clinical diagnosis of neck pain . The median (IQR) neck disability score in symptomatic string instrumentalists in this study 10(14), was mild according to the classification by Vernon and Mior (1991). However, the score is higher than the normative values in the general population (Kato et al., 2012). In a comparable study, the mean NDI score was slightly lower, 13.1(5.5) in patients with uncomplicated neck pain which after management was further reduced to 6.91(4.6) (Gay et al., 2007). Conditions with associated symptomatic neck pain such as radiculopathy, whiplash and spondylosis are often associated with higher disability scores (Fan et al., 2008, Niekel et al., 2009). Playing the upper string instrument requires an intermittent lateral flexion of the neck to support and hold the instrument (Moraes and Antunes, 2012). The postural adaptation increases the likelihood of developing neck complications with time (Moraes and Antunes, 2012).

In this study, it was shown that an increase in the number of anatomical regions affected increases disability scores. String instrumentalists with more ≥ 4 anatomic regions affected reported a higher quick DASH score especially in the participation restriction. This is not surprising as an increase in dysfunction in more anatomical regions will increase activity and participation limitation and eventual disability (Keenan et al., 2006). Musculoskeletal problems of instrumental musicians usually affects more than one anatomic region (Bragge et al., 2006). It is therefore important to explore injury prevention strategies in order to reduce disability associated with playing the musical instrument and other activities of daily living.

It can be concluded that there is a burden of PRMDs among string instrumentalists in South Africa with associated disability which impacts negatively on activities and participation. This study also suggests that morphologic differences between the races could be important in evaluating risk factors and could be of importance in developing an exercise based injury prevention programme. Therefore, reducing the incidence of PRMDs among string instrumentalists may reduce activity limitation and participation restriction which would possibly result in an improved quality of life.

4.9. Limitations of the study

The sampling method in this study allows for selection bias and the three different mode of questionnaire administration could bias the participant in completing the questionnaire therefore the results should be interpreted with caution. Also, psychosocial risk factors as well as extrinsic non-music related factors such as other work demands was not explored and controlled for in this study.

4.10. Summary of chapter

This chapter outlined the process of data collection and discussed the implication of the results of the cross – sectional study to determine the prevalence, distribution and severity of musculoskeletal problems among string instrumentalists in South Africa. The prevalence of musculoskeletal problems among string instrumentalists was high and it affected two or more anatomical regions in this study sample. The distribution of musculoskeletal problems was reported in the upper extremity (especially in the right and left shoulders and the left hand) and the trunk with relatively similar levels of severity. This implies that the distribution of musculoskeletal problems associated with string instrumentalists was patterned according to the demands of the occupation. The next chapter covers the biomechanical analysis of string playing and postural evaluation of the string instrumentalists. The chapter will objectively evaluate the relationship between biomechanical analysis and the presentation of musculoskeletal problems in the neck, right and left shoulders and the hands.

CHAPTER 5

5. BIOMECHANICAL ANALYSIS OF STRING PLAYING

5.1. Introduction to Chapter

This chapter is focussed on explaining joint movements, muscle activity and exposure to ergonomic risk factors when playing a string instrument. An objective evaluation of biomechanical risk factors associated with playing a string instrument and its implication in predisposing the string instrumentalist to PRMDs is explained in this chapter. The outline of the chapter was categorised into the introduction, aim and objectives, methodology, results and discussion.

5.2. Background

Playing related musculoskeletal problems among string instrumentalists are often associated with the anatomical and the physiological demands of string playing (Kaufman-Cohen and Ratzon, 2011, Moraes and Antunes, 2012). Earlier studies have consistently reported problems of string instrumentalists in the neck, low back and shoulders (Moore et al., 2008, Leaver et al., 2011, Moraes and Antunes, 2012). String playing require a balance between dynamic functions of the left hand, the right hand and the trunk (Rolland et al., 1986). The interaction between right and left upper extremity and the trunk is important for understanding the biomechanical demands associated with string playing (Rolland et al., 1986).

String playing requires long hours of practise especially in sitting with the upper extremity, neck and thoracic region in an asymmetric posture which could predispose the string instrumentalist to PRMDs (Kaufman-Cohen and Ratzon, 2011, Moraes and Antunes, 2012). Musculoskeletal disorders could predispose the musician to psychological problems such as performance anxiety (Kenny, 2005, Kenny et al., 2014, Kenny and Ackermann, 2015). The mechanism of injury is not clear but it has been postulated that performance anxiety results in an increase in exertion when then increases muscle activity (Yoshie et al., 2009). Increase in muscle activity has been associated with symptoms of overuse injury among violin and viola players (Reynolds et al., 2014, Steinmetz et al., 2015). Psychological and physical demands of playing a string instrument could predispose the string instrumentalist to musculoskeletal injury (Kenny, 2005, Fehm and Schmidt, 2006, Burin and Osório, 2016).

The integrated theory of work related musculoskeletal disorder by Karsh (2006) postulated that WRMDs are caused by the interaction between the physical demands, psychological demands and the work environment associated with the work. Physical work demand could result in an increase in tissue load which results in musculoskeletal problems (Karsh, 2006).

An increase in tissue load has been reported to be associated with an increase in performance anxiety (Moulton and Spence, 1992).

Biomechanical analysis of movement involves the objective measurement of the joint range of motion, velocity and other movement parameters as well as muscle activity (Colby et al., 2000, Visentin and Shan, 2003, Scarvell et al., 2004, WuChen et al., 2007). In string instrumentalists, biomechanical analysis of performance has been used mainly to measure bowing parameters and muscle activity patterns as it relates to performance related injury (Visentin and Shan, 2003, Fjellman-Wiklund, 2004a, Fjellman-Wiklund, 2004b, Kelleher et al., 2013, Verrel et al., 2014).

Posture and repetition of motion has been hypothesised to predispose the string instrumentalist to musculoskeletal injury (Kelleher et al., 2013). Postural problems are common among musicians (Eijsden-Besseling et al., 1993). An earlier study by (Eijsden-Besseling et al., 1993) comparing postural abnormalities between music students and non-music students showed that music students had more postural abnormalities such as kyphosis, scoliosis, swayback and shoulder asymmetry than non-music students. Musculoskeletal assessment of musicians by Steinmetz et al. (2010) reported that lumbar and scapular dysfunction was present in 49% of the musicians. Kelleher et al. (2013) hypothesised that stabilising and holding the instrument predisposes the string instrumentalist to rotator cuff syndrome, muscle imbalance and cervical dysfunction. Prolonged sitting was hypothesised to predispose the string instrumentalist to lumbar dysfunction (Kelleher et al., 2013).

Postural alignment during music performance is to perform with the barest discomfort (de Araújo et al., 2009). Postural flaws have been reported among musicians which eventually results in increased postural strain during performance (de Araújo et al., 2009). The neck is used to hold the violin and viola in between the chin and the left shoulder while the balance effect of the trunk in the neutral position is used to reduce tension and maintain stability during performance (Rolland et al., 1986, Wilke et al., 2011, Moraes and Antunes, 2012). A study by Shan et al. (2004) reported that repetition of the bowing arm is a risk factor for overuse injury. Long repetitive monotonous activity (Knobloch et al., 2008, Clarsen et al., 2010) and activities that require a rapid increase in load (Mountjoy et al., 2010, Myklebust et al., 2013) are risk factors for shoulder impingement problems.

Overuse injury is common problem among musicians. Physical load and tissue healing after damage are two major predisposing factors for overuse injury (Ashton-Miller, 1999). In proffering injury prevention strategy for string instrumentalists, an understanding of the biomechanical analysis and physical load would be important. Therefore, the aim of this study was to evaluate the joint kinematics, muscle activity in selected muscles and physical load during a music performance.

5.3. Aim and Objectives

The overall aim of this study was to evaluate the biomechanics in the upper extremity and trunk during music performance. The specific objectives of this phase of the study were:

- To determine upper extremity and trunk joint angles when playing
- To determine the muscle activation pattern when playing string instruments.
- To evaluate the exposure of the string instrumentalists to ergonomic risk factors for musculoskeletal problem in the upper extremity
- To evaluate the musculoskeletal integrity of the string instrumentalists.

5.4. Methodology

This section outlines the methodology of the research procedure for this study. The study design, sampling and sample size, outcome measures, pilot study and the procedure of the main study are also explained.

5.4.1. Study design

A cross sectional study design was used to collect information from the volunteers. The cross sectional study was suitable because the design involves the description of a population at a particular point in time (Levin, 2006).

5.4.2. Outcome measures and instruments

The outcome measures and the instruments for this study are outlined in Table 5.1 below:

Table 5.1: Outline of the instruments and outcome measures and the relationship with the specific aims and objectives

Objectives	Instruments	Variables
To determine the upper extremity and trunk kinematics during performance	Inertial motion unit sensor using the MVN BIOMECH®	Neck, upper extremity and trunk joint range of movement
To determine the muscle activity in selected muscles when playing string instruments	Eight channel EMG with wireless electrode	Amplitude of muscle activation in selected muscles – upper trapezius, right and left middle fibre of the deltoid, right and left elbow extensors, right and left elbow flexors, right and left wrist extensors, right and left wrist flexors and erector spinae.
To evaluate exposure of the string instrumentalists to ergonomic causes of PRMDs	Rapid upper limb assessment (RULA)	Postural load on the body
To evaluate the musculoskeletal integrity of the string instrumentalists	The Janda approach (Page et al., 2010)	Muscle imbalance: Upper crossed syndrome
	Activation of the transversus abdominis and multifidus (Hides et al., 2000, Steinmetz et al., 2010).	Lumbo-pelvic stabilisation
	Serratus anterior assessment Kendall et al. (2005)	Scapular stabilisation
	Jamat hand dynamometer	Hand grip strength to measure gross upper extremity strength.
	Kibler's test	Scapular dyskinesia
	Beighton's hypermobility test	Joint hypermobility
	Neer's test Empty can test Hawkins-Kennedy test	Assessment for shoulder impingement

5.4.3. Study participants

The study participants were string instrumentalists in both amateur and professional orchestra in South Africa.

5.4.4. Sampling and Sample size

Samples of between one and 36 participants has been used to measure kinematic analysis in humans using the inertial motion unit sensors (Fong and Chan, 2010, Roh et al., 2012, Kang and Gross, 2016). This is largely due to the accuracy of the equipment that is used in motion analysis and also the huge amount of data that is collected with such studies. A sample of convenience of five violinists and one cellist were recruited and agreed to participate in the study.

5.4.5. Inclusion criteria

The following inclusion criteria was used in inviting participants for the study

- Participants that played one of the following string instruments – violin, viola, cello and the double bass
- Participants that were able to play the Eine Kleine Nachtmusik composition by Mozart.

5.4.6. Music excerpt

The music excerpt performed by the string instrumentalists was the first movement of the 1787 composition by Mozart titled Eine Kleine Nachtmusik. The music was composed for a string ensemble.

5.5. Pilot Study

The pilot study was conducted to evaluate the data collection process, determine the reliability of the measuring instruments and the musculoskeletal assessment tests. The specific objectives of the pilot study were:

- To train research assistants on the data collection procedures
- To assess and evaluate the data collection procedures
- To determine the inter-rater reliability of the musculoskeletal assessment tests.
- To determine the amount of time taken to complete the survey.
- To evaluate the participant recruitment process.
- To determine unforeseen eventualities that could occur in the process of data collection.

Study design: A cross sectional quantitative study was conducted. The pilot study was conducted in three phases. The first, second and third phase of the pilot study were to familiarise the research assistants with the research procedure, determine the inter-rater reliability of the objective musculoskeletal assessment and determine the intra-session reliability of the Xsens MVN BIOMECH® in measuring inertial motion unit (IMU) joint angles in the trunk and upper limb respectively.

Sample size: Five volunteer university students participated in the musculoskeletal assessment while two professional string instrumentalists participated in the intra-session reliability of the Xsens MVN BIOMECH®. The inter-rater reliability of the musculoskeletal test was done by two physiotherapists with 15 and 9 years of practising experience respectively.

Key recommendations:

The pilot study provided valuable information in the preparation for the biomechanical analysis. Musculoskeletal assessments were initially planned according to the anatomical region to be assessed. The result of the pilot study was useful in categorising the musculoskeletal assessments per patient's position. Sitting, standing and lying assessments were conducted. The outcome measures were appropriate and valid for musicians. The biomechanical analysis was the last evaluation conducted. No changes were made to the procedure and the estimated time for the whole exercise was about 1 hour per participant.

Reliability analysis

Inter-rater reliability using Cohen's kappa can be interpreted as follows: 0.41-0.60 (moderate), 0.61-0.80 (substantial) and 0.81-1.00 (almost perfect agreement) (McHugh, 2012). The measure of agreement (kappa) of the musculoskeletal assessment tests showed moderate to strong inter rater reliability for upper crossed syndrome assessment (k=0.55), Hawkins and Kennedy test (k=0.5), lumbar stabilisation tests (k=0.62) and scapular stabilisation test (k=1.00). The correlation coefficient of the intra-session reliability of the Xsens MVN BIOMECH® showed strong correlation with a range of 0.82-0.93 for the joint angle measurement of the upper extremity and trunk. On completion of the pilot study, the main study was conducted. There was no change in the method of data collection used in the pilot study to that of the main study and hence the pilot participants were included in the main study.

5.6. Main Study Procedure

The study was conducted in the movement laboratory at the Department of Physiotherapy, University of the Witwatersrand, Johannesburg, South Africa. A total of six string instrumentalists (five violinists and one cellist) volunteered to participate in this study. The data collection procedure lasted 3 months. Participants were asked to come in comfortable clothes. Volunteers were asked to complete an injury profile questionnaire, after which musculoskeletal assessments were conducted by one physiotherapist. The biomechanical analysis and rapid upper limb assessment were conducted simultaneously. The procedure of the three main processes is explained in the following order – musculoskeletal assessment, kinematic analysis and electromyography.

5.6.1. Musculoskeletal assessment procedure

Musculoskeletal assessment involved subjective postural tests, shoulder impingement tests, scapular dyskinesia measurements, hypermobility test, stabilisation tests of the scapular and lumbar and gross muscle strength. One assessor performed all the musculoskeletal assessment procedures. The procedure of the tests were itemised and followed in the same order for each participant. Table 5.2 below outlines the procedure of the musculoskeletal assessment tests.

Table 5.2(a): Musculoskeletal assessment tests and procedure

<table>
<tr><th>Test</th><th>Procedure</th><th>Implication</th></tr>
<tr><td>Muscle imbalance</td><td>Cervical flexion:
Participant in sitting
Active forward neck flexion
Push up
Patients stand in front of a wall
Arms elevated at 90 degrees
Elbow extended and the participant is asked to do a push up on the wall.
Shoulder abduction:
Patient in sitting
Patient is instructed to abduct the arm
Physiotherapist supports the inferior angle of the scapula</td><td>Cervical flexion
Implication
Prominence of the SCM at mid to distal insertion
Forward head posture
Increased angle (>90 degrees) between the chin and the neck
Impaired respiration
Push up
Implication:
Increased internal rotation of the arms
Nipples that face out superiorly and laterally (in males)
Scapula winging and tipping
Shoulder abduction
Implication:
Forward head with protracted shoulder
Gothic shoulder
Levator notch
Scapular winging and tipping</td></tr>
<tr><td>Lumbo-pelvic stabilisation</td><td>The modified lumbo-pelvic stabilisation palpation test described by Steinmetz et al. (2010) was used in this study.
TrA
Participant in supine
Assessor palpates the insertion of the abdominal muscles on the anterior superior iliac spine
The patient is instructed to suck in the abdomen and a gentle deep tension should be felt under the fingers equally on each side
MF
Participant in supine
Assessor places one hand on the vertebrae and the participants were asked to press their spine against the hand of the assessor</td><td>A change to the tension indicates increased activation of the superficial and global rather than independent contraction of the TrA. The test is also positive if the patient loses the resting the resting lumbar lordosis.</td></tr>
</table>

Table 5.2(b): Musculoskeletal assessment tests and procedure (continued)

Test	Procedure	Implication
Scapular stabilisation (serratus anterior)	• Patients stand in front of a wall • Arms elevated at 90 degrees • Elbow extended and the participant is asked to do a push up on the wall.	Normally the scapular should adduct. Test is positive if the scapula loses contact with the chest wall.
Hand grip strength	Participant were seated, the elbow at 90 degrees. The dynamometer was calibrated for male and female separately. Participants were asked to grip the dynamometer as much as possible using the second rung. Three trials were recorded and the mean of the three trials was finally recorded for analysis. Both hands were tested	n/a
Neer's test	• Patient in sitting position • Therapist stabilizes the scapula to prevent scapula rotation. • Therapist then moves the shoulder into maximal forward flexion. Both hands were tested	The test is positive if the participant reports pain in this position.
Painful arc test	• Participant in standing • Participant was instructed to abduct the arm and to report if there was pain around the gleno-humeral region Both hands were tested	A positive test is considered when the patient reports pain between 60 and 120 degrees which subsides in the range after 120 degrees
Hawkins-Kennedy test	• Participant in standing • Patients shoulder is flexed to 90 degrees and stabilized • The shoulder is then passively moved into internal rotation Both hands were tested	Pain on internal rotation is considered positive for impingement problems.
Beighton's hypermobility test	Passive dorsiflexion of the 5th metacarpophalangeal joint (bilateral testing) Passive hyperextension of the elbow (bilateral testing) Passive hyperextension of the knee (bilateral testing) Passive apposition of the thumb to the flexor side of the forearm (bilateral testing) Forward flexion of the trunk with the knees straight:	Total score of <5 suggests hypermobility
Kibler's test	This test involves measuring the distance from the inferior angle of the scapula to the nearest vertebral spinous process using a tape measure or goniometer in three positions: shoulder in neutral, shoulder at 40-45 degrees of coronal plane abduction with hands resting on hips, and the shoulder at 90 degrees abduction with the arms in full internal rotation.	A difference of <1.5cm between the right and left measurement is considered as scapular asymmetry.

The musculoskeletal integrity of the string instrumentalists was assessed before the biomechanical analysis of the joints of the upper extremity, neck and back as well as muscle activity of specific muscles. The biomechanical analysis procedure involved joint angle measurements of the joints and muscle activity of specific muscles of the upper extremity, cervical and lumbar regions.

5.6.2. Joint kinematic analysis procedure

The kinematic analysis was aimed at recording joint angles in the upper extremity, cervical and lumbar regions. The Xsens MVN BIOMECH® system was used to record motion during the music performance. The Xsens MVN BIOMECH® system uses the inertial motion unit (IMU) sensors to record motion. The software was normalised and calibrated to the body biomechanics of the individual and the results were automatically processed and extracted in the XYZ axis. Volunteers were set up in the Xsens gear with inertial motion sensors placed in the upper arm, scapular region, dorsum of the hand bilaterally and the pelvis as shown in Figure 5.1 below. Joint movement at the right and left shoulder, cervical (C7/T1), scapulothoracic, upper thoracic (T8/T9), lumbar region (L5/S1), right and left elbow, right and left wrist were measured.

Figure 5.1: MVN BIOMECH® ® inertial motion sensors set up

Body dimension of the volunteer which included – weight, height, arm span, hip height, ankle height, hip width, shoulder width and shoe sole were measured as prescribed (Roetenberg et al., 2009). Figure 5.2 below shows the participant position during performance. Participants performed the music excerpt in sitting, the results of the cross sectional study in Chapter 4 showed that 75% of string instrumentalists perform in the sitting position.

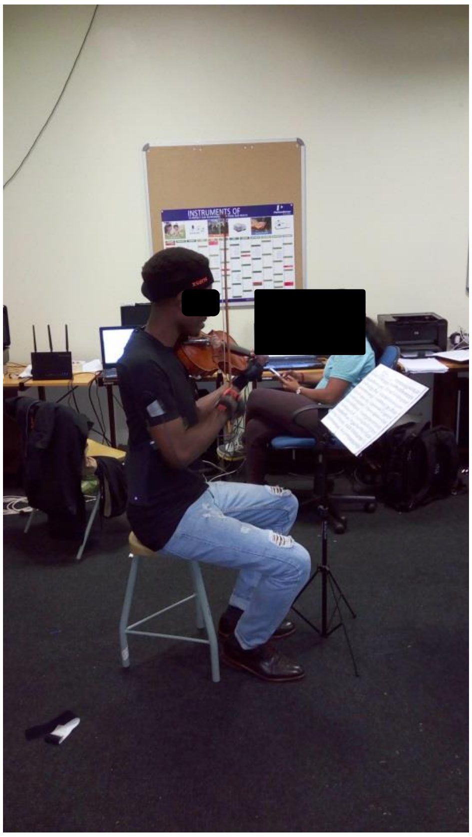


Figure 5.2: Participant set up during performance

a. Calibration

The system was calibrated by asking the volunteer to keep a static position with the arms wide and recording was done for 30 seconds and the measuring position of the IMU was recorded (Roetenberg et al., 2009). Calibration was conducted till movements were consistent with the position of the IMUs. The procedure for electromyography is explained in the section below.

5.6.3. Surface electromyography (sEMG) procedure

Muscle activity in selected muscles was recorded using Lab chart ® surface electromyography. The muscles selected are outlined in Table 5.3 below.

Table 5.3: Outline of muscle placement and arrangement

Set one	Set two
Right and left erector spinae	Right and left wrist flexors
Right and left elbow flexors	Right and left wrist extensors
Right and left elbow extensors	Right and left middle deltoid
Right and left upper trapezius	

Wireless electrodes were placed at the middle point of the following muscles - upper trapezius, right and left middle fibre of the deltoid, right and left elbow extensors, right and left elbow flexors, right and left wrist extensors, right and left wrist flexors and erector spinae. The electromyography was conducted in two sets because the surface electromyography (sEMG) channel used had only eight electrodes. Table 5.3 above outlines the muscles measured in two sets.

a. Skin preparation

Alcohol was used to clean the skin area surface electrodes were attached to.

b. Signal processing and filtering

The signal was recorded at a sampling rate of 1k/s and digitally filtered using a band pass filter low pass 20 Hz and high pass 500 Hz. The signal was normalised to the maximum voluntary contraction of each participant and the root mean square of the percentage maximum voluntary contraction (%MVC) was reported.

c. Maximum voluntary contraction

Maximum voluntary contraction of the selected muscles was conducted according to the following guidelines by Konrad (2005):

I. Upper trapezius – shoulder shrug against manual resistance.
II. Erector spinae – prone back extension.
III. Middle fibre of the deltoid – shoulder abduction at 90 degrees.
IV. Elbow flexor and extensors – elbow flexion in 90 degrees against resistance and elbow extension in full flexion against manual resistance.
V. Wrist flexor and extensors – wrist flexion and extension against resistance.

The next section explains the procedure for the evaluation of the postural load during performance.

5.6.4. Rapid upper limb assessment procedure

Postural load was measured using the rapid upper limb assessment. During performance, the researcher evaluated the posture of the neck and back, the repetition of movements in the upper extremity on a RULA sheet. The scoring sheet is summarised in Figure 5.3 below

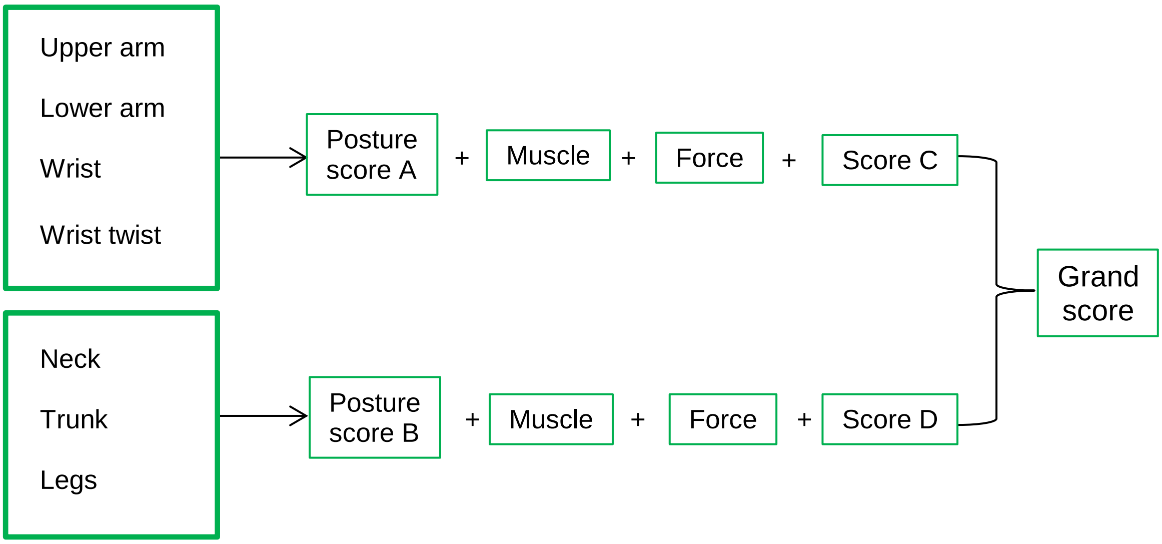


Figure 5.3: RULA method scoring sheet (McAtamney and Corlett, 1993).

The result of the postural load is calculated as a summation of the posture, muscle, force, positon of the arm and wrist as well as a summation of the posture, muscle, force, position of the neck, trunk and legs (McAtamney and Corlett, 1993).

5.7. Data management

The musculoskeletal assessment results were stored in a Microsoft excel format with a unique identifier. Data from the Xsens MVN BIOMECH® were extracted and stored into Microsoft excel. Only the five violinists' kinematic data could be extracted due to computer technical problems. The electromyography results were stored and filtered in Lab chart ®. All the dataset were merged together in one Microsoft excel spread sheet and exported to IBM SPSS 23.0 for analysis.

5.8. Data analysis

The joint angle were extracted from the MVN BIOMECH® to Microsoft excel ® and further extracted to IBM SPSS 23 ® for further analysis. The mean and standard deviation of the joint angles were analysed. Inferential statistics was not conducted to avoid the Type I error due to the small sample size.

5.9. Results

The results of the biomechanical analysis are given in this section. The demographic characteristics of the participants, musculoskeletal assessment tests results, kinematic analysis and the muscle activity of the volunteers are reported in this section.

5.9.1. Demographic characteristics of the participants

A total of six string instrumentalists participated in this study. The mean age of the string instrumentalists in this study was 26 ± 5.7 years with equal representation of male and females with a mean year of experience of 16.5 ± 6.2 years. Table 5.4 below outlines the demographic characteristics and the current history of musculoskeletal problems of each of the participants.

Table 5.4: Demographic characteristics of the participants

	String instrumentalists					
Variables	**A**	**B**	**C**	**D**	**E**	**F**
Age	27	31	32	25	23	21
Gender	Male	Male	Female	Female	Male	Female
Instrument	Violin	Violin	Violin	Violin	Violin	Cello
Practice hrs/week	3	20	30	15	21	8
Years of experience	15	23	25	10	3	7
Presence of musculoskeletal problem	No	Yes	No	Yes	No	No
Location	n/a	-	n/a	Neck	n/a	n/a

5.9.2. Musculoskeletal assessment results

Table 5.5 shows the results of the musculoskeletal assessment categorised into subjective postural evaluation, shoulder dysfunction tests, hypermobility test and stabilisation tests of each participant. Positive (+) and negative (-) results show the presence and absence of musculoskeletal dysfunction respectively.

Table 5.5: Musculoskeletal assessment test results

Musculoskeletal assessment	**Participants**					
	A	**B**	**C**	**D**	**E**	**F**
Subjective postural evaluation						
Shoulder symmetry	Normal	Normal	Normal	Normal	Normal	Normal
Shoulder roundness	Normal	Normal	Normal	Normal	Mild	Normal
Cervical spine posture	Forward head	Neutral	Forward head	Neutral	Neutral	Neutral
Thoracic kyphosis	Normal	Normal	Normal	Normal	Increased	Normal
Lumbar lordosis	Normal	Normal	Normal	Normal	Normal	Normal
Pelvic tilt	Normal	Normal	Normal	Normal	Normal	Normal
Shoulder and scapular dysfunction tests						
Hawkins and Kennedy (Right, Left)	+,+	+,-	+,+	+,+	-,-	-,-
Painful arc test (Right, Left)	-,-	-,-	-,-	-,-	-,-	-,-
Neer's test (Right, Left)	-,-	-,-	-,-	-,-	-,-	-,-
Kibler's test						
0	-	-	-	-	-	-
45	-	-	-	-	-	-
90	-	-	-	-	-	-
Hyper mobility test	2	0	2	8*	0	7*
Upper crossed syndrome	-	-	-	-	-	-
Activation of lumbar stabilisers						
Transversus abdominis	-	+	-	-	-	-
Multifidus	-	+	-	-	-	-
Scapular stabilisers	-	-	-	-	-	-
+, positive; -, negative *<5 – significant						

Subjective assessments

The results of the musculoskeletal assessment showed that participants' A and C had forward head cervical spine posture and participant E had increased thoracic kyphosis. None of the string instrumentalists showed abnormal lumbar lordosis, shoulder roundness, shoulder asymmetry and pelvic tilt.

Scapular and shoulder dysfunction tests

As shown in Table 5.5, the Hawkins-Kennedy test was positive in 3 out of the 5 violinists in both right and left shoulder while the cellist showed no positive signs of the shoulder impingement syndrome.

Hyper-mobility test

Only two of the volunteers (Participant D and E) had hypermobility scores > 5.

Trunk and scapular stabilisers

Activation of the local stabilisers of the spine showed that only participant B had difficulty activating the Transversus abdominis (TrA) and multifidus (MF). None of the string instrumentalists showed objective signs of weak scapular stabilisers.

Gross muscle strength

The average gross muscle strength in kilogramme was 36.5 ± 8.7 and 36.2 ± 7.5 for the right and left upper extremity respectively as shown in Table 5.6.

Table 5.6: Gross muscle strength

	Right		**Left**	
Hand grip strength (Kg)	**Mean**	**SD**	**Mean**	**SD**
Male	40.7	6.1	39.4	4.5
Female	32.4	10.0	33.0	9.4
Gross muscle strength	36.5	8.7	36.2	7.5

The male string instrumentalists had higher gross muscle strength in comparison to their female counterparts. Gross muscle strength in the right upper extremity was higher than the left upper extremity as shown in Table 5.6 above.

Summary of the musculoskeletal assessment tests

Six string instrumentalists with a mean experience of 16.5 ± 6.2 years participated in this study. Only two of the six participants reported musculoskeletal problems. Two of the six participants were hypermobile and four participants showed positive signs of the Hawkins-Kennedy test. One of the participants had difficulty in activating the TrA and MF. No scapular dyskinesia was found in any of the participants. The gross muscle strength in the right upper extremity was higher on the right in comparison to the left. The next section presents the results of the kinematic analysis (joint angle movements during performance).

5.9.3. Joint angle measurements

The joint angle measurements in degrees during performance are reported in two sections. The first section presents the results of the cervical, thoracic and lumbar region and the second section presents the results of the right and left upper extremities. The minimum, maximum and the mean joint angle results of the violinists were reported in the study.

I. Cervical, thoracic and lumbar region

Table 5.7 below shows the mean joint angles of the cervical, thoracic and lumbar region during performance.

Table 5.7: Joint angles of the cervical, thoracic and lumbar regions

Cervical, thoracic and lumbar region (n=5)	**Joint angle in degrees**		
	Mean (SD)	**Minimum**	**Maximum**
T1C7			
Lateral bending	3.51 (2.37)	-2.76	8.49
Axial rotation	-0.24 (4.57)	-9.96	12.67
Flexion-extension	17.53 (1.29)	7.15	21.74
T9T8			
Lateral bending	0.00 (0.99)	-1.24	1.65
Axial rotation	-0.35 (2.50)	-1.33	2.15
Flexion-extension	3.26 (1.91)	0.93	6.24
L5S1			
Lateral bending	0.04 (3.08)	-4.00	5.19
Axial rotation	-1.00 (7.62)	-4.16	6.64
Flexion-extension	9.36 (5.75)	2.73	18.56

a. Neck range of movements (T1C7)

The mean range of motion in the neck was 17.5º flexion and 3.5º left lateral flexion as shown in Table 5.7.

Figure 5.4 below illustrates the waveform of movement at T1C7 in lateral bending, axial rotation and flexion – extension.

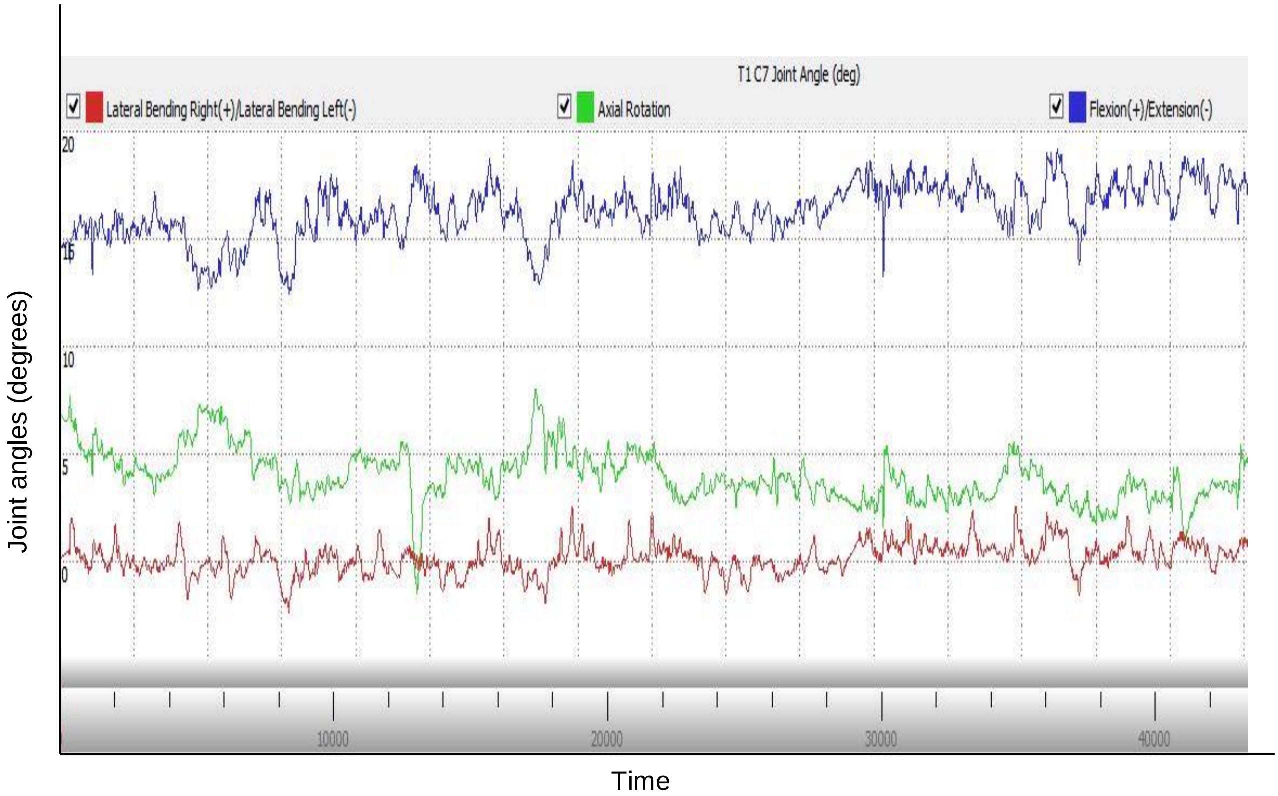


Figure 5.4: Waveform of the range of motion at T1C7

The waveform in Figure 5.4 above shows that the range of movement in the neck in flexion-extension (blue line) was wider when compared with lateral bending and axial rotation.

a. Trunk range of motion (T9T8; L5S1):

At T9T8, the mean range of movement in flexion was 3.3º. However, at L5S1, the mean range of movement was 9.4º flexion and 1º axial rotation to the right. The range of motion at L5S1 was 14.8º (flexion) to 1º (extension) as outlined in Table 5.7.

Figure 5.5 A and B below shows the waveform of the range of movement at T8T9 and L5S1 respectively.

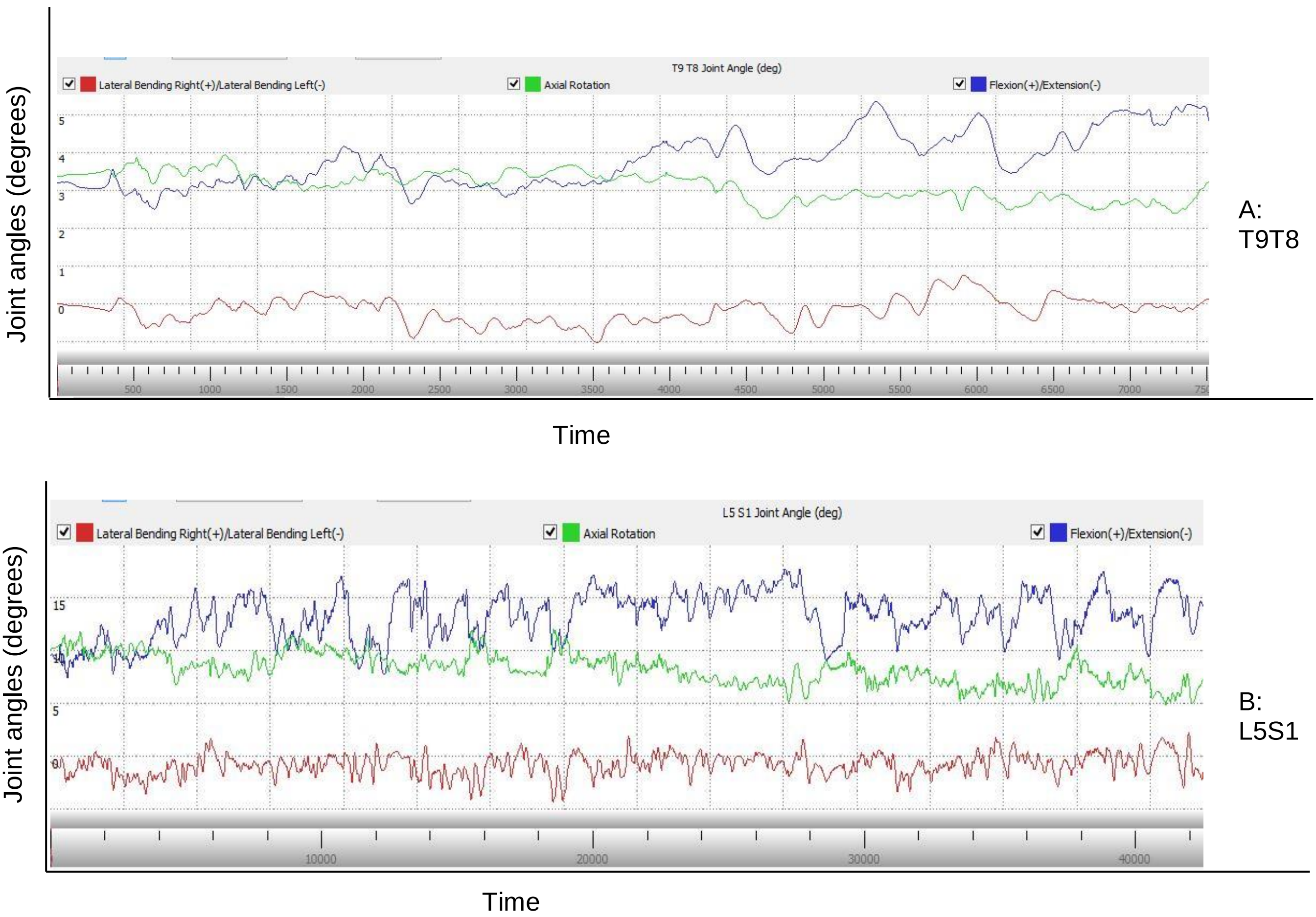


Figure 5.5: Waveform of the range of motion at T9T8 and L5S1

The waveform in Figure 5.6 above shows that there was increased range of movement in L5S1 in comparison to thoracic range of movement at T9T8.

II. Right and left upper extremity joint angles

Table 5.8 and 5.9 below shows the results of the joint angles of the right upper extremity and left upper extremity respectively.

Table 5.8: Right upper extremity joint angles

Right upper extremity (n=5)	Joint angle in degrees		
	Mean (SD)	**Minimum**	**Maximum**
C7shoulder			
Abduction – adduction	-1.49 (7.74)	-12.04	10.15
Internal – external rotation	3.53 (7.63)	-5.23	19.47
Flexion - extension	3.77 (11.18)	-6.96	14.92
Shoulder			
Abduction – adduction	17.09 (8.82)	-7.22	34.88
Internal – external rotation	15.47 (13.66)	2.26	41.97
Flexion - extension	20.10 (14.87)	5.02	38.66
Elbow			
Abduction – adduction	-41.65 (64.25)	-111.10	72.23
Internal – external rotation	58.05 (100.38)	-139.21	173.15
Flexion - extension	57.19 (8.88)	23.42	83.94
Wrist			
Abduction – adduction	-1.72 (15.61)	-37.59	32.65
Internal – external rotation	0.40 (26.79)	-18.48	27.01
Flexion - extension	8.68 (4.59)	-19.24	37.39

Table 5.9: Left upper extremity joint angles

Left upper extremity (n=5)	Joint angle in degrees		
	Mean (SD)	**Minimum**	**Maximum**
C7shoulder			
Abduction – adduction	-2.37 (6.47)	-11.07	0.92
Internal – external rotation	3.02 (8.65)	-4.83	13.50
Flexion - extension	1.19 (12.50)	-4.75	11.21
Shoulder			
Abduction – adduction	3.69 (7.56)	-5.15	16.53
Internal – external rotation	10.92 (13.87)	-0.88	24.70
Flexion - extension	26.40 (21.85)	12.79	34.08
Elbow			
Abduction – adduction	77.51 (85.85)	-73.26	151.47
Internal – external rotation	-12.52 (108.62)	-121.28	124.78
Flexion - extension	68.41 (12.76)	58.14	79.21
Wrist			
Abduction – adduction	2.18 (14.71)	-16.77	18.44
Internal – external rotation	-21.78 (32.39)	-49.51	-1.64
Flexion - extension	8.00 (6.74)	-18.66	25.14

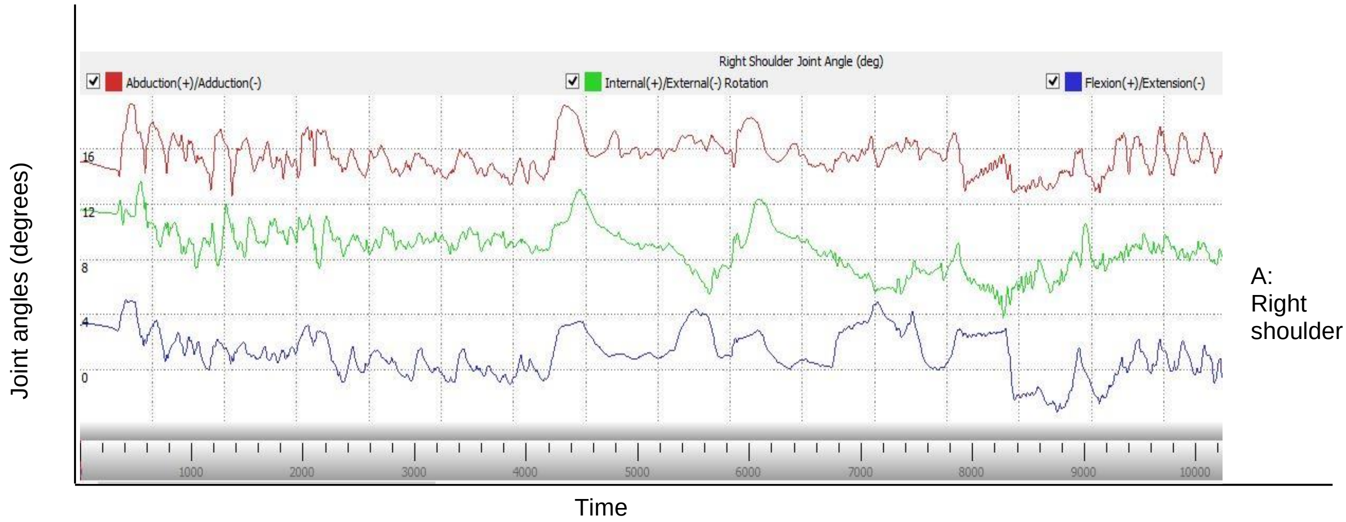
Shoulder range of motion (Shoulder; C7shoulder): In the right shoulder, the mean range of movement was 20º, 15.5º and 17.1º for flexion, internal rotation and abduction respectively. The mean range of movement measured at the scapula-thoracic joint (C7shoulder) was 1.5º, 3.5º and 3.8º for extension, internal rotation and abduction respectively as shown in Table 5.8. In the left shoulder, the mean range of movement was 26.4º, 10.9º and 3.7º for flexion, internal rotation and abduction respectively. The mean range of movement at left C7shoulder (scapula-thoracic) was 2.4º, 3º and 1.2º for adduction, internal rotation and flexion respectively as shown in Table 5.9.

Figure 5.6 A and B below shows the waveform of movement in coronal, transverse and sagittal plane respectively at the C7 shoulder. The red, green and blue waveform represents abduction-adduction, internal-external rotation and flexion-extension movements respectively.

Figure 5.6: Waveform of the range of motion at right and left C7shoulder.

Figure 5.6 above shows that there was an increase in the frequency and repetition of movement in the right C7 shoulder (A) in comparison to the left (B).

Figures 5.7 A and B below shows the waveform of movement in coronal, transverse and sagittal plane respectively at the shoulder. The red, green and blue waveform represents abduction-adduction, internal-external rotation and flexion-extension movements respectively.



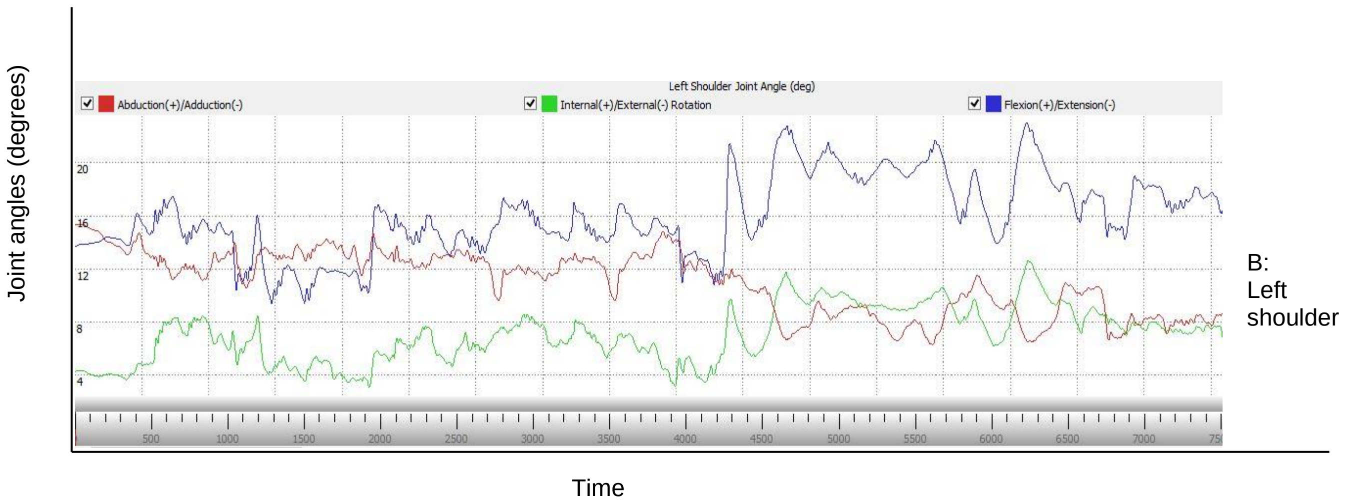
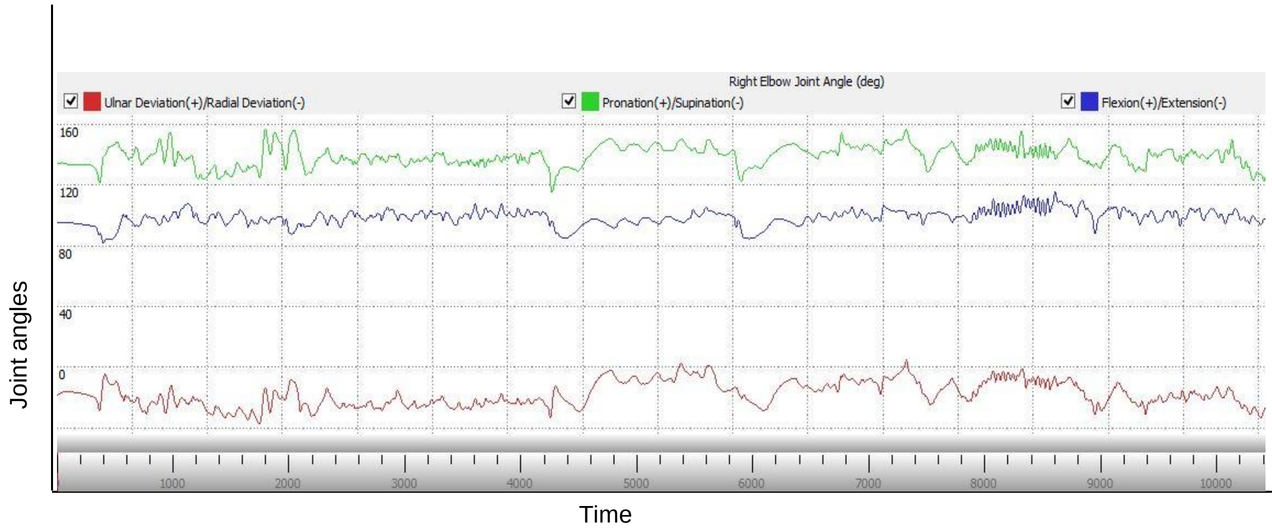


Figure 5.7: Waveform of the range of motion at right and left shoulder

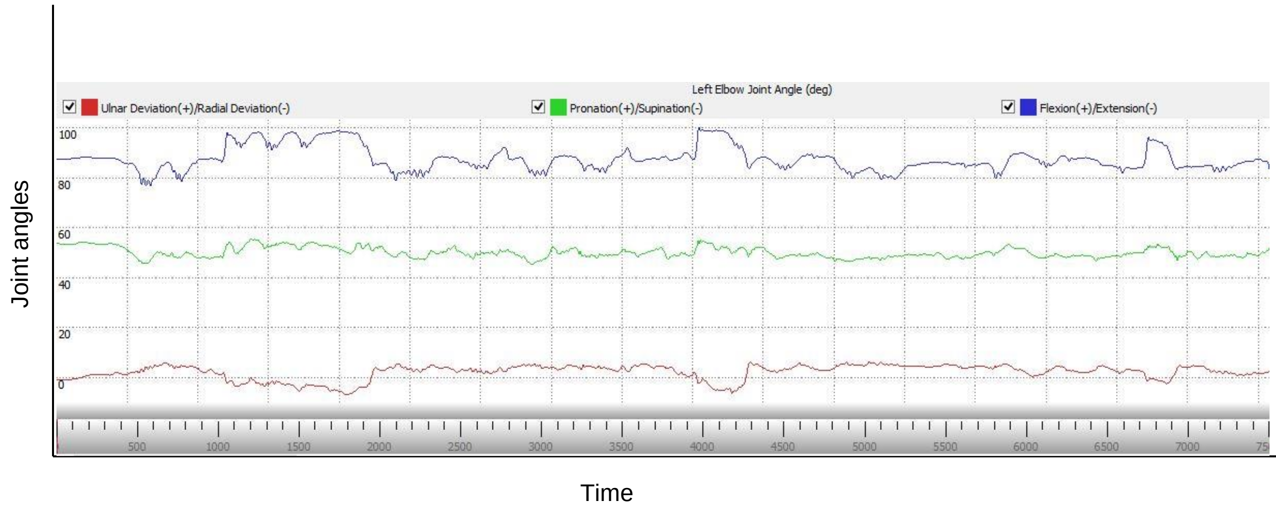
Figure 5.7 above shows that there was an increase in the frequency and repetition of movement in the right shoulder (A) in comparison to the left (B).

Elbow range of motion: The right elbow (the bowing arm), involves a larger range of movement with mean range of movement at the elbow being 57.2º, 58.1º and 41º for flexion, internal rotation and radial deviation respectively as shown in Table 5.8. The left elbow was in a more static state and the mean range of movement was 68.4º, 12.5º and 77º for flexion, external rotation and ulnar deviation respectively as shown in Table 5.9.

Figure 5.8 A and B below shows the waveform of movement in coronal, transverse and sagittal plane respectively at the elbow. The red, green and blue waveform represents ulnar-radial, pronation-supination and flexion-extension movements respectively.



A: Right elbow



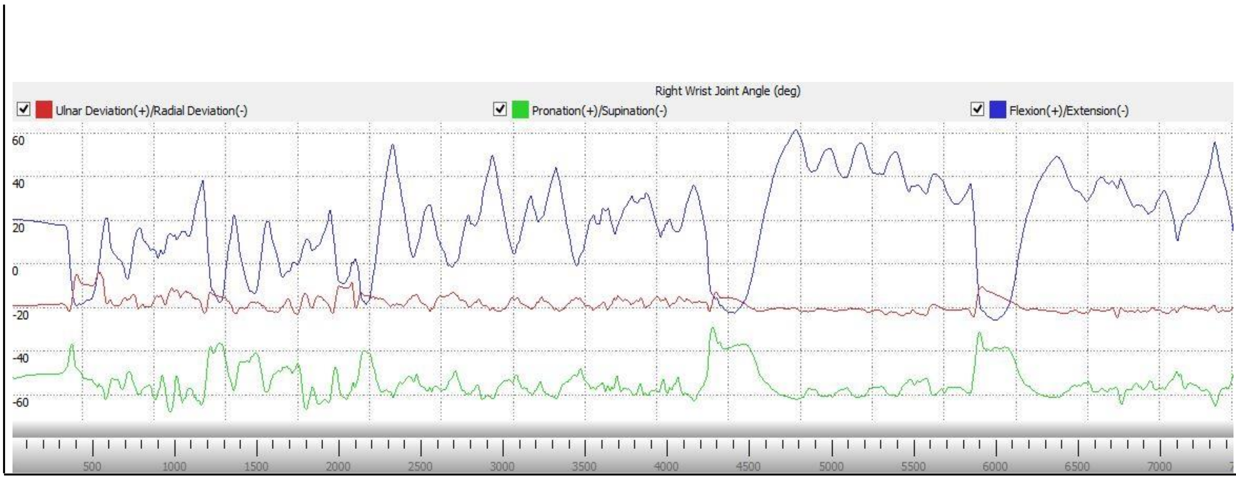
B: Left elbow

Figure 5.8 above shows that there was an increase in the frequency and repetition of movement in the right elbow (A) in comparison to the left (B).

Wrist range of motion: The mean range of movement at the right wrist was 8.7º, 0.4º and 1.7 º in flexion, ulnar deviation and pronation respectively as shown in Table 5.8. In the left wrist, the mean range of movement was 2.2º, 21.8º and 8º in abduction, internal rotation and flexion respectively as shown in Table 5.9.

Figure 5.9 A and B below shows the waveform of movement in coronal, transverse and sagittal plane respectively at the elbow. The red, green and blue waveform represents ulnar-radial, pronation-supination and flexion-extension movements respectively.

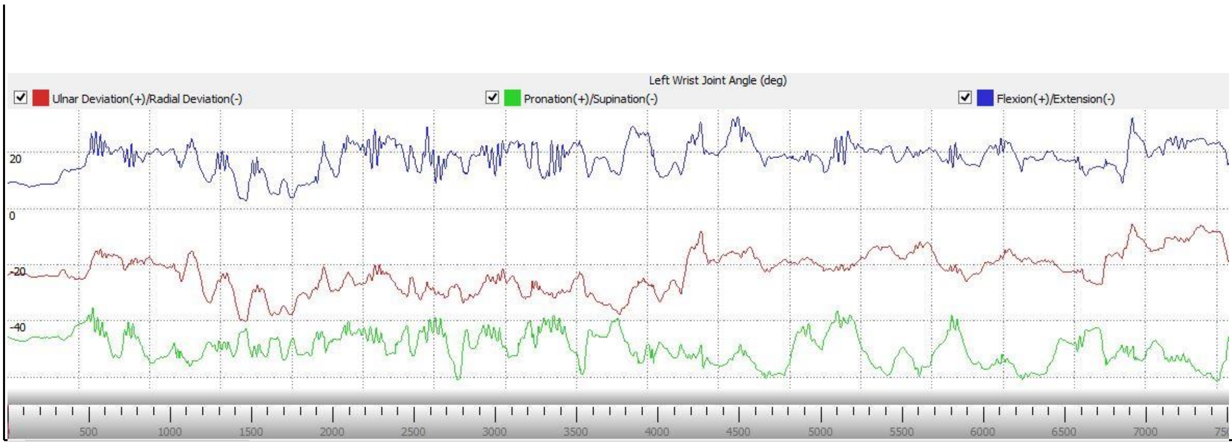
Joint angles



A: Right wrist

Time

Joint angles



B: Left wrist

Time

Figure 5.9 above shows that there was an increase in the frequency and repetition of movement in the left wrist (B) in comparison to the right (B).

Summary of the joint kinematic result

The kinematic analysis was focussed on reporting the mean, minimum and maximum joint angles during a music performance. The results showed that there was increased movement in the joints of the right extremity in comparison to the left except at the wrist joint where the graphical illustration shows that there was increased movement in the left in comparison to the right wrist.

Section 5.9.4 below presents the results of the muscle activity of the selected muscles during music performance.

5.9.4. Muscle activity

The result of the muscle activity of the selected muscles is presented in this section. The root mean square of the amplitude of muscle activity is presented as a percentage maximum voluntary contraction (MVC) in Table 5.10.

Table 5.10: Amplitude of muscle activity level of selected muscle groups

	% Root Mean Square MVC	
Muscle groups	**Right, Mean (SD)**	**Left, Mean(SD)**
Upper trapezius	10.9(9.1)	5.8(3.9)
Middle deltoid	0.6(0.5)	0.6(0.3)
Elbow flexors	3.9(6.3)	6.9(9.9)
Elbow extensors	5.3(7.4)	2.4(3.8)
Wrist flexors	4.0(2.5)	1.3(1.3)
Wrist extensors	4.2(4.4)	2.3(2.8)
Erector spinae	2.7(1.3)	1.7(0.7)

There was increased muscle activity in the right upper trapezius, elbow extensors, wrist flexors, wrist extensors and erector spinae in comparison to the left side. As shown in Figure 5.10 below, asymptomatic string instrumentalists showed increased muscle activity levels in comparison to symptomatic string instrumentalists in the right and left erector spinae, right wrist extensors, left elbow flexors, left deltoid, right and left upper trapezius.

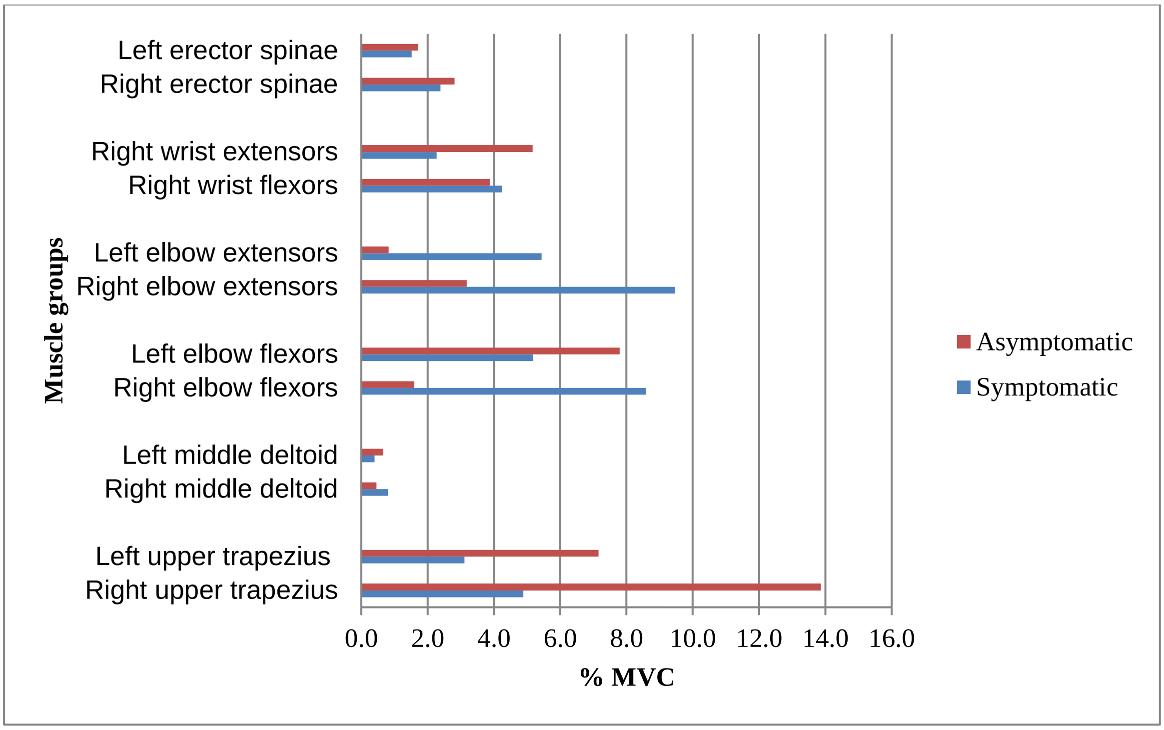
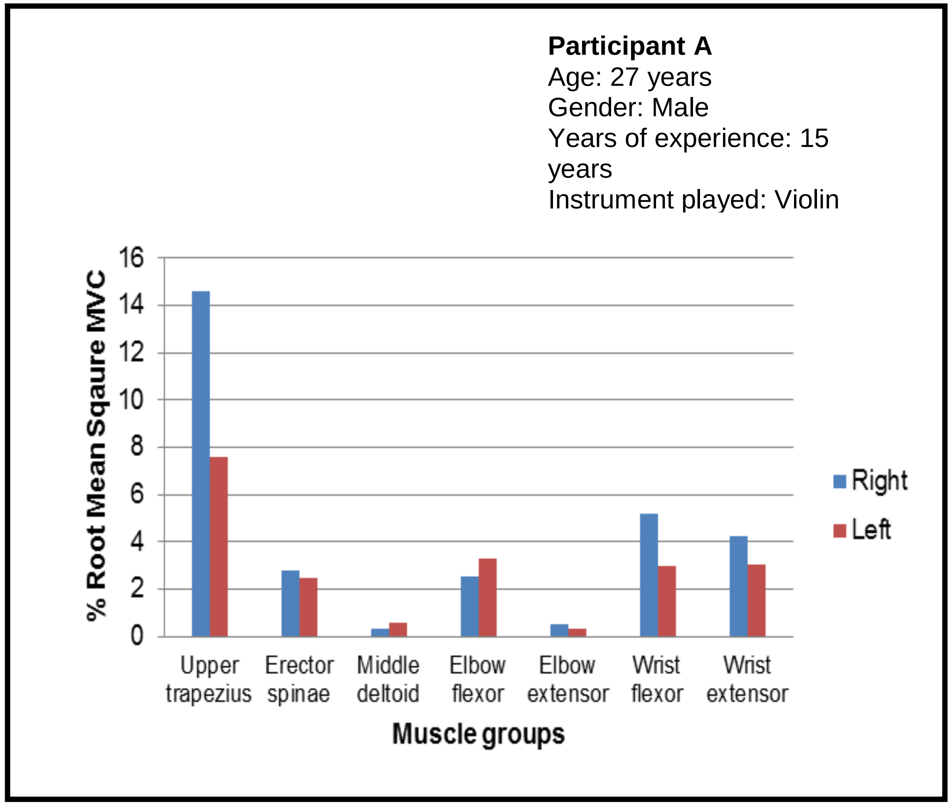


Figure 5.10: Asymptomatic and symptomatic muscle activity level among string instrumentalists

Figures 5.11 – 5.12 below shows the individual muscle activity levels of the string instrumentalists during the music performance.



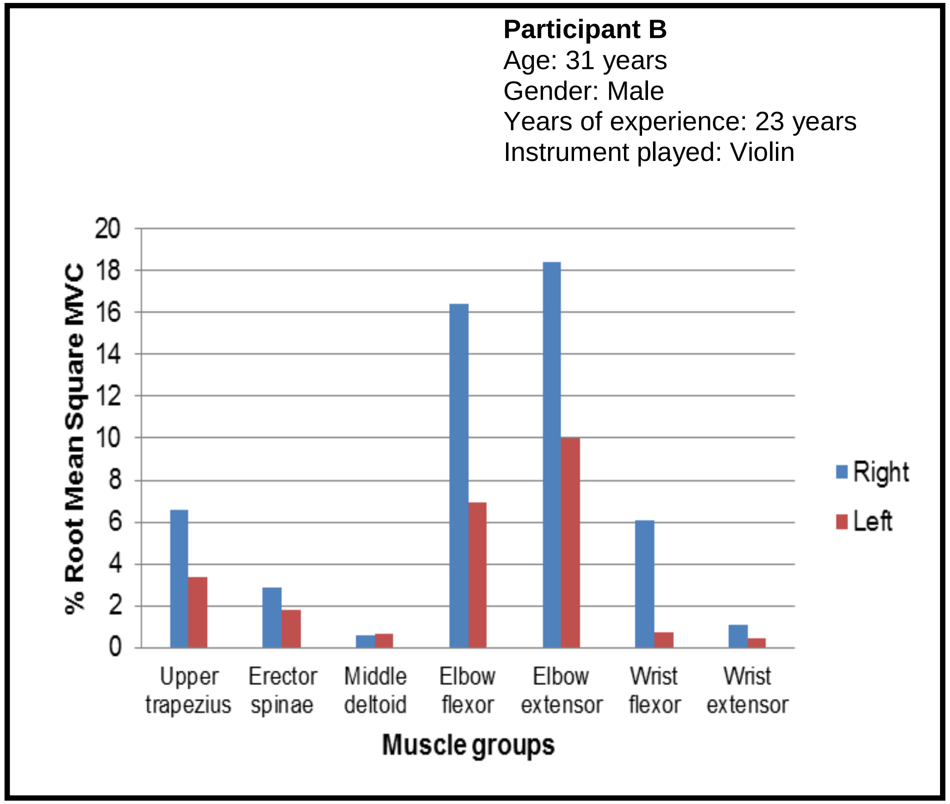
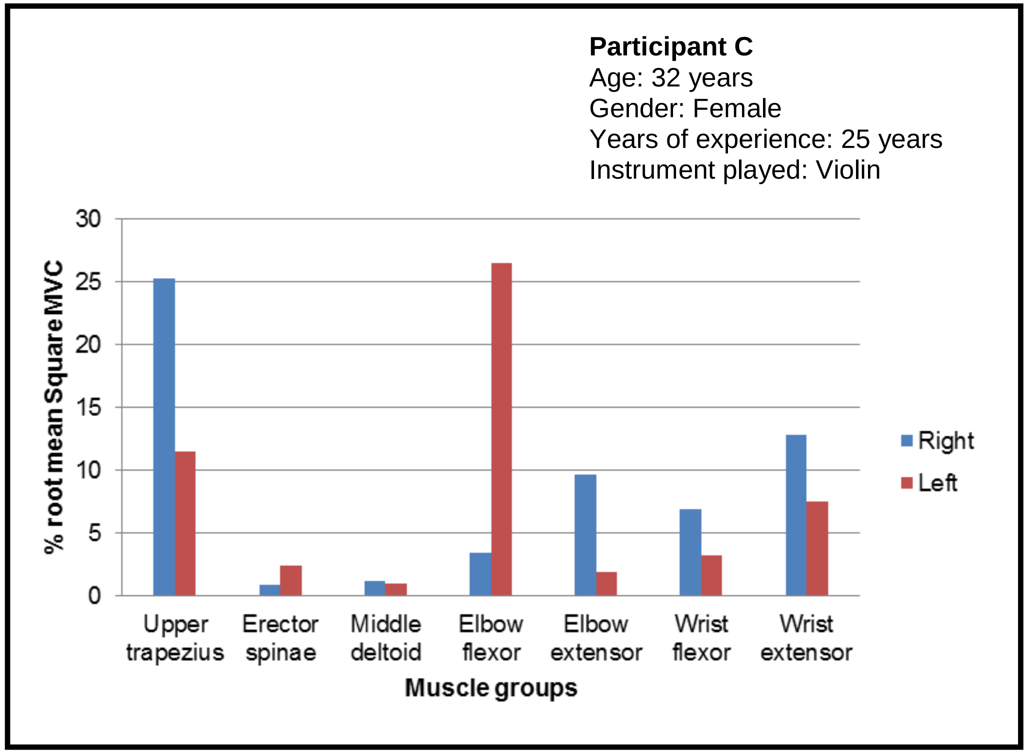


Figure 5.11: Muscle activity level of participants A and B



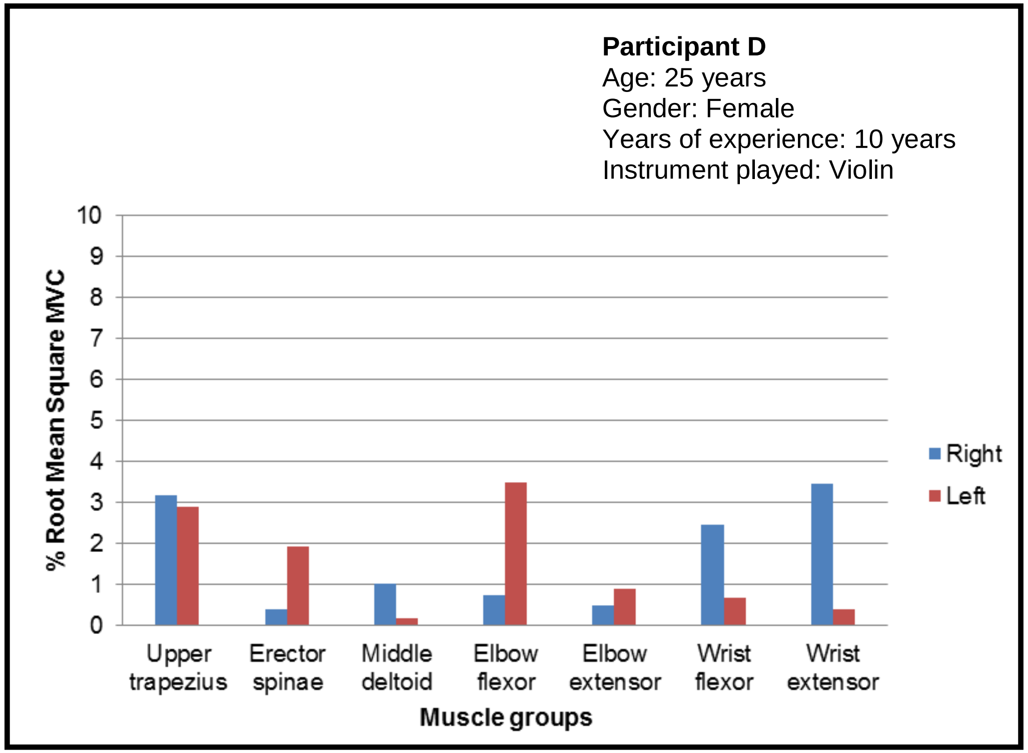


Figure 5.12: Muscle activity levels of participant C and D

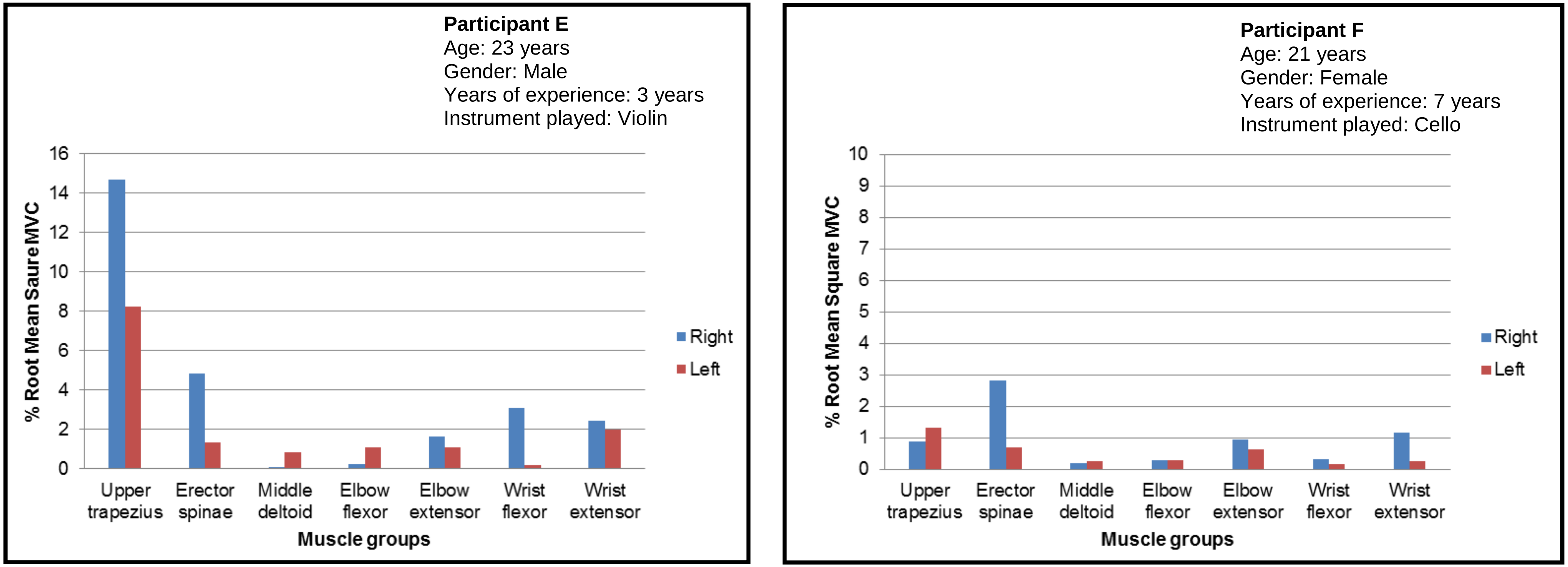


Figure 5.13: Muscle activity level of Participants E and F

As shown in the Figures 5.10 - 5.12 above, all the five violin players showed considerable increase in muscle activity in the right and left upper trapezius in comparison to the cello player (Figure 5.16 F). Participant C (violin player) showed reduced muscle activity in the erector spinae in comparison to the other instrumentalists. There was an increased muscle activity in the right elbow and wrist in comparison to the left elbow and wrist. The next section presents the results of the physical load on the posture using the rapid upper limb assessment (RULA).

5.9.5. Rapid Upper Limb Assessment

The result of the RULA during the music performance is presented in this section. Table 5.11 below outlines the mean score of the rapid upper limb assessment.

Table 5.11: Mean rapid upper limb assessment scores of the string instrumentalists

	Violin (n=5)		**Cello (n=1)**	
RULA	**Right**	**Left**	**Right**	**Left**
A – Arm and wrist analysis	3.6±0.6	2.2±0.5	4	3
C – Arm and wrist + force	4.6±0.6	3.2±0.5	5	4
B – Neck, trunk and leg analysis	2.6±0.9		3	
D – Neck, trunk and leg + force	4.2±0.8		5	
Grand score	4.8±0.5	3.8±0.5	6	5

The mean grand RULA score of the right and left upper extremity was 4.8±0.5 and 3.8±0.5 respectively for the violinists. The cellist showed a high grand score in the right and left upper extremity as shown in Table 5.11. The RULA score was higher in the right upper extremity than in the left upper extremity as shown in Table 5.11.

5.10. Summary of the Results

Six volunteers (5 violinists and one cellist) participated in this study. The mean age of the string players was 26.5 years with an average of 13.8 years of experience. Subjective postural evaluation showed that 3/6 participants had postural problems. Participant E showed reduced lumbar lordosis and forward head posture. Participant A and C showed significant cervical spine forward head posture on subjective evaluation. Objective assessment of the shoulder showed positive signs of shoulder impingement in 3/6 string instrumentalists with no associated scapular asymmetry. Rapid upper limb assessment score was higher on the right in comparison to the left. Only participant B had difficulty in activating the TrA and MF.

Dynamic joint angle measurements showed that there was increased movement in the joints of the right extremity in comparison to the left except at the wrist joint where the graphical illustration shows that there was increased movement in the left in comparison to the right wrist. Muscle activity level was increased in the right upper trapezius, elbow extensors, wrist flexors, wrist extensors and erector spinae in comparison to the left side. Asymptomatic individuals showed an increased muscle activity in the right and left erector spinae, right wrist extensors, left elbow flexors, left deltoid, right and left upper trapezius. The implication of the musculoskeletal assessment, kinematic and electromyography are discussed in the section below.

5.11. Discussion

The aim of this study was to determine upper extremity and trunk angles, muscle activity and musculoskeletal integrity of among string instrumentalists when performing a musical piece. The result of this study was discussed in the following sub sections – musculoskeletal assessment, kinematic analysis and electromyography.

a. Musculoskeletal assessment

Musculoskeletal assessment results of the string instrumentalists in this study showed that the Hawkins and Kennedy test was positive bilaterally in the shoulder in 3/6 string instrumentalists. There was no scapular dyskinesia in any of the string instrumentalists evaluated. Two string instrumentalists with positive Hawkins and Kennedy test also showed forward head posture. Spinal asymmetries such as these have been objectively reported among violinists (Steinmetz et al., 2010, Barczyk-Pawelec et al., 2012). The occurrence of spinal and scapular dysfunction is common among musicians with a higher prevalence among string instrumentalists when compared to other instrument groups (Steinmetz et al., 2010). In this study, only one of the string instrumentalists had postural lumbar stabiliser dysfunction, inability to activate the MF and TrA and none of the string instrumentalists had scapular stabilising dysfunction and upper crossed syndrome. A similar study by Steinmetz et al. (2010) showed that 93% of the musicians evaluated showed signs of postural stabilising system dysfunction and in 72% of all the musicians assessed, more than one stabilisation system was affected. String instrumentalists have been reported to be prone to postural impairments (Steinmetz et al., 2010, Barczyk-Pawelec et al., 2012). The impairment of the postural stabilising system can impact negatively on performance (Steinmetz, 2009). Pain in the neck, shoulder and back can result in a delayed activation of the deep cervical flexors, alter muscle activation and muscle recruitment pattern of the upper trapezius and also delay the activation of the lumbo-pelvic stabilisers while playing the musical instrument (Steinmetz, 2009).

The presence of musculoskeletal dysfunction is synonymous with the presence of PRMDs and in our study only one of the assessed string instrumentalists had a history of musculoskeletal problems. The results of this study might therefore not be comparative to those by (Steinmetz et al., 2010) because 67% of the musicians in their study reported musculoskeletal problems and were more likely to have musculoskeletal dysfunction. The sample size and the mean age of the musicians evaluated in the study by Steinmetz et al. (2010) was larger (n=84) and 32 years respectively when compared to the sample assessed in this study.

In this study, the RULA score was higher in the right upper extremity in comparison to the left upper extremity. This is similar to what was established in the study by Kaufman-Cohen and Ratzon (2011). Their study reported a higher score in the right upper extremity than in the left (Kaufman-Cohen, 2011). Postural loading, perceived physical environment, individual playing characteristics and personal risk factors have been reported to be significant predictors of PRMDs (Kaufman-Cohen and Ratzon, 2011). The repetitive bowing action and the right upper extremity position throughout performance could be responsible for the increased RULA score in the right upper extremity, unlike the left upper extremity which functions mainly as a supporting structure. The grand RULA score of the bowed string instrumentalists in this study for the right and left upper extremity was 4.8±0.5 and 3.8±0.5 respectively. This score is considered to place the worker in a low risk position and change may be considered (Middlesworth, n.d.). The cellist reported a higher grand RULA score which puts the cellist in medium risk position. Inter individual differences and postural flaws is common among musicians (de Araújo et al., 2009) therefore, the postural load of the cellist could not be generalised. Likewise for the violinists, the sample size is not representative of the population and should be interpreted with caution. However, the RULA scores are indicative of a low – medium risk of musculoskeletal injury for string instrumentalists. The art of string playing is an age long skill and the likelihood of altering playing technique might not be feasible in the short term but an intervention programme in conditioning the body to the demands of the profession as well as ergonomic support would have positive outcomes in reducing the risk of musculoskeletal problems among string instrumentalists (Rickert et al., 2013, Rickert et al., 2014b, Rickert et al., 2014a).

b. Joint angles

The results of this study showed that the cervical region is static in an awkward position during the music performance in flexion and left lateral bending with a mean joint angle of

17.5(1.3) and 3.5(2.4) respectively. Work related neck flexion has been reported to be a risk factor for neck pain in a working population (Ariëns et al., 2001).

The mean range of motion in the left and right upper extremity was higher during performance in the shoulder and elbow movements. This is not surprising because the normal range of motion in these joints is higher than in the wrist and scapulo-thoracic joint (Günal et al., 1996). The right shoulder was in an increased abduction – adduction position $(17.1\pm8.8)^o$ in comparison to the left shoulder $(3.7\pm7.6)^o$. In the elbow, the range of motion left elbow $(68.4\pm12.8)^o$ was higher than in the right elbow $(57.2\pm8.9)^o$. Although, the minimum and maximum joint angle in elbow flexion shows that the left elbow joint was held in a reduced range with a difference of 21.2^o in comparison to the right elbow joint in a wider range, with a difference of 60.5^o. The results of this study can be compared to the findings by Shan and Visentin (2003) which measured arm kinematics in violin performance by using a nine camera motion capture system. The average range of motion in the left upper extremity in this study using the inertial motion sensors showed a reduced range of motion in all the segments measured when compared with the study by Shan and Visentin (2003). This study showed an increased joint angles in the left shoulder joints when compared to the study by Shan and Visentin (2003). The left shoulder was positioned in flexion – extension, abduction – adduction and rotation with a mean joint angle of 31 ± 11^o, 13 ± 6^o and 22 ± 10^o respectively. In the right shoulder, the study by Shan and Visentin (2003) could not be directly compared with this study because the joint angle was reported with respect to the string played unlike this study were the mean of the joint angle irrespective of the string played was reported. However, Shan and Visentin (2003) reported that the joint angles in flexion-extension, abduction-adduction and rotation when playing on the G-string is higher than when playing on the E-string. This is not surprising because the position of the G-string on the violin requires the right upper extremity to move across the body during bowing (Rolland, 1986). The left wrist position in this study is similar to the study by Shan and Visentin (2003), the wrist position during performance was at supination, flexion and adduction with mean joint angles of 29^o, 8^o and 0^o degrees respectively. In this study, the joint angles at the left wrist is slight reduced in supination $(21.8\pm32.4)^o$, slightly increased in abduction $(2.2\pm14.7)^o$ and similar in flexion $(8\pm6.7)^o$. Although, discrepancies have been reported between Xsens and a camera based system (Optotrak) in the lower limbs which could be responsible for the differences observed (Zhang et al., 2013). Also, the variation in joint angles can be attributed to inter-individual differences in skills and performance (de Araújo et al., 2009). An analysis of postural flaws of violinists during a musical performance showed that all violinists measured in the study had postural flaws during performance especially in the wrist and neck (de Araújo et al., 2009). Individual violinists often adjust and adapt their own pattern of play to the most suitable pattern and this usually results in inter – individual differences among violinists (Ericsson et al., 1993).

This study measured trunk movement and position associated with performance. The mean range of motion at L5S1 was flexion $(9.4\pm5.8)^{o}$, left lateral bending $(0.04\pm3.1)^{o}$ and axial rotation $(1\pm7.6)^{o}$. The minimum – maximum joint angles at L5S1 was 2.7^{o} and 18.6^{o} respectively. This implies that the trunk position was not in the neutral position throughout the music performance. Neutral position when sitting in a correct ergonomic posture would reduce the risk of back pain (Vergara and Page, 2002). Several injury prevention programmes have identified the importance of trunk training however, the movement pattern associated with trunk performance is not well reported in the literature (Ackermann et al., 2002b, Kava et al., 2010, Chan et al., 2013a, Chan et al., 2014).

In this study, the neck position for the string instrumentalists in this study was mainly in left lateral bending $(3.5\pm2.4)^{o}$ and flexion $(17.5\pm1.3)^{o}$ and this neck position corresponds to the basic violin performance. A comparative study that measured the neck range of motion in violinists by using a three dimensional motion analysis showed that the violinists with neck pain (5.84±2.41) reported significantly increased range of motion in lateral bending to the left side while playing when compared with violinists without pain (1.37±5.46) (Park et al., 2012). However, neck flexion was reduced in the pain group in comparison to the control group (Park et al., 2012).

The kinematic characteristics of the right, left and the trunk in violin performance showed considerable movement in the neck, right, left and trunk and these are the most common regions of musculoskeletal problems in violin players. The neck position is static in an awkward position with the back trying to compensate for the awkward neck position and the bowing action of the right hand and PRMDs from the repeated strain.

c. Muscle activity

The findings in this study showed increased muscle activity in the right upper trapezius in comparison to the left which is similar to the results of muscle activity among professional violin and viola players (Berque and Gray, 2002, McCrary et al., 2016). The %MVC in this study for was highest in the right (10.9±9.1) and left upper trapezius (5.8±3.9). In these studies, the participants reported increased muscle activity in the right upper trapezius in comparison to the left upper trapezius with an increase in the difficulty of the music piece (Berque and Gray, 2002, McCrary et al., 2016). A study by Park et al. (2012), showed contradicting results where muscle activity in the left upper trapezius during performance was increased in comparison to the right upper trapezius. The difficulty of the music piece might be responsible for the differences in the results. Overuse syndrome is often associated with muscle activity (Berque and Gray, 2002). Low load (10% of MVC) with duration of activity are significant factors associated with overuse (Visentin and Shan, 2004). The increased muscle activity in the right wrist flexors in comparison to the left wrist flexors is probably due to the upward and downward bowing action of the right upper extremity in comparison to the static position of the left wrist flexors (Rolland et al., 1986, Wilke et al., 2011).

The role of the upper trapezius in support and providing stability during violin performance has been reported in literature (Press and Levy, 1992). In all the muscles evaluated, the upper trapezius showed an increased muscle activity in comparison to the other muscles and this further confirms the load demand on the upper trapezius during violin performance as well as the muscle involved in the synchronised bowing activity of the right upper extremity. In the left upper extremity, which similarly acts as a support for the violin, the left elbow flexors also show an increased muscle activity, 6.9(9.9) which relates to an increased load in the static position during the course of the performance.

5.12. Limitations of study

This study was aimed at evaluating the biomechanical demands associated with playing the string instrument. One major limitation in this study was the small sample size of the participants. The six volunteers in this study included five violinists and one cellist. The biomechanical demands of performance of the double bassist and violist could therefore not be evaluated. The technical problem with extraction of the kinematic data of the cellist also limited the interpretation of the joint angle position during performance. A minimum of thirteen string instrumentalists per group would have been sufficient to determine the joint angle differences associated with shoulder impingement, a common disorder in string instrumentalists (Lukasiewicz et al. (1999).

5.13. Summary of the Chapter

This chapter explained the methodology and the results of biomechanical analysis of string instrumentalists and its implication for the development of an exercise programme. The joint position as well as the postural load during performance puts the string instrumentalist at risk for developing PRMDs.

The specific joint angles measured, muscle activity and the postural risk of performance as well as the distribution of PRMDs was integrated to explaining a patho-anatomical pathway of PRMDs. Due to the inability to extract the joint kinematic data of the cellist. The deductions and the exercise programme were developed based on the joint kinematics, postural demands and EMG results of the violinists. The integrated pathway was used in developing an exercise based injury prevention programme in Chapters 6, 7 and 8 for violinists.

The next chapter is a scoping review of exercise-based interventions for injury among musicians with the aim of evaluating exercise intervention programmes that have been utilised for musicians. Initially this was viewed as a single scoping review but the outcomes were different although interlinked to the development of the exercise programme. Therefore, the scoping review was reported in two chapters. The first objective of the scoping review was to evaluate the components and implementation strategies of existing exercise programme adapted for musicians. The second objective of the scoping review was to extract reproducible exercise programmes used in the management of work related musculoskeletal problems. The methodology and the results of the two scoping reviews are presented in Chapter six and seven respectively.

CHAPTER 6

6. EXERCISE BASED INJURY MANAGEMENT AMONG MUSICIANS – A SCOPING REVIEW

6.1. Introduction to Chapter

This chapter is a scoping review of literature on exercise based injury management programmes for musicians. This chapter is aimed at reviewing exercise based injury prevention and management practices among musicians in order to identify gaps that can be explored in developing an exercise based injury prevention programme for string instrumentalists. The background, aim, methodology and the specific exercise based management are reported in this chapter.

6.2. Background

Over the last three decades the focus of musical instrument playing related health problems has shifted to a more preventative approach (Brandfonbrener, 1997, Ackermann et al., 2002b, Chan et al., 2014). Musculoskeletal problems are the most common instrument playing related health problems in musicians with varying degrees of severity which is dependent on the instrument played, gender, years of experience and exposure (Yeung et al., 1999, Bragge et al., 2006, Leaver et al., 2011). The demands of playing a musical instrument share similarities to the demands of an athlete in the amount of time required for practising and learning skills, as well as the demands on the neuro-musculoskeletal systems (Dommerholt, 2009, McCrary, 2016). The demands of playing a musical instrument requires repetition, skill acquisition which involves long practice hours, posture and other environmental and intrinsic factors (Kaufman-Cohen and Ratzon, 2011). Exercise programmes have been used consistently to reduce the incidence of musculoskeletal problems in sports (Gatterer et al., 2012, Longo et al., 2012). Similarly, exercise programmes have been adapted and developed to reduce the incidence of musculoskeletal problems among musicians (Ackermann et al., 2002b, Cooper et al., 2012, Chan et al., 2014).

Exercise based interventions are an integral component of injury prevention and holistic rehabilitation in work-related musculoskeletal problems (Ferreira et al., 2006, Oesch et al., 2010, Sihawong et al., 2011). In recent years holistic exercise injury based approaches have been employed to manage musculoskeletal problems associated with playing musical instruments (Chan and Ackermann, 2014, Chan et al., 2014). A number of the injury prevention strategies have been established in countries such as Australia, United Kingdom, Netherlands and Canada where health practitioners have been involved in the management of playing related musculoskeletal problems. Devroop (2014) recently suggested an injury prevention model that could be adopted for the South African musicians. This model comprised of adapting existing injury prevention strategies to suit the nuanced differences of the South African population (Devroop, 2014). Similarly, Rennie-Salonen and de Villiers (2016) also suggested an inclusion of health promotion with the aim of preventing injuries in the undergraduate teaching of music students in South Africa.

Practice habits and demands of performance of musicians has been considered to share several similarities with sports (Dommerholt, 2009, McCrary, 2016). Exercise based injury prevention is focused mainly on conditioning the athlete to the demands of the profession (Longo et al., 2012, Steffen, 2013a). Exercise based injury prevention programmes include core training, neuromuscular facilitation and plyometric patterned with regards to the demands of the profession (Kilding et al., 2008, Longo et al., 2012, Steffen, 2013b). Therefore, including an exercise based injury prevention programme as part of the occupational health promotion programme for musicians may reduce the incidence of playing related musculoskeletal problems.

Scoping reviews have been used to map out existing research and identify potential research gaps by exploring literature (Crooks et al., 2010, Hanass-Hancock et al., 2013, O'Flaherty and Phillips, 2015). Several exercise based injury prevention strategies have been adapted for musicians (Brandfonbrener, 1997, Ackermann et al., 2002b, Chan et al., 2014). An exploration of the components, implementation and prescription of exercise programmes for musicians in order to identify gaps, challenges and successes would be important in developing an exercise based injury prevention programme for string instrumentalists.

6.3. Aim of the Study

The overall aim of this study was to present the results of a scoping review that evaluated the components, implementation and prescription of exercise programmes for musicians. The results of this study can assist future studies in adapting, developing and implementing a holistic exercise programme to reduce musculoskeletal problems among musicians.

6.3.1 Objective of the study

The objective of this study was to:

- To establish the content and structure of an exercise based injury prevention programme for the prevention of PRMDs among musicians.

6.4. Methodology

In recent years, scoping reviews have been used to review evidence, identify gaps in research, and map out existing evidence about a topic and to explore the grey areas to provide answers to pertinent questions (Crooks et al., 2010, Hanass-Hancock et al., 2013, O'Flaherty and Phillips, 2015). A scoping review is better suited for the aim of this study which was to map out what have been with regards to exercise based intervention in musicians in order to identify gaps that could assist in developing an exercise based injury prevention programme for musicians. A scoping review allows the inclusion of a range of study designs without much emphasis on the quality of the study that can be used in clarifying identified grey areas in the study (Levac et al., 2010, Dijkers, 2015). The methodology of the scoping review followed the protocol earlier developed which involved five steps namely: identifying research questions and relevant studies, study selection, charting of data and summarising and collating results as shown in the Figure 6.1 below (Arksey and O'Malley, 2005).

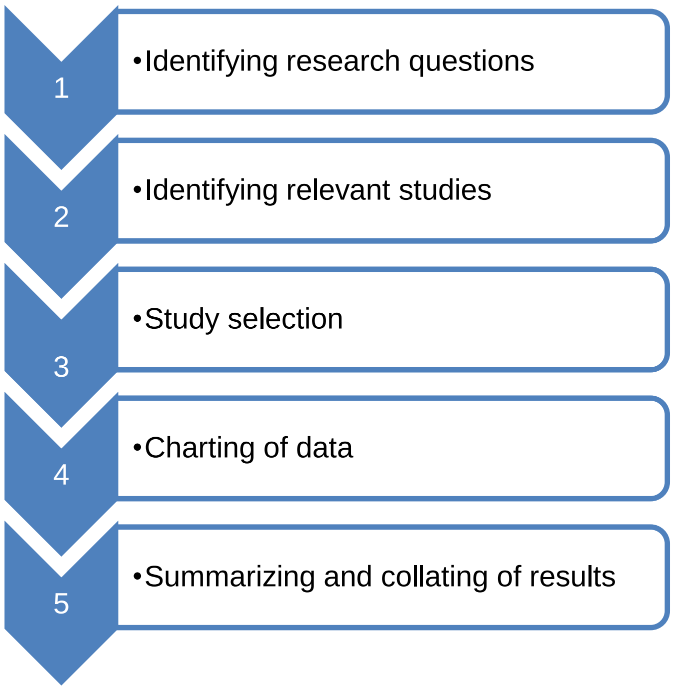


Figure 6.1: Stepwise methodology of the scoping review process (Arksey and O'Malley, 2005).

This method has been adopted in various studies (Archer et al., 2011, Hanass-Hancock et al., 2013). The methodology of the scoping review process is outlined in the five stages as shown in Figure 6.1 above.

6.4.1. Identifying the research question

The research question for this scoping review was based on the exercise prescription guideline of the American College of Sports Medicine (2014). The question that was supposed to be answered was:

- What are the content and structure of an exercise based injury prevention programme for the prevention of PRMDs among musicians.

The research objectives of the scoping review were:

- To evaluate the content and structure of an exercise based injury prevention programme for the prevention of PRMDs among musicians.
- To evaluate the implementation strategy of the exercise based injury prevention programme for the prevention of PRMDs among musicians.

6.4.2. Identifying relevant studies

6.4.2.1. Search strategy

The following databases – Physiotherapy Evidence Database (PEDro), MEDLINE via PubMed, Cumulative Index to Nursing and Allied Health Literature (CINAHL), the Cochrane Controlled Trials Register in the Cochrane Library, Physiotherapy Evidence Database (PEDro), ProQuest 5000 International, ProQuest Health and Medical Complete, EBSCO MegaFile Premier, Science Direct and SCOPUS were searched.

The following search terms were used in various combinations using the Boolean search strategy: 'musicians', 'instrumentalists', 'musculoskeletal', 'injury', 'rehabilitation', 'exercise' and 'management'. The combination was used in the following pattern – "Musician" OR "instrumentalist" AND "injury AND "exercise", Musician" OR "instrumentalist" AND "injury AND "management", Musician" OR "instrumentalist" AND "injury AND "rehabilitation".

6.4.2.2. Eligibility criteria

The inclusion and exclusion criteria for the studies were as follows:

a. Types of participants

This scoping review included all studies done on participants that were performing arts musicians. The studies included adult participants who were 18 years and older. Studies using both male and female participants were included. Studies done where participants had exercise for systemic diseases or traumatic musculoskeletal problems were not included.

Studies with participants that were involved in a physical activity based intervention study were also excluded.

b. Phenomena of interest

Exercise programme for musculoskeletal injury among musicians, related exercise prescription and the implementation strategy employed/suggested were included in the scoping review. All other forms of exercise intervention were excluded from the scoping review. Studies from all countries were considered in this scoping review to get a global view of exercise intervention strategies in the prevention of PTMDs.

c. Types of Outcomes

Studies looking at exercise programme for musculoskeletal injury among musicians and any related exercise prescription and the implementation strategies used were included in this scoping review.

d. Types of sources

This scoping review considered both experimental and epidemiological study designs including randomised controlled trials, non-randomised controlled trials, quasi-experimental studies, before and after studies, prospective and retrospective cohort studies, case control studies and analytical cross sectional studies for inclusion. Descriptive epidemiological study designs including descriptive cross sectional studies were also considered. Only peer-reviewed studies were included in the scoping review.

6.4.3. Study selection

A total of 176 studies were identified from the ten databases. A review of the abstract and title included 41 articles and excluded 135 articles. Nine duplicates and 20 articles that did not meet the inclusion criteria were removed, leaving 12 articles. Twelve articles were included in the scoping review. The flowchart of the study selection process is outlined in Figure 6.2.

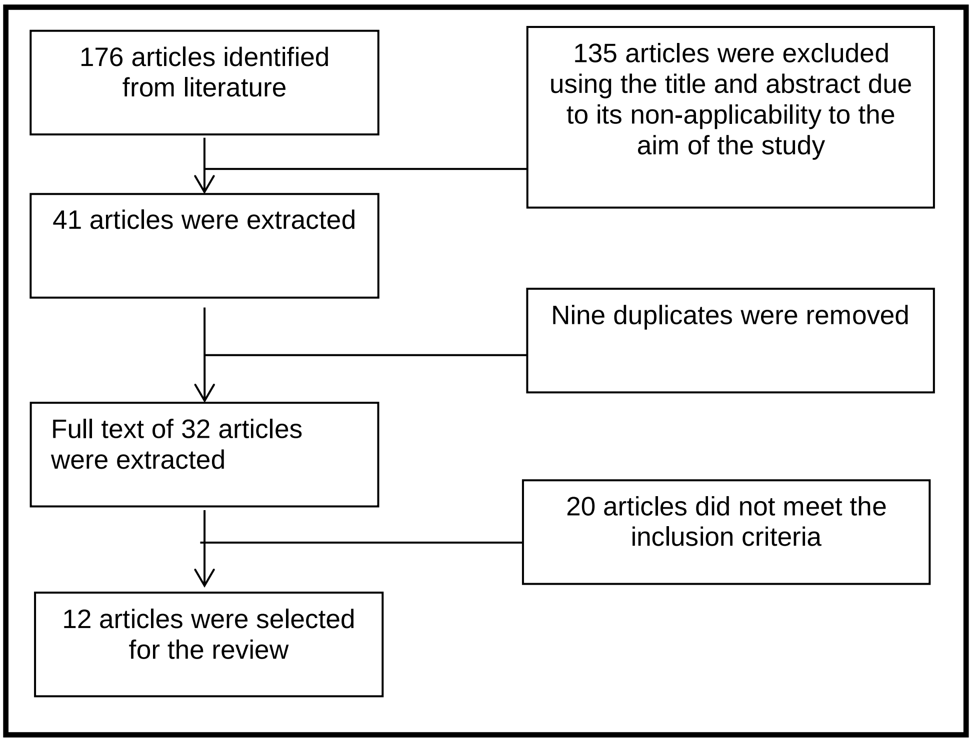


Figure 6.2: Flowchart of the study selection process

6.5. Results

The data extracted from the selected studies included – the demographics of the population studied, outcome measures and methodology as charted in Table 6.1. The components, prescription, implementation strategy and the key outcomes of the exercise programme were also extracted as shown in Table 6.2. The exercise components were charted based on the exercise prescription guideline by the American College of Sports Medicine (2014), which involves exercise type, frequency and sets and repetition, and additionally the implementation process.

6.5.1. Characteristics of the included studies

Table 6.1 outlines the characteristics of the included studies. The characteristics extracted included the study design, population and outcome measures.

Table 6.1: Characteristics of included studies

Author	Study design	Population	Outcome measures
McCrary (2016)	RCT	55 music students and professional orchestra musicians with a mean age of 28.2 (12.3) years. 15 males and 40 females participated in the study.	Muscle activity: MVC pre-test and post test Perceived exertion: Ratings of perceived exertion (RPE)
Chan et al. (2014)	RCT	53 professional orchestra musicians with the mean age of 44 years. 20 males and 33 females participated in the study.	PRMDs: Perceived exertion: RPE
Chan et al. (2013b)	Pre-post intervention	144 professional orchestra musicians with the mean age of 45 (9.3) years were recruited. The gender distribution of the participants was not reported.	Programme uptake and compliance: PRMD: Perceived exertion: RPE
Chan et al. (2013a)	Formative evaluation process	Four physiotherapists with over 20 years of experience participated in the study.	Exercise programme
Ajidahun and Phillips (2013a)	Delphi study	Seven professionals with experience in the health of the performing artists participated in the study. Years of experience range: 3-12 years	Warm up exercise programme
Cooper et al. (2012)	Quasi experimental design	126 high school string instrumentalists (violin, viola, cello and double bass) with an age range of 14-18 years participated in the study of which there were 35 males and 65 females.	Perceived level of self-discomfort: Perception of discomfort survey (POD)
Lee et al. (2012)	Pre-post experimental design	Two college musicians (one male and one female) participated in the study.	PRHP: 23 item health pain injury inventory Physical and musical efficacy: Physical and musical efficacy Indices (PME)
Kava et al. (2010)	Pre-post-test design	14 music students participated in the study. Music students (N=14)	Posture: Breath control: Muscle tension: Endurance:
De Greef et al. (2003)	RCT	53 professional orchestra musicians with a mean age of 46 years participated in the study of which there were 18 males and 32 females.	Perceived physical competence: Physical competence scale (PCS) PRMDs: WHQM
Ackermann et al. (2002b)	Pre-post experimental design	19 undergraduate music students participated in the study.	PRMDs: Perceived exertion: RPE Muscle strength and endurance: Dynamometer
Spahn et al. (2001)	RCT	44 music students with an age range of 19-35 years participated in the study. 70% and 30% were females and males respectively.	**PRMDS:** Kiel modification sensitive symptom list (KASSL). The Frankfurt body concept scales (FKKS). **Anxiety:** The hospital anxiety depression scale (HADS) Epidemiological questionnaire for musicians Questionnaire on coping with work as a musician - evaluatory questionnaire
Brandfonbrener (1997)	RCT	315 professional orchestra musicians participated in the study. The age and gender of the participants was not reported.	Musculoskeletal problems: Physical assessment and self-reported questionnaire.

6.5.2 Study design and population

A total of 12 studies were included in this scoping review as outlined in Table 6.1. Ten of the twelve studies were exercise based intervention studies (Brandfonbrener, 1997, Spahn et al., 2001, Ackermann et al., 2002b, De Greef et al., 2003, Kava et al., 2010, Cooper et al., 2012, Lee et al., 2012, Chan et al., 2013b, Chan et al., 2014, McCrary, 2016) while two were exercise development studies (Ajidahun and Phillips, 2013a, Chan et al., 2013a).

The study design in the included studies was mainly randomized controlled trials, pre-and post-test design, quasi experimental design. Randomized controlled trials were used in five studies (Brandfonbrener, 1997, Spahn et al., 2001, De Greef et al., 2003, McCrary, 2016), one study used a quasi-experimental design (Cooper et al., 2012). The exercise development studies used formative evaluative process (Chan et al, 2013) and a Delphi study (Ajidahun and Phillips, 2013a). The experts recruited in both studies were experts in the health of performing artists (Ajidahun and Phillips, 2013a, Chan et al., 2013a).

The population studied were professional orchestra musicians (Brandfonbrener, 1997, De Greef et al., 2003, Chan et al., 2013b, Chan et al., 2014, McCrary, 2016) and music students (Ackermann et al., 2002b, Kava et al., 2010, Cooper et al., 2012, Lee et al., 2012, McCrary, 2016) in all the experimental studies. More females participated in five of the ten intervention studies (Spahn et al., 2001, De Greef et al., 2003, Cooper et al., 2012, Chan et al., 2014, McCrary, 2016). Gender distribution was not reported in the other five studies. The mean age of the participants in the selected studies ranged from 14-46 years.

The exercise development studies used formative evaluative process (Chan et al, 2013) and a Delphi study (Ajidahun and Phillips, 2013a). The participants recruited in both studies were physiotherapists (Ajidahun and Phillips, 2013a, Chan et al., 2013a) and experts in health of performing artists (Ajidahun and Phillips, 2013a).

6.5.3 Outcome measures

As shown in Table 6.1 above, the primary outcome measured in the selected studies was to determine the effectiveness of the exercise based injury prevention programme on incidence, frequency and severity of musculoskeletal problems (Brandfonbrener, 1997, Spahn et al., 2001, Ackermann et al., 2002b, De Greef et al., 2003, Kava et al., 2010, Cooper et al., 2012, Lee et al., 2012, Chan et al., 2013b, Chan et al., 2014, McCrary, 2016). The secondary outcome measured was to determine the effect of the intervention programme on perceived physical competence, anxiety, physical and musical efficacy. The two studies aimed at developing an exercise programme that was focussed on two different things. Chan et al. (2013a) developed an exercise programme with the aim of preventing musculoskeletal problems among professional musicians regardless of the instrument played and they also measured programme uptake and compliance. Ajidahun and Phillips (2013a)'s study determined the content of a warm up programme aimed at preventing musculoskeletal programme among musicians. One study measured programme uptake as well as compliance of the exercise programme by using an integrative approach of small group learning and the use of digital video to reinforce the exercise programme to improve compliance (Chan et al., 2013b).

6.5.4 Exercise components and rationale

Table 6.2 outlines the key findings of the exercise rationale and specific exercises respectively. Included in the table are the key findings of the study as well as exercise prescription parameters.

Table 6.2: Exercise rationale, protocol and key findings

Author	Aim/Rationale	Specific exercise and prescription	Key findings
McCrary (2016)	The effects of four different warm up protocols on muscle activity and exertion during performance was evaluated.	Warm up protocols: Cardiovascular warm up: moderate to high intensity activities for 15 minutes Core muscle strengthening: dual loading gluteal bridges, leg crossovers, opposite arm/extension and dynamic plank (20RM each). Shoulder strengthening: Shoulder 'A', Shoulder 'T' and Shoulder 'W' (10 RM each) Musical warm up group: playing of graduated scales on the instrument.	Perceived exertion: RPE decreased for all warm up groups and there was no significant difference between the three groups. Muscle activity: Significant pre-and post-test difference in the right upper trapezius in the musical warm up group and the right lower trapezius in the core muscle warm up group.
Chan et al. (2013a) Chan et al. (2014)	The effects of a developed exercise programme for the prevention of musculoskeletal injury for the reduction of musculoskeletal injury and exertion during performance for professional orchestra.	Exercises (the intervention was for a period of 9-12 weeks) Control: Low-load activation of supporting musculature of the local body region, scapular retractor and depressor activation (12RM, 3 sets) Control, proprioception and balance: Increasing difficulty through unstable and changing position, alternating arm and leg fall-outs on pool noodle (6RM, 3 sets, 30-40 seconds consistent loading). Control, proprioception and resistance: Exercises modified into functional movement patterns with added resistance, deep neck stabiliser activation with cervical rotation and with resistance. Strengthening exercises: Deep neck flexor and extensor, low load activation of the lumbar multifidus, abdominal muscles, gluteal muscle group.	Perceived exertion: There was a significant reduction in RPE at T1 and T2 respectively in the intervention group ($p<0.01$). PRMDs: There was a significant reduction in PRMDs in the exercise group ($p<0.05$) but no statistical significance between the group's 6 months follow up.
Chan et al. (2013b)	Compliance to exercise programme developed by Chan e al, 2013, would improve with the assistance of a digital video disc for home use.	Same as Chan et al. (2013a) and Chan et al. (2014)	Uptake and compliance: 25% of the participants commenced the programme. 50% of the participants completed the programme. PRMDs: Significant reduction on PRMDs frequency and severity was reported post-intervention. Perceived exertion: No significant changes on RPE. There was moderate effect on strengthening muscles that supported playing while the least effect was ability to cope with stress. Participants reported moderate positive effect on performance.

Table 6.2: Exercise rationale, protocol and key findings (continued)

Author	Aim/Rationale	Specific exercise and prescription	Key findings
Ajidahun and Phillips (2013a)	Warm up exercise for musicians	Warm up exercise: Stretching, postural awareness, strengthening and conditioning The warm up exercise programme was suggested to last for 5-15 minutes. The prescription parameters were not reported.	The warm up exercise programme was focussed on stretching, postural awareness, strengthening and conditioning exercises of the muscles of the upper extremity and trunk
Cooper et al. (2012)	Physical intervention of easily performed stretches during rehearsals would reduce discomfort during performance	Wrist rotations, shoulder deltoid exercise and forward Oppositional finger-wrist press, hand/ finger extensions and fist clench and unclench Hand wringing, arms – bicep curls and shoulder – deltoid variation (ear to shoulder) Handshakes, arms – triceps extension and fingers clenched and unclenched All stretches were performed during rehearsals and the prescription was 4 sets, 4 times over 2 weeks	Intervention group reported significantly lower levels of discomfort (M=1.35) after rehearsals when compared with the control group.
Lee et al. (2012)	Yogic breathing exercises, strengthening and flexibility exercises would reduce injury and improve self-efficacy.	Upper chest, middle chest, lower chest and the complete chest Composite upper extremity stretch, pectoralis stretch Exercises for cervical retraction, resisted scapular retraction, resisted chest pull, pelvic clock All exercises were performed daily for a period of 20 minutes over 4 weeks.	The combined breathing and strengthening exercise showed increased physical efficacy awareness and comfort of posture and awareness of tension
Kava et al. (2010)	Endurance of the scapular and trunk muscles is necessary to support the workload of the distal upper extremity.	Biceps curl, reverse fly, lateral raise, triceps extension, shoulder forward flexion, bent over row, back extension, shoulder extension, opposite shoulder and hip extension, sit ups and push ups. Prescription: The prescription of each exercise was 15-20RM. All exercises were performed for a period of 13 weeks.	PRMDs: Increase in trunk endurance reduces fatigue and PRMDs Breath control: Improved breath control after exercise in both groups
De Greef et al. (2003)	The effect of specific exercises identifying the strong and weak points in playing, the position of the musician at rest and during performance, the coping with movement patterns and effort thereby developing a programme focussed on all the identified patterns (Groningen programme).	Groningen programme: the programme consisted of the following – Warm up and cool down, mobility exercises, strength and endurance exercises and specialised exercise specific to the demands of the musician. The programme was implemented over a period of 15 weeks. The specific exercise and the prescription parameters were not reported.	Musculoskeletal disorders: Decrease in musculoskeletal disorders Physical competence: Increased perceived physical competence Clinical relevance, moderate effect size (d=0.21)

Table 6.2: Exercise rationale, protocol and key findings (continued)

Author	Aim/Rationale	Specific exercise and prescription	Key findings
Ackermann et al. (2002b)	Resistance training would reduce exertion and reduce musculoskeletal injury.	Warm up and cool down (5 minutes). Strength and endurance exercise: Biceps curl, reverse fly, lateral raise, triceps extension, shoulder forward flexion, bent over row, back extension, shoulder extension, opposite shoulder and hip extension, sit ups and push ups. Prescription: Strength (6-8RM with Swill ball), endurance (25-30 RM). The duration of the exercise programme was 45 minutes and the implementation lasted for 6 weeks.	Perceived exertion: The endurance group had significant drop in RPE ratings. PRMDs: No significant difference in PRMDs after 6 weeks between the two groups.
Spahn et al. (2001)	Education on injury prevention would have a positive effect on psychological and physical health.	Health education Exercise: Posture exercises Exercises for foot, leg, pelvis, lower back, abdominal muscles and upper extremity Breathing exercises The prescription parameters were not reported.	PRMDs: Significant reduction in musculoskeletal injury in the test group Performance anxiety: Significant reduction in anxiety in both groups
Brandfonbrener (1997)	Strengthening and flexibility exercise and warm up would reduce musculoskeletal symptoms Education of the musicians on injury risk factors and importance of the exercise would improve cooperation.	Exercise Warm up and cool down Strengthening and flexibility exercises The specific exercises were not reported. The exercises were performed for a period of 15 minutes daily.	PRMDs: No significant difference in the musculoskeletal injury between experimental and the control group.

As shown in Table 6.2 above, warm up exercise were included as a part of the overall exercise intervention in four studies (Brandfonbrener, 1997, Ackermann et al., 2002b, De Greef et al., 2003, Chan et al., 2014). Only two studies reported on the specific warm up exercises done (De Greef et al., 2003, Chan et al., 2014). General physical activity was done as warm up prior to the specific exercises in the Groningen study (De Greef et al., 2003). Chan et al. (2014) included breathing exercises, large body movements, trunk rotations and stretching exercises as warm up exercises. McCrary et al. (2016) evaluated the effects of three different warm up protocols on perceived efficacy. Rated Perceived Exertion (RPE) was significantly decreased in the entire warm up protocols (core strengthening, cardiovascular training and shoulder strengthening) (McCrary, 2016). There were no significant difference in perceived exertion between the three groups of violinists (McCrary, 2016).

The specific exercises in the Groningen programme cannot be assessed, although the types of exercise prescribed were conditioning, strengthening, mobility, warm up and cool down and specialised exercises patterned according to the needs of the different instrumentalists (De Greef et al., 2003). The Groningen programme reported a decrease in musculoskeletal disorders and an increase in perceived physical competence (De Greef et al., 2003). Ackermann et al. (2002b) compared the effects of strength or endurance exercise on musculoskeletal injury among undergraduate music majors. Both strength and endurance exercise training programmes showed significant reduction in perceived exertion but there was no significant difference between the two groups in frequency and prevalence of musculoskeletal problems after six weeks (Ackermann et al., 2002b).

A comparison of trunk endurance exercise programme as well as shoulder strengthening programmes and Pilates on musical performance and musculoskeletal injuries showed that both groups had improved breath control as well as increased trunk endurance thereby reducing fatigue and musculoskeletal disorders (Kava et al., 2010). A recent exercise programme developed by Chan et al. (2014) for musicians irrespective of the instrument played was focussed more on improving neuromuscular control and proprioception of the shoulder and scapular region as well as strengthening the deep neck flexors and training of the core stabilisers (Chan et al., 2014). The exercise showed a significant reduction in musculoskeletal problems and perceived exertion in the intervention group ($p<0.05$) (Chan et al., 2014). Lee et al. (2012) incorporated yogic breathing exercises with strengthening and flexibility exercise and the two musicians showed an increase in physical efficacy and postural awareness.

The repetitive maximum of the core muscle exercises for the management of back pain was reported to be between 10 - 20 Repetitive Maximum (RM) (Kava et al., 2010, Chan et al., 2014, McCrary, 2016). Stretching exercises during rehearsal was reported to be done over four sets at rehearsals (4 times x 2 weeks) (Cooper et al., 2012). The repetitive maximum for trunk endurance exercise was 15-20 RM in the study by Kava et al. (2010); whereas, Ackermann et al. (2002b) reported repetitive maximum for endurance and strength training as 25-30 RM and 6-8 RM respectively. Chan et al. (2014) used progressive loading depending on the capacity of the musician. A warm up exercise was scheduled for 5-15 minutes in the Delphi study by Ajidahun and Phillips (2013a) and practiced for 5 minutes and 10 minutes in the studies by Brandfonbrener (1997) and McCrary (2016) respectively.

6.6. Discussion

The aim of this scoping review was to evaluate the components, prescription and implementation of exercise programmes utilised to manage playing health related problems among musicians. Literature has established that playing related health problems are associated with playing the musical instrument (Bragge et al., 2006, Moraes and Antunes, 2012). Exercise based interventions have been shown to reduce musculoskeletal problems and reduce perceived exertion (Brandfonbrener, 1997, Spahn et al., 2001, Ackermann et al., 2002b, De Greef et al., 2003, Kava et al., 2010, Cooper et al., 2012, Lee et al., 2012, Chan et al., 2013b, Chan et al., 2014, McCrary, 2016).

The focus of injury prevention programmes among musicians has shifted from primarily improving skills to a more holistic approach of physical conditioning as it relates to performance (Chan et al, 2013 and Chan et al, 2014). A holistic approach to understand the process and reduce musculoskeletal injuries among musicians is important (Brandfonbrener, 1997, Spahn et al., 2001, Ackermann et al., 2002b, De Greef et al., 2003, Kava et al., 2010, Cooper et al., 2012, Lee et al., 2012, Chan et al., 2013b, Chan et al., 2014, McCrary, 2016). Exercise programmes were mainly adapted from basic physiotherapeutic exercises to suit the target demands of the anatomic structures associated with playing a musical instrument (Brandfonbrener, 1997, Spahn et al., 2001, Ackermann et al., 2002b, De Greef et al., 2003, Kava et al., 2010, Cooper et al., 2012, Lee et al., 2012, Chan et al., 2013b, Chan et al., 2014, McCrary, 2016). Components of the exercise programme were focussed on the anatomic regions that have direct association with the demands of playing the musical instrument. From the study findings, these are mainly the neck, back and upper extremity.

a. Strength versus endurance versus core stabilisation training

The back is a commonly injured area among musicians (Leaver et al., 2011, Moraes and Antunes, 2012). Its integral role in stabilising posture might be a plausible cause (Granata and Wilson, 2001, Hammill et al., 2008). Strength training, endurance training and core stabilisation training as well as Pilates exercises were used differently in these studies to prevent or reduce injury in the back (Ackermann et al., 2002b, Kava et al., 2010, Lee et al., 2012, Chan et al., 2014). The prescribed exercises showed a reduction in the incidence of musculoskeletal problems (Ackermann et al., 2002b, Kava et al., 2010, Lee et al., 2012, Chan et al., 2014) . The review showed that neither strength training, endurance training nor core stabilisation training are effective in the management of musculoskeletal injury and none of the three exercises showed a significant advantage over each other. A comparison between strength and endurance training as well as endurance and Pilates training showed no significant difference, although the various exercise pattern showed a significant reduction in musculoskeletal injury (Ackermann et al., 2002b, Kava et al., 2010). Training of the core stabilisers with proprioceptive and neuromuscular control training of the back, neck and shoulder also showed a significant reduction in musculoskeletal injury (Chan et al., 2014). Strength or endurance or core stabilisation training showed no significant advantage over the other in reducing musculoskeletal problems (Kava et al., 2010). Each of the exercises – Pilates, strength training, endurance training and core stabilisation exercises have prophylactic effect by increasing strength and endurance of the global stabilisers and the local stabilisers respectively (Ackermann et al., 2002b, Kava et al., 2010). An improvement in strength and endurance as well as training of the core stabilisers has been reported to be associated with positive outcomes in rehabilitation and a reduction in the incidence of musculoskeletal injury generally (Abdelraouf and Abdel-aziem, 2016).

This implies that developing an exercise based injury prevention programme, either of the three exercises would achieve similar goal in injury prevention for musicians. However, stabilisation exercises would be more important in preventing low back pain in this population. Poor feed forward activation of the local stabilisers is a risk factor for back pain (Hammill et al., 2008) and maintaining spinal stability to reduce the onset of muscle fatigue and overuse injury can be achieved by training of the core stabilisers (Granata and Wilson, 2001). Therefore, in developing an injury prevention programme for string instrumentalists with low load muscle activity, training of the correct feed forward activation and general lumbar stabilisation training would have a prophylactic effect on performance related back pain.

b. Proprioception and neuromuscular control

In this study, only one study included neuromuscular control exercises as a component of their exercise programme(Chan et al., 2013a). Chan et al. (2013a) reported positive outcomes in their study which included neuromuscular control as well as strength and endurance training in their exercise programme for the management of PRMDs in professional orchestra. Recent exercise based injury prevention in sports and rehabilitation have included a more proprioceptive and neuromuscular control approach in their exercise based programme and positive results have been reported in the rehabilitation of musculoskeletal injuries (Steffen, 2013a, Steffen, 2013b, Schiftan et al., 2015). The positive outcomes would be due to feed forward activation training involved in neuromuscular control training (Van Vliet and Heneghan, 2006, Borghuis et al., 2008). The neural pathways are trained to anticipate movement for better control of joint movement. The feed forward activation has been suggested to be important in the preventing and rehabilitation of musculoskeletal injury (Van Vliet and Heneghan, 2006)

Neuromuscular control is an important component in the acquisition of skills in string playing (Baader et al., 2005, Konczak et al., 2009). Musculoskeletal dysfunction has been associated with altered neuromuscular control (Rathleff et al., 2013, Terada et al., 2014). This suggests that, altered neuromuscular control due to musculoskeletal dysfunction would result in an altered skill control required for optimal performance. It would be important to include neuromuscular control exercises in an exercise based injury prevention programme for string instrumentalists.

c. Stretching

In this study, stretching exercise showed positive outcomes in the two intervention studies that utilized flexibility training as part of their exercise programme (Cooper et al., 2012, Lee et al., 2012). The role of stretching pre-activity in injury prevention is unclear (Shrier, 1999, Weldon and Hill, 2003, Small et al., 2008). However, muscle stretching has been hypothesized to increase muscle compliance which results in the extensibility of the muscle that leads to a reduction in muscle force (Witvrouw et al., 2004). Cooper et al (2012) was the only study that evaluated the role of exercises specifically in string instrumentalists. In as much as the prophylactic effect of stretching exercises is unclear, stretching of the shoulder and forearm muscles during breaks at practice significantly reduced discomfort and perceived exertion among string instrumentalists (Cooper et al., 2012). This suggests that in string instrumentalists, stretching exercises could be effective in reducing perceived exertion and discomfort.

d. Education

In this study, education on risk factors reduced performance anxiety but the inclusion of specific exercises reduced incidence of musculoskeletal injuries as well as well reduce performance anxiety (Spahn et al., 2002). This shows that physical conditioning of the musician as well as education on injury mechanism could be effective in reducing the risk of musculoskeletal injury when compared to health education alone. Health promotion programmes with an understanding of the mechanism of injury and the risk factors has been shown to reduce musculoskeletal injury (Cherkin et al., 2001, Wand et al., 2004) as well as improve compliance (Van Poppel et al., 2004).

e. Implementation and compliance

Chan et al. (2013b), further evaluated compliance to the exercise programme among professional orchestra members and they reported that compliance was poor and participants with poor compliance reported a higher incidence of musculoskeletal injury. Compliance with exercise programme in the management of musculoskeletal dysfunction is a challenge in rehabilitation (Dorflinger et al., 2013, Bennell et al., 2014). High adherence to exercise programmes shows reduction in the incidence of musculoskeletal injury and improvements in outcome measures (Steffen, 2013a, Steffen, 2013b). Adequate communication with the patient about the importance and its role in injury management and objective self-report measures would improve compliance and subsequently reduce the incidence of musculoskeletal injury, improve function and reduce pain (Dorflinger et al., 2013, Bollen et al., 2014).

In implementing an exercise based injury prevention programme for string instrumentalists, it would be important to consider compliance and adherence to the programme. Exploring the opinion of musicians on possible implementation strategies would be important in attaining optimal effect of an exercise programme in the prevention of PRMDs among musicians.

In conclusion, the scoping review showed that exercise plays a role in the prevention and management of PRMDs as it reduces musculoskeletal problems and perceived exertion. The focus of the exercises used in the studies was mainly to strengthen the muscles in the region with a high prevalence of musculoskeletal injuries which are the back, neck and shoulder regions. The anatomical and physiological demands of performance vary across various instruments and prescribing the same exercise might not achieve an optimal result. The physical demands of holding the various instruments varies, therefore, exercises need to be patterned per the specific demand and performance parameters of each instrument.

Developing a broad exercise programme might not be as effective as developing a specific instrument based exercise programme.

The recommendations for exercise development for musicians should:

- Explore adapting strength, endurance, stretching and stabilisation exercises as preventive measures for PRMDs would be effective.
- Incorporate health promotion and education on the specific effect of the exercise programme on the body structure and performance.
- Explore the opinion of musicians on possible implementation strategies in order to ensure adherence and compliance.

6.7. Summary of chapter

This chapter explored exercise based intervention for musculoskeletal problems among musicians. The components of the exercise were focussed on motor control, strengthening, endurance training and stretching of the muscles of the upper extremity and trunk. Implementation strategies to ensure compliance and programme uptake needs to be explored. The exercise development process was conducted in two phases, 1) extraction of reproducible exercise programmes from WRMDs management and 2) integration of the exercise programme with the demands of playing the string instrument. The next chapter is focussed on Phase 1 of the exercise development process.

CHAPTER SEVEN

7. EXERCISES FOR WORK RELATED MUSCULOSKELETAL DISORDERS (WRMDS) – A SCOPING REVIEW

7.1. Introduction to chapter

This chapter is a scoping review of literature on exercise based management of work related musculoskeletal disorders in the general population. The aim of the chapter is to review the component and structure of existing exercises with the objective of adapting the exercises for string instrumentalists. The background, aim, objectives, methodology, results and the discussion of the scoping review are presented in this chapter.

7.2. Introduction

Work related musculoskeletal problem is common in the general population and it is usually caused by the physical and psychological demands of the job (Punnett et al., 2005, Karsh, 2006). The theory of work related musculoskeletal disorders by Karsh (2006) explained the interaction between the physical and psychological demands of the work as it relates to WRMDs. The theory postulated that an imbalance between dose and exposure would predispose the worker to musculoskeletal problems (Karsh, 2006). Psychological demands would likewise increase anxiety which has been associated with musculoskeletal injuries (Van Kemenade et al., 1995, Fehm and Schmidt, 2006, Hoberg, 2008, Burin and Osório, 2016).

Preventative measures such as ergonomic, postural education and health promotion have been implemented in several work populations for musculoskeletal problems (Schonstein et al., 2003, Schaafsma et al., 2010, Rota et al., 2011, Schaafsma et al., 2011, Schaafsma et al., 2013, Mayer et al., 2015). The effect of exercise therapy alone and in combination with other risk factors has shown significant reduction work related outcome measures such as pain, disability and return to work (Oesch et al., 2010, Schaafsma et al., 2010, Schaafsma et al., 2011, Schaafsma et al., 2013). Predisposing factors to PRMDs among musicians are synonymous to the risk factors for other WRMDs (Bragge et al., 2006). The postural demands of playing a string instrument as well as repetitive movement predisposes the musician to injuries of the upper extremity, neck and back (Bragge et al., 2006, Moraes and Antunes, 2012, Rickert et al., 2012).

Exercise intervention in the management and prevention of PRMDS among musicians has been utilized in several studies (Ackermann et al., 2002b, Cooper et al., 2012, Chan et al., 2014). Only two studies developed a holistic exercise intervention utilizing the injury mechanism and demands of performance as a guideline in the prevention and management of musculoskeletal problems in musicians generally (Ackermann et al., 2002b, Chan et al., 2014). Exercise intervention in these studies was adapted from existing physiotherapeutic exercises and the intervention has shown positive outcomes in the management of PRMDs (Ackermann et al., 2002b, Cooper et al., 2012, Chan et al., 2014). Different instrument groups have different demands on the body structure and the physical demands vary as well as varying anatomic distribution of PRMDs (Bragge et al., 2006, Furuya et al., 2006, Yoshimura et al., 2008, Allsop and Ackland, 2010). It would be imperative to consider the specific physical demands of playing in the development of injury prevention exercise programmes. Therefore, the aim of this study is to extract reproducible exercise programme that has been used in the management and prevention of WRMDs to develop a specific exercise programme for string instrumentalists.

7.3. Aim and objectives of the study

The aim of this phase of the study was to extract specific exercise programmes used in the prevention/or rehabilitation of work related musculoskeletal problems. The objective of this study was to:

- To extract specific reproducible exercise programme that have been used to prevent/manage work related musculoskeletal problems

7.4. Methodology

The methodology of the scoping review followed the protocol developed by Arksey and O'Malley (2005). Figure 7.1 below shows the outline of the five steps of the scoping review methodology.

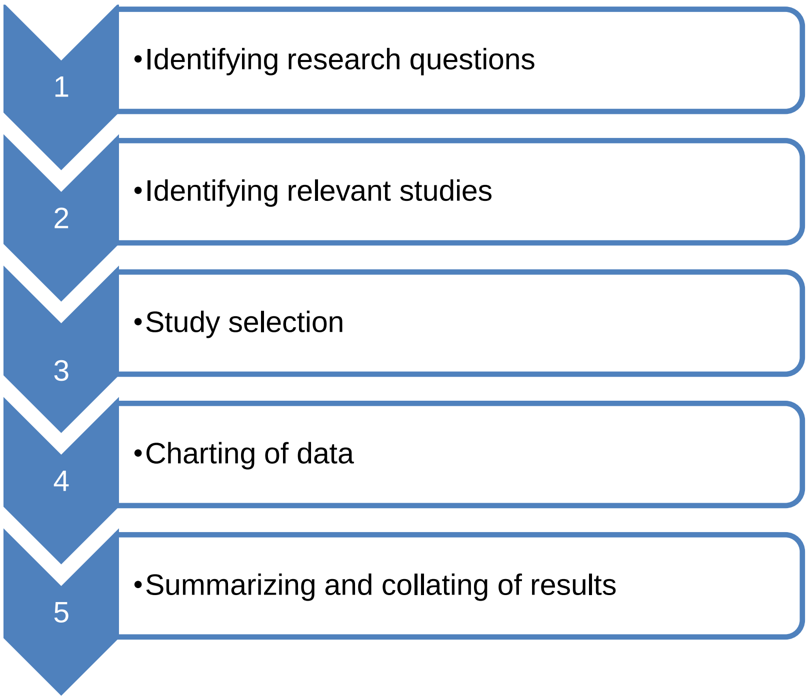


Figure 7.1: Stepwise methodology of the scoping review process (Arksey and O'Malley, 2005).

7.4.1. Research question

The research question for this scoping review was based on the exercise prescription guidelines of the American College of Sports Medicine (2014). The specific research questions are:

- What specific exercise programmes have been used to prevent/or manage work related musculoskeletal problems?
- What are the exercise prescription parameters?

The research objectives of the scoping review were:

- To evaluate the content and structure of an exercise based injury prevention programme for the management of WRMDs.
- To extract specific reproducible exercise programme that have been used to prevent/manage work related musculoskeletal problems

7.4.2. Identifying relevant studies

7.4.2.1. Search strategy

The following databases – Physiotherapy Evidence Database (PEDro), MEDLINE via PubMed, Cumulative Index to Nursing and Allied Health Literature (CINAHL), the Cochrane Controlled Trials Register in the Cochrane Library, Physiotherapy Evidence Database (PEDro), ProQuest 5000 International, ProQuest Health and Medical Complete, EBSCO MegaFile Premier, Science Direct and SCOPUS were searched.

The following search terms were used in various combinations using the Boolean search strategy: “injury” OR “pain” AND “neck” AND “work” AND “exercise”,, “injury” OR “pain” AND “back” AND “work” AND “exercise”,, “injury” OR “pain” AND “elbow” AND “work” AND “exercise”,, “injury” OR “pain” AND “trunk” AND “work” AND “exercise”,, “injury” OR “pain” AND “trunk” AND “work” AND “exercise”,, “injury” OR “pain” AND “hand” AND “work” AND “exercise”,, “injury” OR “pain” AND “shoulder” AND “work” AND “exercise”, “impingement” AND “exercise”.

7.4.2.2. Eligibility criteria

Work related disorders in this study were defined by the list developed by the European SALTSA panel outlined in Table 7.1 (Sluiter et al., 2001, Aptel et al., 2002). The diagnosis was used as part of the search terms. Specific anatomic regions that have been reported in literature to be affected by playing a musical instrument such as the back were also included.

Table 7.1: List of 12 Work related musculoskeletal disorders in the upper limb

WRMD-UL diagnosis
Neck pain with referred pain
Rotator cuff syndrome
Medial and lateral epicondylitis
Ulnar nerve entrapment in the cubital tunnel
Radial tunnel syndrome
Flexor and extensor tendinitis in the hand and fingers
De Quervain tenosynovitis
Carpal tunnel syndrome
Ulnar nerve entrapment
Raynaud’s phenomenon
Osteoarthritis
Nonspecific MSD-UL

The inclusion and exclusion criteria for the studies were as follows:

a. Types of participants

This scoping review included all studies done on participants that were managed for WRMDs. The studies included all participants irrespective of age and gender. Studies done where participants had exercise for systemic diseases or traumatic musculoskeletal problems were not included. Studies with participants that were involved in a physical activity based intervention study were also excluded.

b. Phenomena of interest

Reproducible exercise programmes for the management of WRMDs were included in the scoping review. All other forms of exercise intervention were excluded from the scoping review. Studies from all countries were considered in this scoping review to get a global view of exercise intervention strategies in the prevention of PRMDs.

c. Types of Outcomes

Studies looking at exercise programme for WRMDs and any related exercise prescription and the implementation strategies used were included in this scoping review.

d. Types of sources

This scoping review considered both systematic reviews and experimental study designs including randomised controlled trials, non-randomised controlled trials, quasi-experimental studies, before and after studies for inclusion. Only peer-reviewed studies were included in the scoping review.

7.4.3. Study selection

A total of 4334 articles were identified from the literature search. 563 articles were identified from the title and abstract. 310 duplicates were removed. Of the 253 articles left, 74 articles were included in this scoping review. This included 23 systematic review articles and 55 experimental articles. The flowchart of the study selection process is outlined in Figure 7.2 below.

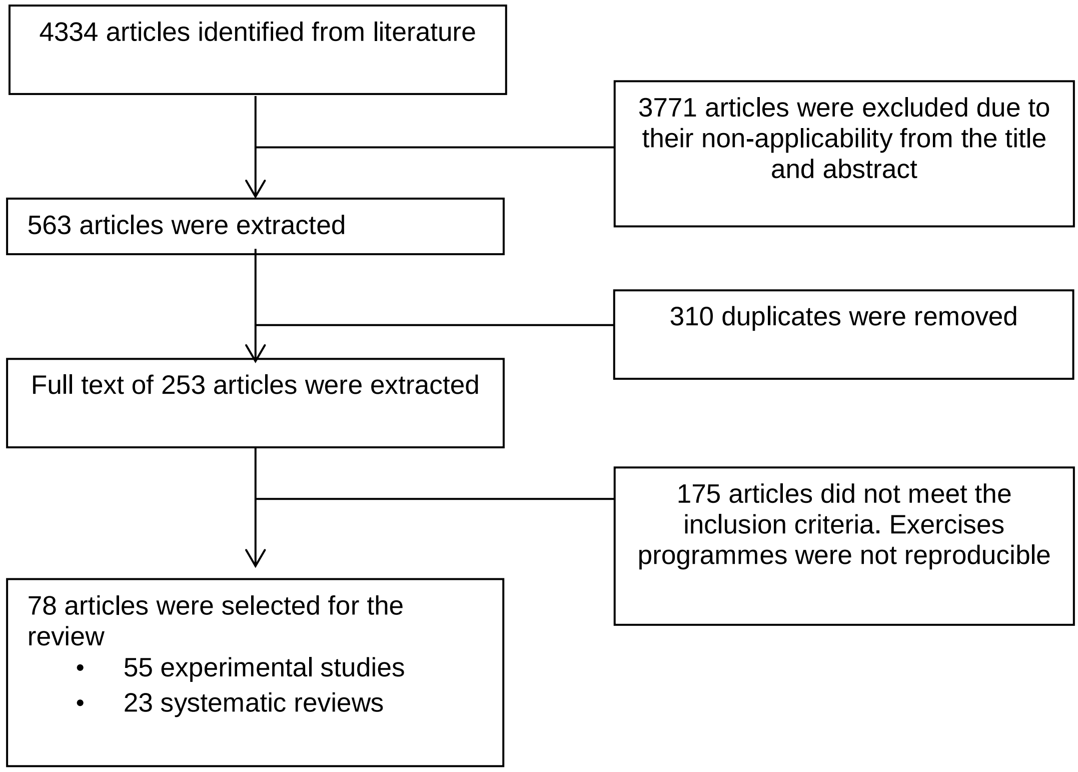


Figure 7.2: Flowchart of the study selection process

7.5. Results

The purpose of a scoping review is not primarily to assess the quality of the studies but to identify the key concepts and state of knowledge on a particular issue (Arksey and O'Malley, 2005, Levac et al., 2010). In this study, the focus was on identifying exercises that were pertinent to work related musculoskeletal problems. The rationale for this was that the theoretical basis of the predisposing risk factors for PRMDs is synonymous with work related musculoskeletal problems (Bragge et al., 2006).

The demographics of the population studied, intervention, outcome measures, methodology and the key outcomes of the exercise programmes were extracted by using the evidence based medicine framework for the retrieval of information in intervention studies (Huang et al., 2006, Boudin et al., 2010). The extracted information is charted in Tables 7.2 – 7.8.

7.5.1. Characteristics of the included studies

The characteristics of the included studies are extracted according to the type of studies. The results are presented in the following order – systematic review studies and intervention studies (shoulder, cervical, forearm/wrist, non-specific upper extremity and lumbo-pelvic region).

7.5.1.1. Systematic review studies

Table 7.2 outlines the characteristics of the systematic review studies which include the population, intervention, conditions and the key outcome of the review.

Table 7.2: Characteristics and the key outcomes of the systematic review studies

Reference	Aim	Population	Intervention	Studies included	Meta analysis	Key outcomes of the individual studies
Peters et al. (2016)	A review of current prevention interventions for tendinopathy was conducted	Studies focussed on the prevention of tendinopathy in the in the ankle, knee, hip, groin, shoulder or elbow were included.	Stretching, shoe adaptations & hormone replacement therapy	10	No	None of the individual studies showed significant positive results. The study recommended that the preventive mechanism of stretching exercises should be further explored.
Gross et al. (2016)	Long term effect of exercise therapy on pain, disability, patient satisfaction, QoL in adults with neck pain was reviewed.	Randomized controlled trials with the aim of determining the effectiveness of exercises to a control in the management of neck pain were included.	General exercise therapy	27	Yes	Strengthening + endurance /stretching exercise showed positive moderate evidence in the management of chronic neck pain and cervico-genic headache.
Saragiotto et al. (2016)	The effectiveness of motor control exercises in patients with chronic NSLBP was reviewed	Randomized controlled trials with the aim of determining the effectiveness of motor control exercises on NSLBP were included	Motor control exercises	29	Yes	Quality of evidence of the included studies was generally low. Motor control exercises showed little or no clinical significance in the reduction of pain and disability.
Schaafsma et al. (2013)	An evaluation of the effectiveness of physical conditioning to improve work outcomes among workers with back pain was the aim of the study	Randomized controlled trials with the aim of the determining the effectiveness of physical conditioning programmes among workers were included in the study.	Physical conditioning exercises	25	Yes	Quality of evidence of the included studies was low. Intense physical conditioning was shown to probably reduce the duration of sick leave slightly when compared with usual care at 12 months follow up. The quality of evidence was moderate.
Hoogvliet et al. (2013)	The effectiveness of exercise therapy and mobilisation techniques for both medial and lateral epicondylitis was the aim of the review.	Studies focussed on determining the effectiveness of exercise therapy + mobilisation in the management of epicondylitis was included.	Exercise therapy and mobilisation	12	No	Stretching + strengthening exercises showed positive moderate evidence in the treatment of lateral epicondylitis in comparison to ultrasound + massage.
van den Dolder et al. (2012)	The effectiveness of exercise & soft tissue massage for the treatment of non-specific shoulder problems	Studies focused on the effectiveness of soft tissue massage and or exercise for nonspecific shoulder pain were included	Soft tissue massage and exercise	23	Yes	High dose strengthening exercise regimen was more effective than low dose exercise regimen in improving function and pain in the treatment of non-specific shoulder pain.
Schaafsma et al. (2011)	To assess the effect of physical conditioning programs on time lost from work among patients with back pain compared to no or alternative interventions.	Randomized controlled trials with the aim of evaluation the effect of physical conditioning on time lost from workers with work related back pain were included	Physical conditioning exercises	23	Yes	Physical conditioning was more effective in decreasing time off work among patients sub-acute and chronic back pain. The results of the meta-analysis showed that the effect of physical conditioning programs in reducing sick leave for workers with back pain is uncertain.
Sihawong et al. (2011)	The effectiveness of various types of exercise for the management of neck pain among workers was the study aim.	RCTs with the aim of determining the effectiveness of exercise for the management of neck pain in office workers were included.	Exercise therapy	9	No	There was strong evidence to support the positive outcomes strength and endurance exercises in the management of neck pain among office workers. There was moderate evidence to support the use of muscle endurance exercises for reducing disability attributed to neck pain in office workers.

Table 7.2: Characteristics and the key outcomes of the systematic review studies (continued)

Reference	Aim	Population	Intervention	Studies included	Meta analysis	Key outcomes of the individual studies
Van Middelkoop et al. (2011)	This reviewed was aimed at determining the effectiveness of physical and rehabilitation interventions for CLBP	RCTs with the aim of evaluation of rehabilitation interventions with adults were included.	Exercise therapy, back schools, conventional physiotherapy and multidisciplinary rehabilitation.	83	No	Exercise therapy reduced pain intensity and disability significantly compared to usual care. Multidisciplinary treatment was found to be more effective in reducing pain intensity compared to no treatment and singular mode of active treatments.
van Middelkoop et al. (2010)	The aim of the study was to evaluate the effectiveness of exercise in patients with LBP.	RCT studies that compared exercises with other treatment options were included.	Exercise therapy	37	Yes	Exercise therapy seems to be effective for the prevention of low back pain (LBP), but only few recent trials are conducted. This therapy is not effective for acute LBP, whereas it is effective for chronic LBP
Oesch et al. (2010)	A comparative effectiveness of exercise therapy versus the usual care on work disability in patients with back pain was the aim of the study.	RCTs with the aim of determining the effectiveness of exercise and usual care on low back pain were included.	Exercise therapy Usual care	23	Yes	The result of the study showed that exercise showed improvement on the long term on work disability for non-acute nonspecific low back pain (NSLBP).
Bell and Burnett (2009)	The effectiveness of exercise on LBP and disability was the aim of the study.	Studies with the aim of evaluate the effects of exercise on back pain and or disability in the workplace were included	Strength, stretching and/or cardiovascular exercises	15	No	The result of the study showed that various exercises were used to prevent LBP and conclusion could not be drawn in the effectiveness of the programs. Specific exercises to specific work demands with adequate dosages should be explored in further trials.
Woodley et al. (2007)	The aim of the study was to determine the effectiveness of eccentric exercises in the treatment of common tendinopathies.	RCTs with the aim of evaluating the use of eccentric exercises to treat tendinopathies were included.	Eccentric exercise	11	No	The results of the study showed that evidence to support the effect of eccentric exercise over other modalities in the management of chronic tendinopathy is limited.
Rackwitz et al. (2006)	The aim of the study was to evaluate the effectiveness of segmental stabilisation exercises on LBP and return to work.	RCTs with the aim of effectiveness of segmental stabilisation exercises on LBP with adults were included.	Segmental stabilisation exercises (SSE)	7	No	The results of the study showed that: There was no significant difference in the outcome in acute LBP treated with SSE or GP Chronic LBP treatment showed that SSE was more effective than general practitioner (GP) treatment.
Ferreira et al. (2006)	The aim of this study was to determine the effects of specific stabilisation exercise (SSE) on spinal or pelvic pain	RCTs evaluating the effects of stabilisation exercises for spinal pain were included.	Specific stabilisation exercise (SSE)	12	No	The results of the review showed that SSE was effective in reducing pain and disability in chronic low back but not in acute low back pain.
Hayden et al. (2005)	The aim of the study was to determine the effectiveness of exercise therapy in adults with NSLBP.	Studies evaluating the effects of exercise on NSLBP were included	Exercise therapy	61	Yes	The results of the study showed that exercise has no effect in the management of acute LBP. Patient specific designed strength and stabilisation programs were effective in the management of chronic LBP.

Table 7.2: Characteristics and the key outcomes of the systematic review studies (continued)

Reference	Aim	Population	Intervention	Studies included	Meta analysis	Key outcomes of the individual studies
Rainville et al. (2004)	The aim of the study was to evaluate the effects of exercise in the management of chronic back pain.	Studies evaluating the effects of exercise in the rehabilitation of back pain were included.	Exercise therapy	15	No	The results of this study showed that regular exercise showed moderate evidence in decreasing the risk of further damage and improve function.
Sarig-Bahat (2003)	The aim of the study was to determine the effects of exercises in the treatment of mechanical neck pain in adults.	Studies evaluating the effects of exercise on mechanical neck disorder in adults were included.	Exercise therapy	17	No	The results of the showed that dynamic strengthening exercises and proprioceptive neuromuscular facilitation (PNF) was effective in the management of mechanical neck disorders.
Schonstein et al. (2003)	The aim of the study was to determine the effect of physical conditioning on time lost in workers with back and neck pain.	Studies evaluating the effect of physical conditioning programmes on neck pain were included.	Physical conditioning	21	No	The results of this study suggest that specific exercises are less effective in reducing days lost at work than physical conditioning oriented programs.
Linton and van Tulder (2001)	The aim of the study was to evaluate preventive interventions for neck and back problems.	Studies evaluating the effect of preventive measures on back and neck pain were included.	Lumbar supports, back schools, education, exercises, ergonomics, risk factor modification Modification	20	No	The results of this study showed consistent evidence that exercises prevent neck and back pain; however, the effect of exercise in comparison to other interventions is not consistent. A bio-psychosocial model to injury prevention model evaluating risk factors and tailored program to the individual and work demands was suggested.
Van Tulder et al. (2000)	The aim of this study was to evaluate the effectiveness of exercise therapy on pain and disability in workers with LBP.	RCT studies with the aim of determining the effect of exercise in adults with NSLBP were included	Exercise therapy	39	No	The results of this study showed that there was strong evidence for the effect of exercise therapy in the management of nonspecific low back pain (NSLBP) than usual care.
Scheer et al. (1995),	The aim of the study was to determine the efficacy of various treatments for acute LBP of disc origin.	Studies focussed on the management of discogenic LBP were included for the review	Bed rest, exercise, back school, case management methods, manipulation	10	No	The results of this study showed that exercise programmes were often used with other modalities and this makes efficacy difficult. However, exercise was shown to have to effect on return to work in acute low back pain (LBP). Spinal flexion and extension, strengthening of the lumbar and abdominals and aerobic exercises were mainly prescribed.
Scheer et al. (1997)	The aim of the study was to evaluate the effectiveness of interventions on return to work of sub-acute and chronic LBP patients.	RCT studies evaluating the effectiveness of interventions on sub-acute and chronic LBP were included for review	Exercise therapy Cognitive and behavioural strategies	9	No	The result of the study showed that interventions showed no clear effectiveness in return to work among workers.

Population

A total of 23 systematic review articles were included in this scoping review as outlined in Table 7.2 above. Of the 23 systematic reviews included in this study, 14 studies were focussed on intervention of exercise in the rehabilitation of musculoskeletal problems in the back (Scheer et al., 1995, Scheer et al., 1997, Van Tulder et al., 2000, Linton and van Tulder, 2001, Hayden et al., 2005, Ferreira et al., 2006, Rackwitz et al., 2006, Bell and Burnett, 2009, Oesch et al., 2010, van Middelkoop et al., 2010, Schaafsma et al., 2011, Van Middelkoop et al., 2011, Schaafsma et al., 2013, Saragiotto et al., 2016), four studies in the upper extremity (Woodley et al., 2007, van den Dolder et al., 2012, Hoogvliet et al., 2013, Peters et al., 2016) and four in the neck (Sarig-Bahat, 2003, Schonstein et al., 2003, Sihawong et al., 2011, Gross et al., 2016).

Intervention

Only four studies reviewed the effects of exercises in the prevention of WRMDs in the upper extremity and trunk (Linton and van Tulder, 2001, Bell and Burnett, 2009, van Middelkoop et al., 2010, Peters et al., 2016). In the upper extremity, stretching exercises showed no significant positive result in the prevention of tendinopathy in the upper extremity and lower limb (Peters et al., 2016). In the back, exercise therapy was reported to be effective in the prevention of low back pain and effective in the treatment of chronic low back pain (van Middelkoop et al., 2010). The study by Linton and van Tulder (2001) showed positive outcomes of exercise in the prevention neck and back pains but the effect of exercise in comparison to other intervention was not consistent. Bell and Burnett (2009) concluded that various exercises were used to prevent low back pain but the effectiveness of the programs was uncertain.

Key outcomes

Of the four studies that evaluated the effectiveness of exercises in the management of neck pain, three studies showed that a combination of strengthening and endurance exercises (Sihawong et al., 2011, Gross et al., 2016) or strengthening and PNF exercises (Sarig-Bahat, 2003) showed moderate positive evidence on pain. Schonstein et al. (2003) in their study showed that physical conditioning was more effective in reducing time loss at work in workers with neck pain. In the low back, physical conditioning (Schaafsma et al., 2011, Schaafsma et al., 2013), exercise therapy (Van Tulder et al., 2000, Rackwitz et al., 2006, Oesch et al., 2010, Van Middelkoop et al., 2011), specific stabilisation therapy (Hayden et al., 2005, Ferreira et al., 2006) showed moderate positive evidence in the treatment of chronic back pain. Two studies showed no positive outcomes of exercise in the outcomes measured – acute back pain and return to work (Scheer et al., 1995, Scheer et al., 1997).

The characteristics of the intervention studies for cervical and shoulder region are outlined in section 7.5.1.2 below.

7.5.1.2. Intervention studies

The characteristics of the intervention studies for the cervical and shoulder region, lumbar, forearm and wrists are extracted. The extracted information includes - the population, intervention, conditions and the key outcome of the studies.

a. Intervention studies for cervical and shoulder region.

The characteristics of the experimental studies focussed on the cervical and shoulder region as well as the exercises utilized are reported in this section.

Characteristics of the intervention studies in the cervical and shoulder region

Table 7.3 below presents the results of the population, intervention, condition and key outcome of the studies reviewed in the cervical and shoulder region.

Table 7.3: Characteristics and key outcomes of exercise interventions in the cervical and shoulder region.

Reference	Aim	Method	Population	Intervention	Control	Outcome measures	Key outcomes
Sihawong et al. (2013)	To evaluate effects of exercise programme on neck pain	Cluster RCT	Office workers (N=567) Intervention group Age: 37.2 (10.1) years Gender (f%): 47.6 Control group Age: 36.9 (10.7) years Gender (f%): 52.4	Stretching and endurance training	Advise on physical activity	Pain – Visual Analogue Scale (VAS) Disability – Neck disability Index (NDI) Quality of life – SF-36	There was a 55% reduction in the incidence of neck pain among office workers in the intervention group. The exercise programme showed no effect on pain intensity, disability, quality of life and health status.
Andersen et al. (2012)	To investigate how strength training for neck and shoulder muscles is most effective.	RCT	Office workers (N=447) 1WS: Age: 47(10), Gender, f/m: 72/44 3WS: Age: 46(10), Gender, f/m: 87/39 9WS: Age: 45 (10), Gender, f/m: 61/45 Reference: Age: 46(10), Gender, f/m: 59/42	Strength training 1WS – 1 hr per week 3WS – 20 min, 3 times per week 9WS – 7 min, 9 times per week	No intervention	Neck and shoulder pain intensity Disability – DASH Muscle strength Adherence	Specific strength training reduced pain. There was no significant difference between the times. 3WS showed a higher reduction in pain in the neck and shoulder. Adherence: 1WS had lower adherence 9WS had a slower increase in training load progression.
Engebretsen et al. (2011)	To evaluate the effect of shockwave therapy and supervised exercises on sub-acromial pain.	RCT	Patients with sub-acromial pain (N=104) Group A Age: 49 (9.3) years Gender(f/m): 26/26 Group B Age: 47 (11.7) years Gender(f/m): 26/26	I - Supervised exercises (strength) II - Radial Extracorporeal Shock-Wave Therapy	NA	Pain: VAS Disability: Shoulder Pain and Disability Index (SPADI)	There was no significant difference in pain and function between the two treatment groups after one year. Both treatments showed significant improvement. More patients in the supervised exercise group had returned to work.
Blangsted et al. (2008)	To evaluate two different worksite intervention on neck and shoulder problems	RCT	Office workers with neck pain (N=549) Specific resistance training (SRT): Age: 47.3 (9.3) years Gender (f/m): 126/54 All round physical exercise Age: 43.1 (9.5) years	Specific resistance training All round physical exercise	Education on health promotion	Musculoskeletal symptoms – Nordic Musculoskeletal Questionnaire (NMQ) Perceived work ability – work ability index	Both interventions showed significant reduction in the duration and intensity of neck and shoulder symptoms. SRT was more effective in preventing the development of neck-shoulder symptoms than physical exercise in asymptomatic individuals.
Tunwattanapong et al. (2016)	To determine the effectiveness of stretching exercise on neck pain	RCT	Office workers (N=96) Treatment group Age: 34.2 (9.0) years Gender (f): 91.7% Control group Age: 36.5 (8.7) years Gender (f): 89.6%	Stretching exercises	Brochure on ergonomics was made available to the control group	Pain: VAS Disability: Northwick Park Neck Pain Questionnaire (NPNPQ) Quality of life: SF-36	Stretching exercises significantly reduced neck pain and increased function in office workers with moderate to severe pain.

Table 7.3: Characteristics and key outcomes of exercise interventions in the cervical and shoulder region (continued).

Reference	Aim	Method	Population	Intervention	Control	Outcome measures	Key outcomes
Ylinen et al. (2007)	To compare the effects of stretching exercise vs manual therapy in chronic neck pain management	RCT	Women with non-specific neck pain (N=125) Group A Age: 42 (9) years Group B Age: 44 (8)	Group A: manual therapy Group B: stretching exercises	NA	Pain: VAS	Both showed significant reduction in pain. There was no significant difference in the effect of both treatment measures.
Bae et al. (2011)	To determine the effect of an exercise therapy intervention on the management of shoulder impingement syndrome	RCT	Patient with shoulder impingement (N=35) Experimental: Age: 49.9 (5.5) years Gender (f/m): 11/6 Control: Age: 48.3 (4.3) years Gender (f/m): 12/6	Motor control and strengthening exercises	Conservative physiotherapy	Disability: SPADI Muscle strength	There was a significant pain reduction in the experimental group when compared with the control group.
Bernhardsson et al. (2011)	To evaluate the effect of specific strength exercise on pain and function in patients with sub-acromial impingement syndrome.	Non RCT	N=10 Age: 54 (8.6) Gender (F/M): 6/5	Experimental: Eccentric strength training of the rotator cuffs	NA	Pain: VAS Function: Patient-Specific Functional Scale (PSFS) Western Ontario Rotator cuff index.	There was clinical and statistical reduction in pain intensity in 8/10 subjects Clinical and statistical reduction in pain intensity in 8/10 subjects.
Borstad et al. (2009)	The aim of this study was to evaluate work related factors for shoulder pain as well as to determine the effect of home exercises on the onset of shoulder pain.	Non RCT	Construction apprentices (N=208). Experimental group: Age: 27.0(6.4) years Control group: Age: 26.5 (5.9) years	Stretching & strengthening exercises	No intervention	Pain: VAS Shoulder impingement tests	There was small increased relative risk for new onset of shoulder pain in the control group.
Ludewig and Borstad (2003)	The aim of this study was to evaluate the effect of an exercise programme on pain and shoulder function.	RCT	Male construction workers Experimental: Age: 48 (1.8) years Symptomatic control: Age 49.2 (1.8) years Asymptomatic control: Age: 49.4 (2.5) years	Stretch, relaxation and strengthening exercises	No intervention	Pain: shoulder rating questionnaire Disability: shoulder pain and disability index	Exercise for shoulder pain in construction workers was effective in preventing shoulder disorders in this population.
Hagberg et al. (2000)	The aim of the study was to compare the effects of isometric shoulder endurance exercises with isometric strength training exercises on exertion and shoulder function.	RCT	Isometric shoulder strength Age: 37.6 (9.9) years Isometric endurance training Age: 39.8 (7.6) years All the subjects are female	Isometric shoulder strength Isometric endurance training	NA	Pain and perceived exertion: VAS and Borg Rating of Perceived Exertion Scale	Isometric shoulder strength training was more effective in improving strength, but the differences between the two types of training were not great

Table 7.3: Characteristics and key outcomes of exercise intervention s in the cervical and shoulder region (continued).

Reference	Aim	Method	Population	Intervention	Control	Outcome measures	Key outcomes
Bang and Deyle (2000)	To compare the effectiveness of 2 physical therapy treatment approaches for impingement syndrome of the shoulder	RCT	Manual therapy + exercise group: Age: 42(10.1) years Gender (F/M): 10/18 Exercise group: Age: 45 (8.4) years Gender: 12/12	Group 1: Manual therapy + exercise (endurance and strength) Group 2: Exercise (endurance and strength)	NA	Shoulder function: Functional assessment questionnaire Pain: VAS Isometric strength: Stabilized electronic dynamometer	The manual therapy and exercise group showed a better significant improvement in pain, strength and function with patients with sub-acromial impingement.
(Abdel-aziem and Draz, 2016)	To investigate the efficacy of deep neck flexor exercises in the management of neck pain.	RCT	Age: Group 1: 48.5 (7.82) years Group 2: 47.90 (6.79) years Group 3: 50.10 (4.71) years Gender: NR	Group 1: Physical therapy agents (PTA) Group 2: PTA + isometric stretching Group 3: PTA + deep neck flexor exercise	NA	Pain: VAS Disability: NDI Range of motion	There was a significant reduction in neck pain in all the three groups. At follow, improvement was maintained only in Group 3. Group 3 maintained
LeePark and Kim (2013)	To examine the effects of deep flexor muscle-strengthening exercise on the neck-shoulder posture, and the strength and endurance of the deep flexor muscles.	RCT	High school students (N = 30) All aged 17 years All participants are female	Deep flexor muscle-strengthening exercise	Neck–shoulder stretching exercises	Head tilt angle, neck flexion angle, forward shoulder angle and cranio-cervical flexion test	There was significant increase in strength and endurance of the deep neck flexors.
Ma et al. (2011)	To compare the effects of biofeedback with those of active exercise and passive treatment in treating work-related neck and shoulder pain.	RCT	Biofeedback group Age: 31.3 (8.6) years Gender (f/m): 10/5 Active exercise Age: 34.2 (10.3) years Gender (f/m): 11/4 Passive exercise Age: 35.3 (9.4) years Gender (f/m): 10/5 Control group Age: 30.0 (10.3) years Gender (f/m): 9/6	Biofeedback group Active exercise (strength and stretch) Passive exercise (inferential therapy)	NA	Pain – VAS Disability – NDI Muscle activity EMG	EMG showed significant reductions in Cervical erector spinae (CES) muscle activity but insignificant average reductions in the Upper trapezius (UT) muscles. Biofeedback produced general relaxation of the UT. All the intervention improved NDI and muscle activity. More favourable long term outcomes from biofeedback training compared with conventional therapies.
Dusunceli et al. (2009)	To determine the efficacy of neck stabilisation exercises in the management of neck pain.	RCT	Group I: Age: 53.8(6.8) years, Gender (f/m): 12/8 Group II: Age: 52.5 (5.80) years, Gender (f/m): 14/6 Group III: Age: 50.2 (4.8) years, Gender (f/m): 14/6	Group I – Physical therapy agents (PTA) Group II – PTA +isometric stretch exercise Group III – PTA + neck stabilisation exercise	NA	Pain: VAS Disability: NDI	All the groups showed significantly reduction in pain and disability. The improvement was only maintained in Group III Outcomes improved significantly in all the groups but it was maintained only in group III.

Table 7.3: Characteristics and key outcomes of exercise intervention s in the cervical and shoulder region (continued).

Reference	Aim	Method	Population	Intervention	Control	Outcome measures	Key outcomes
Kadi et al. (2000), Waling et al. (2002) & Waling et al. (2000) Ahlgren et al. (2001)	To examine the effects of training on the structural characteristics of the trapezius muscle in women with work-related trapezius myalgia	RCT	Strength: Age: 38 (6) years Endurance: Age: 38.5 (5.6) years Coordination: Age: 37.6 (6) years. All participants were females	Group I: strength exercises Group II: endurance training Group III: coordination training	NA	Muscle biopsy	Strength training induced an increase in proportion of Type IIA fibres Different training methods have similar effect on myalgia pain
Ahn et al. (2015)	To compared the effects on neck-shoulder pain and mobility of strengthening exercises for the neck flexors and scapular retractors performed on a Swiss ball and a mat	RCT	Swiss ball: Age: 21.8(1.1) years Gender (f/m): 8/2 Mat exercise: Age: 21.8 (1.9) years Gender (f/m): 8/2	Swiss Ball group: Strengthening exercises for the neck flexors and scapular retractors Mat exercise group: Strengthening exercises for the neck flexors and scapular retractors,	NA	Pain: VAS Craniocervical (CV) angle	Pain was significantly reduced and increased neck flexion for stabilisation exercises in the Swiss ball group when compared with the mat group.
Zebis et al. (2014)	To determine the time-wise effect of specific resistance training on neck pain among industrial technicians with frequent neck pain symptoms.	RCT	Experimental Age: 42 (11) Control Age: 43 (10) years	Strengthening exercises	Patients were advised on physical activity	Pain: VAS Training load and adherence : logbook	Specific strength training reduced neck pain among female industrial workers Adherence was highest during the 1st seven weeks of training and decreased drastically after the 10th week
de Amorim et al. (2014)	To assess the effectiveness of global postural re-education (GPR) relative to segmental exercise (SE) in the treatment of scapular dyskinesia associated with neck pain	Clinical trial	Global postural reduction group: Age: 40 (11.2) years Gender (f/m): 10/5 Stretching group: Age: 36.4 (12.6) years Gender (f/m): 11/4	Global postural reduction (GPR) Stretching exercise (SE)	NA	Neck and upper extremity function: NDI and DASH Pain: VAS HQoL: SF 12	Both GPR and the SE improved function and pain and quality of life in patients with neck pain + scapular dyskinesis.
Andersen (2008)	The aim of this study was to determine the effectiveness of Specific strength training (SST) of the painful muscle versus general fitness training (GFT) on work-related neck muscle pain.	RCT	Specific strength group: Age: 44 (9) years General fitness group: Age: 45 (9) years REF: Age: 42 (8) years	SST – high intensity strength training GFT – High intensity general fitness training	Reference group	Pain: VAS	SST and GFT showed significant improvement in neck muscle pain in employed women. Although, SST showed a marked decrease in pain over prolonged training period
Häkkinen et al. (2008)	To compare the effectiveness a home-based combined strength training and stretching programme against stretching alone in the treatment of chronic neck pain.	RCT	Patients with chronic neck pain Stretching group Age: 40 (10) years Gender, f: 44 Strength + stretch Age: 41 (9) years; Gender, f: 47	Group I: stretching only Group II: strength and stretching	NA	Neck pain and disability	Both groups showed significant improvement in outcomes measured

Population

As outlined in Table 7.3 above, a total 25 studies evaluated the effectiveness of exercises alone or with other physiotherapeutic modalities in the management of work related musculoskeletal problems in the cervical and shoulder region. The age range of the participants was 17-53.8 years. Of the 25 studies, eight studies were focussed on the management of pain and dysfunction in the neck (Ylinen et al., 2007, Andersen, 2008, Häkkinen et al., 2008, Dusunceli et al., 2009, Sihawong et al., 2013, Zebis et al., 2014, Abdel-aziem and Draz, 2016, Tunwattanapong et al., 2016), six studies were focussed on the management of shoulder dysfunction (Bang and Deyle, 2000, Ludewig and Borstad, 2003, Borstad et al., 2009, Bae et al., 2011, Bernhardsson et al., 2011, Engebretsen et al., 2011) and eleven studies were focussed on the management of both neck and shoulder dysfunction (Hagberg et al., 2000, Kadi et al., 2000, Waling et al., 2000, Ahlgren et al., 2001, Waling et al., 2002, Blangsted et al., 2008, Ma et al., 2011, Andersen et al., 2012, LeePark and Kim, 2013, de Amorim et al., 2014, Ahn et al., 2015).

Intervention

Specific exercises utilized in rehabilitation were mainly strength and endurance exercises (Bang and Deyle, 2000, Hagberg et al., 2000, Kadi et al., 2000, Waling et al., 2000, Ahlgren et al., 2001, Waling et al., 2002, Blangsted et al., 2008, Sihawong et al., 2013), strength training (Andersen, 2008, Häkkinen et al., 2008, Bernhardsson et al., 2011, Engebretsen et al., 2011, Andersen et al., 2012, Zebis et al., 2014, Ahn et al., 2015), stretching exercises (Ylinen et al., 2007, Häkkinen et al., 2008, Dusunceli et al., 2009, de Amorim et al., 2014, Abdel-aziem and Draz, 2016, Tunwattanapong et al., 2016), motor control and strengthening exercises (Bae et al., 2011), stretching and strengthening exercises (Ludewig and Borstad, 2003, Borstad et al., 2009, Ma et al., 2011), deep neck flexor training (LeePark and Kim, 2013, Abdel-aziem and Draz, 2016), neck stabilisation exercises (Dusunceli et al., 2009).

Key outcomes

Stretching exercises with endurance exercises and specific resistance training showed positive outcomes in the prevention and treatment of neck and shoulder pain (Ludewig and Borstad, 2003, Blangsted et al., 2008, Häkkinen et al., 2008, Borstad et al., 2009, Sihawong et al., 2013). Stretching exercises and stretching with postural education improved function and pain reduction in neck and shoulder dysfunction (de Amorim et al., 2014, Tunwattanapong et al., 2016). Ylinen et al. (2007), in their randomized controlled trial study reported that both stretching exercise and manual therapy showed significant effect in the reduction of pain in the neck and there was no significant difference between the two treatments. Stabilisation exercises of the deep neck flexors showed positive outcomes in the management of neck pain, with improvement maintained at follow-up (Dusunceli et al., 2009, Ahn et al., 2015, Abdel-aziem and Draz, 2016). Both isometric strength and endurance training improved outcomes of pain and perceived exertion in women with neck and shoulder pain (Hagberg et al., 2000). Manual therapy with strength and endurance training showed better significant result in the management of pain and function with sub acromial impingement (Bang and Deyle, 2000). Strength and endurance of the deep neck flexors showed positive outcomes in comparison to stretching exercises on neck-shoulder posture among high school students (LeePark and Kim, 2013). Biofeedback as well as active and passive exercises reduced disability in comparison to conventional therapies (Ma et al., 2011). High intensity strength training of painful muscles showed significant positive outcomes over a prolonged training period (Andersen, 2008). Motor control exercises showed not superior advantage over strengthening exercises on pain in shoulder impingement syndrome dysfunction (Bae et al., 2011). Eccentric strength training showed both clinical and statistical reduction in pain in patients with impingement syndrome (Bernhardsson et al., 2011).

Extracted intervention exercise for cervical and shoulder dysfunction

The specific extracted exercises grouped according to strength, endurance, stretching and stabilisation exercises are outlined in Table 7.4 below.

Table 7.4: Extracted exercises for the cervical and shoulder regions

Strength exercises		
Specific exercise	**Prescription parameters**	**References**
Serratus anterior muscle, humeral external rotation	Progressive strength training 3 sets, 10-20RM for 3 weeks	Ludewig and Borstad (2003)
Push up plus exercise for the serratus anterior, humeral external rotation for the infraspinatus and teres minor using elastic bands	Progressive strength training 3 sets, 10-20 RM daily	Borstad et al. (2009)
Strengthening for the rotator cuff.	Not reported	Bang and Deyle (2000), Engebretsen et al. (2011)
Specific resistance training with dumbbells – shoulder extension, abduction, abduction (supraspinatus) and shoulder lift. Static neck exercises in sitting – strap positioned around the head, forward and sideways movement resisting the inelastic strap. Rowing was done with the aid of ergometers (10 all out bout, 15-30 seconds)	2-3 sets, 10-15 RM Load: 50% of maximum load	Blangsted et al. (2008)
Front raise, lateral raise, reverse fly, shrugs, wrist extensor exercise with dumbbells. Over rows, flyers and pull overs	Progressive loading: Onset – 15 RM (70% maximal intensity) Later – 8-12RM (75 – 85% maximal intensity	Zebis et al. (2014) (Andersen et al., 2012, Dalager et al., 2015) Andersen et al. (2011) Häkkinen et al. (2008) Andersen (2008)
Strength with machine – arm ergometer	12 RM	(Ahlgren et al., 2001) (Waling et al., 2000) (Waling et al., 2002) Kadi et al. (2000)
Exercise for the upper trapezius	Isometric shoulder strength: 5 seconds and 10 contractions	Hagberg et al. (2000)
Resisted shoulder elevation exercises with Thera-band, active lumbar flexion (hug the knees), active lumbar extension, active movements of the neck ROM, shoulder stretching exercises, horizontal adduction stretch.	5-8 RM	Ma et al. (2011)
Shoulder rotation in 2 planes with elastic tubing, ulnar and radial deviation of the wrist using sledgehammers, eccentric training of the wrist extensors using a Thera-band, wrist flexion and extension, flexion of the hand using a hand gripper, extension of the hand and fingers.	20 RM and later 8 RM	Sundstrup et al. (2014)
Endurance exercises		
Specific exercise	**Prescription parameters**	**References**
Longus capitis, longus colli, rectus capitis anterior and lateralis	Repeat contraction 10 times	(Abdel-aziem and Draz, 2016)
Exercise for upper trapezius	Isometric endurance: 4 times with 2 minutes rest in between and 3 times for 12 weeks	Hagberg et al. (2000)
Endurance with machine	12 RM	Ahlgren et al. (2001), Waling et al. (2000) Waling et al. (2002)
Endurance exercises of the neck flexors (20seconds)	3 sets	Horneij et al. (2001)
Endurance exercises for shoulder muscles	10 times (3 sets)	Horneij et al. (2001)

Table 7.4: Extracted exercises for the cervical and shoulder regions (continued)

Stabilisation, postural education and motor control		
Specific exercise	**Prescription parameters**	**References**
Inter-scapular, shoulder and UE – unilateral arm raises, reciprocal arm raises and bilateral arm raises	10-15 RM	Dusunceli et al. (2009)
Strengthening exercises of the scapular retractors	10 RM hold for 10 seconds	Ahn et al. (2015)
Scapular stabilizing exercises: Shoulder shrug and scapular retraction exercises	Not reported	Bernhardsson et al. (2011)
Neck straightening exercise	5 times for 3-5 seconds	Häkkinen et al. (2007)
Flexibility exercises		
Specific exercise	**Prescription parameters**	**References**
Upper trapezius, levator scapulae, pectoralis and capitis posterior	Hold each muscle in stretched position for 30s twice for each workday.	Sihawong et al. (2013)
Deep neck flexors, scapular muscles, shoulder and cervical	Hold for 10 seconds and repeat 10 times	Abdel-aziem and Draz (2016)
Stretching towards lateral flexion for the upper part of the trapezius, ipsi-lateral flexion and rotation for the scalene and flexion for the extensor muscles	Hold each movement for 30 seconds and repeat 3 times.	Ylinen et al. (2007)
Upper trapezius towards lateral flexion, ipsilateral flexion and rotation (scalene) and towards flexion (extensor muscles)	30 seconds and repeated 2-3 times.	Häkkinen et al. (2007)
Posterior and anterior muscle chain Segmental stretching exercises	Once a week for 10 weeks	de Amorim et al. (2014)
Cervical, shoulder, chest and scapular muscles	Not reported	Dusunceli et al. (2009)
Pectoralis minor, posterior shoulder stretch	Hold each muscle for 30s / repetition and 5RM each day.	Ludewig and Borstad (2003)
Stretching of the upper trapezius	3 sets 15 RM twice a day	Bernhardsson et al. (2011)
Neck stretching, shoulder stretching, shoulder rolling, trunk stretching and back extension	20–30 repetitions/ session	Tunwattanapong et al. (2016)
Posterior shoulder stretch, upper trapezius and pectoralis major (5 times/day)	5 times per day	Borstad et al. (2009)
Anterior shoulder musculature and posterior shoulder musculature	Not reported	Bang and Deyle (2000)
Stretching of the pectoralis muscles, rectus femoris, hamstring and iliopsoas muscles	Hold for 20-30 seconds	Horneij et al. (2001)

Table 7.4 above outlines the extracted exercises used as intervention in the management of musculoskeletal problems in the cervical and shoulder region. Strengthening, endurance, stretching and stabilisation exercises were mainly used as intervention. The prescription of the exercises was mainly progressive resistance strength and endurance training.

b. Intervention studies for forearm and wrist region.

The characteristics of the experimental studies focussed on the forearm and wrist region as well as the exercises utilized are reported in this section

Characteristics of the intervention studies in the forearm and wrist region

Table 7.5 below shows the results of the characteristics of the included studies in the forearm and wrist which includes the population, intervention, condition and key outcome of the studies reviewed.

Table 7.5: Characteristics and key outcomes of exercise interventions in the forearm and wrist region

Reference	Aim	Method	Population	Intervention	Control	Outcome measures	Key outcomes
Drechsler et al. (1997)	To compare two treatment techniques for tennis elbow	RCT	Patients with tennis elbow (N=18) Age: 46 Gender: 10 females and 8 males	Neural tension group: Neural mobilisation (ULTT IIb) Standard treatment group: Stretching and strengthening exercises	NA	Pain: Strength: Hand dynamometer	No significant difference in outcomes between the two groups Both treatment protocols improved the outcomes.
Khamwong et al. (2011)	To understand the preventative effects of PNF stretching on exercise induced muscle damage.	RCT	Experimental: Age: 20.5 (0.9) years Control: Age: 21.1 (1.6) years	PNF		Pain – VAS Upper extremity ROM Thermal pain threshold – cold pain threshold	This study showed that PNF stretching prior to exercise can reduce the symptoms of muscle damage, especially pain threshold, ROM, and muscle strength
Wen et al. (2011)	To compare the effect of exercise in the treatment of chronic lateral epicondylosis.	Prospective randomized study	Patients with chronic lateral epicondylosis. Experimental: Age: 48 (9) years Gender (f/m): 5/9 Control: Age: 43.9 (4.7) years Gender (f/m): 8/6	Eccentric exercise training	Local modality treatments, iontophoresis, ultrasound	Pain: Grip strength:	The experimental group showed significant pain reduction but overall grip strength showed no significant difference between the groups.
Stasinopoulos et al. (2010)	To compare the effects of a home exercise programme and a supervised exercise programme for the treatment of lateral elbow tendinopathy	RCT	Patients with lateral elbow tendinopathy Home exercise Age: 44.38 (5.39) years Gender (f/m): 19/16 Supervised exercise Age: 45.72 (6.21) years Gender (f/m): 18/17	Home and supervised exercise programme Exercise programme was the same for both groups (Slow progressive eccentric exercises of the wrist extensors and static stretching exercises of the ECRB tendon)	NA	Pain and function: VAS Grip strength: Jamar hand dynamometer	Exercise programme was effective in managing lateral elbow tendinopathy. Supervised exercise programme was more effective than home programmes.
Martinez-Silvestrini et al. (2005)	To evaluate the effectiveness of eccentric strengthening	RCT	Stretch group Age: 43.1 years Concentric group Age: 47 years Eccentric group 46.6 years	Stretching + conservative therapy Stretching + concentric strengthening Stretching + eccentric strengthening	NA	PFG, VAS, PRFEQ and DASH	Eccentric strengthening for the wrist extensors in subjects with lateral epicondylitis demonstrated improvement at six weeks
Pienimäki et al. (1996)	To test the effect of active exercise programme in the treatment of chronic epicondylitis.	RCT	Exercise group: Age: 43(33-53) years, Gender: 12/8 Ultrasound group: Age: 41(31-53) years, Gender: 13/6	Progressive stretching and strengthening exercises Pulsed ultrasound therapy	NA	Pain Grip strength Isokinetic torque	Significant improvement in pain arm function and muscular performance when compared with pulsed ultrasound in patients with chronic lateral epicondylitis

Table 7.5: Characteristics and key outcomes of exercise interventions in the forearm and wrist region (continued)

Reference	Aim	Method	Population	Intervention	Control	Outcome measures	Key outcomes
Dalager et al. (2015)	To determine the effect of one weekly hour of specific strength training on compliance, muscle health and performance	Cluster RCT	Group 1(1WS): Age: 46.5(10.2) years Gender (f): 62% Group 2 (3WS) Age: 46.5 (10.5) years Gender (f): 69% Group 3 (9WS) Age: 45.4 (9.7) years Gender (f): 58% Group 4 (3MS) Age: 45.1 (10.7) years Gender (f): 58% Reference group Age: 45.6 (10.0) years Gender (f): 58%	Strength training Group 1: One supervision, 60 minutes training per week Group 2: 3 supervision, 20 min training per week Group 3: Nine supervision, 7 minutes training session Group 4: 3 minimal supervision, 20 minutes training session	NA	Compliance: training diary Musculoskeletal outcomes Self-efficacy Muscle performance test: Maximal muscle strength and strength endurance	Different strength training schedules in terms of different training frequency and session duration showed similar results regarding compliance and the effects on the health, behaviour and performance outcomes
Rota et al. (2011), Mongini et al. (2012)	To evaluate the effectiveness of an educational and physical program, neck and shoulder pain in a working community.	Workplace controlled trial	Female office workers (N=308). Group I (registry office) Age: 48 (43-53) years Gender, f: 150 Group II (tax office) Age: 44 (36-50) years Gender, f: 158	Group I & Group II Posture and relaxation exercises + visual feedback to monitor excessive contraction	NA	Frequency of symptoms	The data show the effectiveness of our cognitive program in reducing the burden of physical and psychological complaints in a large, working population.
Horneij et al. (2001)	To compare the effects of two different intervention programmes in working home-care personnel on neck, shoulder and back pain.	Prospective randomized trial	Home-care personnel Individual physical exercise: Age: 43(24-62) years Stress management: Age: 45 (23-62) years Control: 44(27-60) years	Individual physical exercise: Balance, endurance, stretching, functional exercises and cardiovascular exercises		Musculoskeletal disorders – NMQ Perceived pain – NMQ Perceived exertion – Borg scale	That neither the IT nor the SM programme made an impact on neck, shoulder or back pain could be shown unequivocally
Jakobsen et al. (2015a) Jakobsen et al. (2015b)	To compare the effect of physical exercise at work or home on musculoskeletal pain	Cluster RCT	Female health workers (N=200) Home: Age: 44(10) years Work: Age: 40(12) years	Both groups performed strength training, brief ergonomic training and education	NA	Perceived exertion, Pain	Healthcare workers allocated to the workplace exercise group significant reduction in pain intensity and exertion from baseline to follow up.
Sundstrup et al. (2014)	To compare conventional ergonomic training and resistance training on pain	RCT	Slaughterhouse workers (N=66) Gender: NR Resistance training: Age: 48 (9) years Ergonomic training: Age: 43 (9) years	Resistance training Ergonomic training	NA	Pain – VAS Work disability – DASH	There was clinical significant improvement in pain and disability after 10 weeks in the group that had resistance training.

As outlined in Table 7.5, thirteen studies evaluated the effectiveness of exercises in the management of WRMDs in the upper extremity. The age range of the participants in the studies was 21.1-48 years. Of the thirteen studies, five studies was focussed on determining the effect of exercise therapy in the management of tendinopathy in the upper extremity (Pienimäki et al., 1996, Drechsler et al., 1997, Martinez-Silvestrini et al., 2005, Stasinopoulos et al., 2010, Wen et al., 2011) and one study was focused on determining the prophylactic effects of PNF on muscle damage (Khamwong et al., 2011). Intervention studies in seven studies were focussed on the upper extremity, neck and trunk as whole.

A comparison of neural mobilisation with stretching and strengthening exercises in the management of lateral epicondylitis, both treatment techniques showed positive outcomes (Drechsler et al., 1997). The prophylactic effect of PNF on exercise induced muscle damage reduced muscle damage symptoms (Khamwong et al., 2011). Strength training showed significant positive outcomes in the management of lateral epicondylitis (Pienimäki et al., 1996, Drechsler et al., 1997, Martinez-Silvestrini et al., 2005, Stasinopoulos et al., 2010, Wen et al., 2011).

Extracted interventions exercise for forearm and wrist region

The specific extracted exercises grouped according to strength, endurance, stretching and neural mobilisation exercises are outlined in Table 7.6 below.

Table 7.6: Extracted exercises for the forearm and wrist

Stretch		
Specific exercise	**Prescription parameters**	**References**
Wrist extensors	Hold stretch at the end for 30 seconds, Maximal forearm pronation and ulnar deviation 5-10 repetitions hold for 30s	Pienimäki et al. (1996), Drechsler et al. (1997)
	Hold stretch for 6-8 seconds	Wen et al. (2011)
	Stretch held for 30-45 seconds	Stasinopoulos et al. (2010)
Strength		
Specific exercise	**Prescription parameters**	**References**
Wrist extensors	Graduated strengthening exercise 3 sets 12-15 repetitions with dumbbells	Pienimäki et al. (1996), Wen et al. (2011) Stasinopoulos et al. (2010), Drechsler et al. (1997)
Neural mobilisation	Neural mobilisation (ULTT IIb)	Drechsler et al. (1997)

Table 7.6 above outlines the extracted exercises used as intervention in the management of musculoskeletal problems in the forearm and wrist. Strengthening, stretching and neural mobilisation exercises were used as intervention.

c. Intervention studies for lumbar region.

The characteristics of the experimental studies focussed on the lumbar region as well as the exercises utilized are reported in this section

Characteristics of the intervention studies in the lumbar region

Table 7.7 below shows the results of the characteristics of the included studies in the lumbar region which includes the population, intervention, condition and key outcome of the studies reviewed.

Table 7.7: Characteristics and key outcomes of exercise interventions in the lumbar region

Reference	Aim	Method	Population	Intervention	Control	Outcome measures	Key outcomes
Inani and Selkar (2013)	To compare the effect of core stabilisation exercises and conventional exercises in NSLBP	RCT	Patients with NSLBP N=30 Age: 20-50 years Gender: 10 females, 20 males	Group A Stabilisation exercises Group B Conventional exercises Both groups had SWD and intermittent lumbar traction	NA	Pain: Visual Analogue Scale (VAS) Functional status: Modified Oswestry Disability Index (ODI) scale	Core stabilisation exercises showed significant improvement in pain, disability and functional status in the patients when compared to conventional exercises.
Dettori et al. (1995)	To determine the effects of spinal exercises on acute low back pain	RCT	Army personnel with acute LBP (N=149) Group I: Age: 28.6 years Gender, %m: 84.2 Group II: Age: 30.6 years Gender, %m: 77.4 Group III: Age: 26.1 years Gender, %m: 80	Group A: flexion exercises Group B: extension exercises	Prone lying + ice pack	Self-reported pain Straight Leg Raise (SLR): Spinal mobility with a flexible tape	Outcomes did not significantly differ in all the three groups. At 1 week, SLR and functional ability improved in the exercise groups.
Chen et al. (2014)	The aim of the study was to determine the effectiveness of a stretching exercise program (SEP) on LBP	RCT	Nurses (N=127) Experimental Age: 30.67 (4.45) years Control Age: 37.70 (8.88) years	Experimental Stretch exercise programme (SEP) and core muscle training	Usual activity	Self-efficacy and pain	The results of this study showed that the reduction of VAS scores was significant in the experimental group at the second, fourth, and sixth months, in comparison with the control group, indicating that the SEP can significantly reduce the level of LBP in nurses.
Park et al. (2013)	To investigate the effects of a Nintendo Wii exercise program on chronic work-related LBP compared with stability exercise	RCT	Lumbar stabilisation Age: 43.37 (5.42) years Nintendo Wii exercise (NEW) Age: 44.1 (5.48) years Control group Age: 45.5 (5.34) years	Lumbar stabilisation group: Physical therapy modalities + lumbar stabilisation Nintendo Wii exercise: Physical therapy modalities + Nintendo Wii exercise	Physical therapy modalities	Pain: VAS Back strength: Balance ability:	Exercise programmes significantly improved physical function related LBP NWE showed significant improvement in physical and mental composite of the quality of life.
Stankovic et al. (2012)	To determine the effect of stabilisation exercise on back muscles.	RCT	Experimental Age: 49.5 (11.8) years Gender(f/m): 60/40 Control Age: 49.5 (12.4) years Gender (f/m): 37/23	Stabilisation exercises	Traditional Regan-Michelle's protocol	Pain: ADL: SF-36 Disability: ODI	Stabilisation program with specific individual aerobic exercise showed positive effects in function and pain in the management of chronic low back pain.
Pillastrini et al. (2009)	To determine the effectiveness of an extension exercise program in the prevention and management of LB/neck pain.	Cluster randomized trial	Nursery school teachers Experimental: Age: 44.7 ± 7.4 years Control: Age: 43.5 ± 7.9 years	Strengthening exercises and stabilisation exercises	NR	RMDQ ODI LBP Neck pain	A six session extension-oriented exercise program, conducted in the occupational setting, can be decisive in the prevention and management of low back and neck complaints and in reducing consequent LBP functional disability among nursery school teachers, as assessed at a two month follow-up.

Table 7.7: Characteristics and key outcomes of exercise interventions in the lumbar region (continued)

Reference	Aim	Method	Population	Intervention	Control	Outcome measures	Key outcomes
Søgaard et al. (2012)	The aim of the study was to assess the effects of exercises on changes in muscle activation, oxygenation and pain of the upper trapezius.	RCT	General fitness training: Age: 45.5 (8) years Specific strength training: Age: 44.6 (8.5) years Control (reference): Age: 42.5 (11.1) years All the participants were females.	General fitness training: Specific strength training:	Health counselling regarding to workplace ergonomics, diet, health, stress management and relaxation	Pain: Visual analogue scale Muscle activity: EMG and MMG Perceived exertion: Borg scale Tissue oxygenation: Near infrared spectroscopy Blood pressure	Pain was decreased in the GFT group during repetitive work. The SST reduced the overall pain during rest and at work probably due to reduced load.
Nassif et al. (2011)	The aim of this study was to evaluate a specific workplace intervention for the management of chronic lower back pain.	RCT	Male automotive employees (N=32) Experimental: Age: 45.13 (9.1) years Gender (n): 21 Control: Age: 45.3 (8.8) Gender (n): 11	Experimental: Physical therapy and physical exercise programme (strengthening, flexibility, cardiovascular and PNF).	No direct intervention	Pain: NPS and Dallas pain questionnaire Disability: Quebec back pain disability, Roland Morris Low back pain and disability questionnaire Kinesiophobia: Tampa scale for kinesiophobia	Intervention showed positive results in the experimental group in all the outcomes measured.
Muthukrishnan et al. (2010)	The aim of the study was to examine the differential effect of core stability exercise training and conventional physiotherapy regime on altered postural control parameters in patients with chronic low back pain	RCT	Group I – conventional physiotherapy + back ergonomic advice Group II – core stabilisation exercises + ergonomic advice	Group I – conventional physiotherapy + back ergonomic advice Group II – core stabilisation exercises + ergonomic advice Traction and interferential therapy was also administered in both groups	NA	Disability: RMDQ Fear: FABQ Pain: VAS	Both treatment methods showed significant improvement on pain and disability. There was no significant difference between the improvements in the both groups.
Hagen et al. (2010)	The aim of the study was to determine the effects of a standardised physical exercise programme on return to work in patients with back pain.	RCT	Intervention: Age: 40.7 (10.5) years Gender (f/m): 65/59 Control Age: 41.6 (11.0) years Gender (f/m): 61/61	Intervention: standardised physical exercise programme (warm up, stretch exercises, circuit training and relaxation exercises) + brief intervention	Brief intervention Brief intervention – education on how to cope with back pain and activities of daily living.	Pain: NPRS Self-reported disability: Roland Morris Questionnaire FABQ	Both groups showed improvements in the outcome measures. Note: both groups showed increased frequency in physical activity
Harts et al. (2008)	The aim of the study was to investigate the effectiveness of dynamic extension exercise programs on LBP.	RCT	Group I Age: 44(10) years Group II Age: 42(10) years Group III Age: 41(9) years	Strengthening programme (I &II) Group I – High intensity training Group II – Low intensity training Group III – Waiting list	NA	Disability – Roland Morris Disability Questionnaire QoL – Sf-36	Initial significant different between the HIT* and the LIT but the difference disappeared after 16 weeks.

Table 7.7: Characteristics and key outcomes of exercise interventions in the lumbar region (continued)

Reference	Aim	Method	Population	Intervention	Control	Outcome measures	Key outcomes
Yang et al. (2010)	The aim of the study was to assess the effect of back school + core strengthening exercises in the treatment of patients with low back pain.	Single centre prospect ive trial	Patients with low back pain All subjects (N=227) Age: 54.1 (22.3) years Gender (f/m): 104/38	Intervention: Back school + core strengthening exercises	NA	Physical disability: ODQ Pain: Brief pain inventory	Intervention was effective in reducing back specific disabilities and pain
Helmhout et al. (2008)	The aim of the study was to evaluate the effectiveness of specific lumbar extensor training compared with regular physical therapy (PT) in workers with nonspecific non-acute low back pain (LBP)	RCT	Group I Group II	I – lumbar extensor strength training II – conventional physiotherapy	NA	Function – RMDQ Pain – Visual analogue scale	No significant difference was found between the two treatment programmes.
Browder et al. (2007)	To examine the effectiveness of an extension-oriented treatment approach in the management of back pain.	RCT	All subjects (48) Age: 39 (10.2) years Gender %f: 31.3	Experimental group: exercise + mobilisation to promote extension	Strengthening exercises	Self-report measures – ODQ, NPRS and FABQ	EOTA subjects showed significant improvement in disability than the control group.
Ljunggren et al. (1997)	The aim of the study was to compare the effects of two different exercise programmes on LBP patients.	Compar ative study	Experimental: Age: 39.0(10.4) years Gender (F/M): 34/28, Control: Age: 40.2 (9.5) years Gender (F/M): 22/42	Experimental: TerapiMaster – a device for general exercise (strengthening exercises)	Conventional physiotherapy exercises (strengthening exercises)		No significant difference on the outcomes of back pain between the two groups
Dettori et al. (1995)	The aim of the study was to evaluate the effect of back training programme in the prevention back pain.	RCT	Group I Age: 28.6 years Gender, %m: 84.2 Group II Age: 30.6 years Gender, %m: 77.4 Group III Age: 26.1 years Gender, %m: 80	Group I – flexion exercises Group II – extension exercises Group III – Control (prone lying + ice pack)	NA	Self-reported pain Spinal mobility with a flexible tape Straight Leg Raise (SLR)	Outcomes did not significantly differ in all the three groups. At 1 week, SLR and functional ability improved in the exercise groups.
Gundewall et al. (1993)	To evaluate the effects of back training programme in the prevention of back pain.	RCT	Hospital employees Experimental group Age: 37.7 (11.1) years Control group Age: 37.3 (9.9) years	Strength and endurance exercise program for the back	No intervention	Pain Muscle strength	Back muscle strength increased in the experimental group Exercise programme was effective back pain and also reduce the intensity of back pain.

As outlined in Table 7.7 above, seventeen studies were included in the study. Of the 24 studies, Fifteen studies were identified from literature that utilized exercises only or in conjunction with other intervention modalities such as physical therapy agents, education, ergonomics and back school in the management of back pain (Gundewall et al., 1993, Dettori et al., 1995, Ljunggren et al., 1997, Browder et al., 2007, Andersen, 2008, Harts et al., 2008, Helmhout et al., 2008, Hagen et al., 2010, Muthukrishnan et al., 2010, Yang et al., 2010, Søgaard et al., 2012, Stankovic et al., 2012, Inani and Selkar, 2013, Chen et al., 2014, Zebis et al., 2014). The rationale of the exercise intervention was mainly to strengthen the weak muscles of the lumbar extensors, core stabilisation exercises of the stabilisers and stretching exercises. Two studies compared the effect of strength training with varying intensity (Harts et al., 2008) and comparing conventional exercises with the use of equipment (Ljunggren et al., 1997). Ten studies used exercise based intervention solely in the management of back pain (Gundewall et al., 1993, Dettori et al., 1995, Ljunggren et al., 1997, Harts et al., 2008, Helmhout et al., 2008, Hagen et al., 2010, Søgaard et al., 2012, Stankovic et al., 2012, Inani and Selkar, 2013, Chen et al., 2014) while the five studies additionally included conventional physiotherapeutic interventions as part of the intervention (Browder et al., 2007, Muthukrishnan et al., 2010, Yang et al., 2010, Nassif et al., 2011, Park et al., 2013). Strength and endurance training of the lumbar extensors was the sole intervention in five studies while core stabilisation exercises were the sole component of the intervention in two studies. The other studies reported the use of flexibility, strengthening, endurance and core stabilisation exercises in various combination. The mean age range of the participants in these studies was 27.6 – 54.1 years.

Extracted interventions exercise for the lumbar region

The specific extracted exercises grouped according to strength, endurance, stretching and stabilisation exercises are outlined in Table 7.8 below.

Table 7.8: Extracted endurance exercises for the lumbar region

Stretching exercise		
Specific exercise	**Prescription**	**References**
Iliopsoas, hamstrings, quadriceps, hip abductors and adductors), calf muscles, neck and shoulder muscles.	Stretching – 13 minutes,	Hagen et al. (2010)
Pelvic tilt, partial curl, lying supine hamstring stretch, double knees to chest, spinal twist, cat stretch, camel stretch, stretches back of leg and lower back, stretches lower back, side of hip and neck, stretches side of hip hamstrings Hip flexor stretch Standing quadriceps stretch	3-20 second hold 2-10 times	Chen et al. (2014) Inani and Selkar (2013)
Endurance		
Specific exercise	**Prescription**	**References**
Endurance exercise of back muscles and abdominal muscles	3 sets	Horneij et al. (2001), Gundewall et al. (1993)
Flexion: Pelvic tilt, partial sit ups, double knee to chest Extension: Prone press up + ice	10 RM 20 RM held for 5 seconds	Dettori et al. (1995)
Prone, upright, quadruped lumbar extension. Quadruped hip extension, bridging, abdominal isometric and upright abdominal contraction	Progressive training 2 – 20 RM, 10-20 seconds	Pillastrini et al. (2009)
With machines		Harts et al. (2008) Helmhout et al. (2008)
Hip strengthening exercises	3 sets 10 RM 3 times per week	Kendall et al. (2015), Ljunggren et al. (1997)
Isometric exercises of the spine – hollowing in abdominals and isometric for back extensors.	Not reported	Inani and Selkar (2013)

Table 7.8: Extracted endurance exercises for the lumbar region (Continued)

Stabilisation exercises		
Specific exercise	**Prescription**	**References**
Bridging, curl ups, cat camel, posterior pelvic inclination + exercises on unstable support to improve proprioception and balance Isometric contraction of stabilizing muscles of the lower back, abdominal wall and pelvic floor.	Not reported	Stankovic et al. (2012)
Core stabilisation: in four phases (activation phase, skill precision, superficial and deep muscle co-activation and functional re-education.	Not reported	Inani and Selkar (2013)
Isolated contractions of the deep abdominal muscles (TrA) and strengthen the primary stabilisers of the spine (Oblique abdominal, MF, and quadratus lumborum and erector spinae).	3-10 RM at end range for 2-3 seconds	Browder et al. (2007)
Stabilisation exercises as described by the big 3 (McGill) – curl up, side bridge and the bird dog. The bird dog exercise can progress from 4 point kneeling to 3 and to 2 point kneeling. Abdominal hollowing was performed to activate the transversus abdominis	Not reported	Yang et al. (2010)
Circuit training: Supine lying on ball Prone lying on ball Kneeling on ball Sitting on ball Balance board – 4 point kneeling and standing Standing on balance board Four point kneeling – exercises for abdomen, back and hips	Circuit training – 34 minutes.	Hagen et al. (2010)
Main contractions in various positions (four – point kneeling, supine, prone, sitting and standing).	10 contractions with 10 second hold	Muthukrishnan et al. (2010)
Standard back bridge, back bridge with alternate leg straight, back bridge with one leg, standard hands and knees, hands and knees with alternate arm straight forward, hands and knees with alternate leg straight backward, side bridge.	3 sets and hold for 15 seconds	Park et al. (2013)
Alternate arm and leg (bird exercise)	10-30 seconds, 8-12 times	Chen et al. (2014)
Lumbo – pelvic motor control exercises	Not reported	Kendall et al. (2015)

Table 7.9 above outlines the extracted exercises used as intervention in the management of musculoskeletal problems in the lumbar region. The extracted exercises were stabilisation, lumbo-pelvic exercises, strengthening and endurance training of the back muscles and stretching exercises of the lumbo-pelvic region.

7.6. Discussion

The aim of this study was to extract reproducible exercise programmes that can be adopted for string instrumentalists from existing studies. The results from the review were used to inform an exercise based injury prevention programme for string instrumentalists. Systematic reviews of evidence on the effect of specific exercises and intervention studies were reviewed in this study. Exercises for musculoskeletal dysfunction in the shoulder, lumbar, cervical and forearm and wrist regions were reviewed.

The common musculoskeletal problems identified from this study were in the upper extremity, lumbar, cervical and shoulder. Shoulder impingement syndrome, lumbar dysfunction and neck pain were the most common conditions managed from the identified studies. This is not surprising, back pain, neck pain and shoulder impingement are common WRMDs (Svendsen et al., 2004, Linaker and Walker-Bone, 2015).

In the systematic review studies, exercise therapy was effective in the management of chronic low back pain (CLBP) in that significant reduction in pain and disability was reported (Ferreira et al., 2006, Oesch et al., 2010, van Middelkoop et al., 2010, Van Middelkoop et al., 2011). A comparison of the effect of exercise programmes on the acute, sub-acute and chronic low back pain showed that exercise therapy was more effective in the chronic back pain group and exercise showed no effect in the acute back pain group (Hayden et al., 2005). The aim of exercise therapy in the management of chronic back pain is mainly focussed on improving strength and endurance as well as improving the core stability of the lumbo-pelvic region (Ferreira et al., 2006, Oesch et al., 2010, van Middelkoop et al., 2010, Van Middelkoop et al., 2011). Chronic low back pain results in a decreased muscle strength (da Silva et al., 2005) and altered muscle recruitment pattern (Silfies et al., 2005, Nelson-Wong et al., 2012). In the acute stage, there might not necessarily be significant reduction in muscle strength and altered muscle recruitment pattern as well as compensatory mechanism; therefore the exercise therapy programme would not be effective in improving outcomes.

Lumbar dysfunction was one of the most common musculoskeletal problems identified from the review. Altered motor coordination and poor motor control has been associated with low back pain (Silfies et al., 2005, Nelson-Wong et al., 2012). Core stabilisers are activated through a feed-forward mechanism before skilled movements can be performed in the extremities (Brumitt and Dale, 2009). Altered muscle recruitment pattern results into faulty movement patterns which are characterized by delayed activation of the core stabilisers which can result into joint instability and increased risk of lumbar dysfunction (Borghuis et al., 2008, Arab et al., 2011).

In the intervention studies, exercise programmes with the inclusion of stabilisation training showed significant reduction in pain and disability in the lumbar region (Pillastrini et al., 2009, Yang et al., 2010, Stankovic et al., 2012, Inani and Selkar, 2013, Park et al., 2013, Chen et al., 2014). A workplace injury prevention programme for high school teachers which included strength and stabilisation exercises showed significant positive outcomes in reducing pain and disability (Pillastrini et al., 2009). Interventions comparing strength and endurance exercises with other conventional physiotherapy treatment showed little or no significant difference in the outcome of both interventions, although both showed significant positive outcome in the management of low back pain (Ljunggren et al., 1997, Helmhout et al., 2008). This reiterates the importance of the core stabilisers in reducing the risk of lumbar dysfunction.

In the cervical region, exercise therapy showed positive moderate outcome in the treatment of chronic neck pain (Sarig-Bahat, 2003, Sihawong et al., 2011, Gross et al., 2016). Strengthening and endurance training of the deep neck flexors as well as stretching of the neck muscles were the exercises used in rehabilitation. The deep neck flexors functions mainly in stabilizing the neck during movements (Cholewicki et al., 1997). Pain and dysfunction often alters the activation mechanism and results in a delay when arm movement is involved which could result into cervical dysfunction (Côté et al., 2001). Endurance training of the neck stabilisers would show significant improvement in the management of neck pain.

Shoulder impingement syndrome was the most common shoulder problem in this study. It is a condition where the rotator cuff tendons (subscapularis, infraspinatus, teres minor and supraspinatus) are compressed during shoulder movements resulting into pain in the bursa and tendons (Michener et al., 2003). Posture and repetition of movement has been reported to be risk factors for impingement syndrome (Buckle and Devereux, 2002, Van Rijn et al., 2010). Pain management using conventional physiotherapy and exercises aimed at restoring range of motion and improving strength were used to manage shoulder impingement syndrome (Bang and Deyle, 2000, Bae et al., 2011, Bernhardsson et al., 2011, Engebretsen et al., 2011).

In other studies, that used physical conditioning which is a combination of strength, endurance, stabilisation and stretching exercises developed to target the demands of the work, was found to be effective in reducing time off work as well as reduce the duration of sick leave among office workers (Schaafsma et al., 2011, Schaafsma et al., 2013). This confirms the hypothesis that exercises specific to the physical demands of a job would be effective in the prevention of musculoskeletal problems (Bell and Burnett, 2009). The theory of WRMDs by Karsh (2006) postulated that specific job demands is an important risk factor in developing WRMDs , therefore, in the prevention of musculoskeletal problems, the specific demands of job should be explored. An adaptation of an injury prevention exercise programme designed for the specific needs of playing the football has shown significant positive outcomes in recent years (Bizzini et al., 2013, Steffen, 2013a, Steffen, 2013b)

Apart from the effect a work specific designed exercise programme has in the prevention and management of WRMDs, implementing the exercise programme at work or home would have a significant influence on adherence and compliance. Stasinopoulos et al (2010), reported that supervised exercise programmes has shown more effectiveness in the management of lateral tendinopathy. In another study, workplace exercise intervention showed significant improvement at follow up on pain when compared to home exercise intervention (Jakobsen et al., 2015a, Jakobsen et al., 2015b).

In conclusion, exercise therapy in the prevention of work related musculoskeletal problems would be effective. It is pertinent that the exercises should be adapted based on the physical demands of the work in order to achieve maximal effect. Stabilisation exercises of the lumbar and cervical region should be important to the overall programme because of their protective effect in preventing injuries. Specific exercises targeted at preventing the risk of shoulder impingement syndrome should be evaluated. General improvement in strength of the upper extremity should be explored. Physical conditioning which include strength, endurance, stretching and stabilisation exercise training of a worker to the demands of the job would be effective in preventing work related injury. Possible implementation strategies to ensure compliance and adherence to the developed exercise programme with respect to string instrumentalists should be explored.

7.7. Summary of chapter

The aim of this chapter was to extract reproducible exercise programme from literature. The importance of developing a work specific exercise programme was explained. The components of the specific exercise programmes were explained. The next chapter outlines the exercise development process by adopting specific exercises extracted from this study.

CHAPTER 8

8. DEVELOPMENT AND VALIDATION OF AN EXERCISE PROGRAMME FOR STRING PLAYERS

8.1. Introduction to chapter

This chapter presents the exercise development and validation procedure, results and discussion. The exercise programme was developed to suit the physical demands of playing the violin. Possible strategies that can be used to implement the exercise programme are presented in this chapter. The theoretical rationale that underlies the development of the exercise programme is given. The process of validation of the exercise programme is presented and discussed.

8.2. Theoretical rationale of the exercise components

Playing related musculoskeletal disorders among string instrumentalists are mainly in the neck, shoulders and low back (Moraes and Antunes, 2012). Figure 8.1 below is an illustration of the prevalence of PRMDs in the upper extremity, neck and trunk from the cross sectional study result presented in Chapter 4.

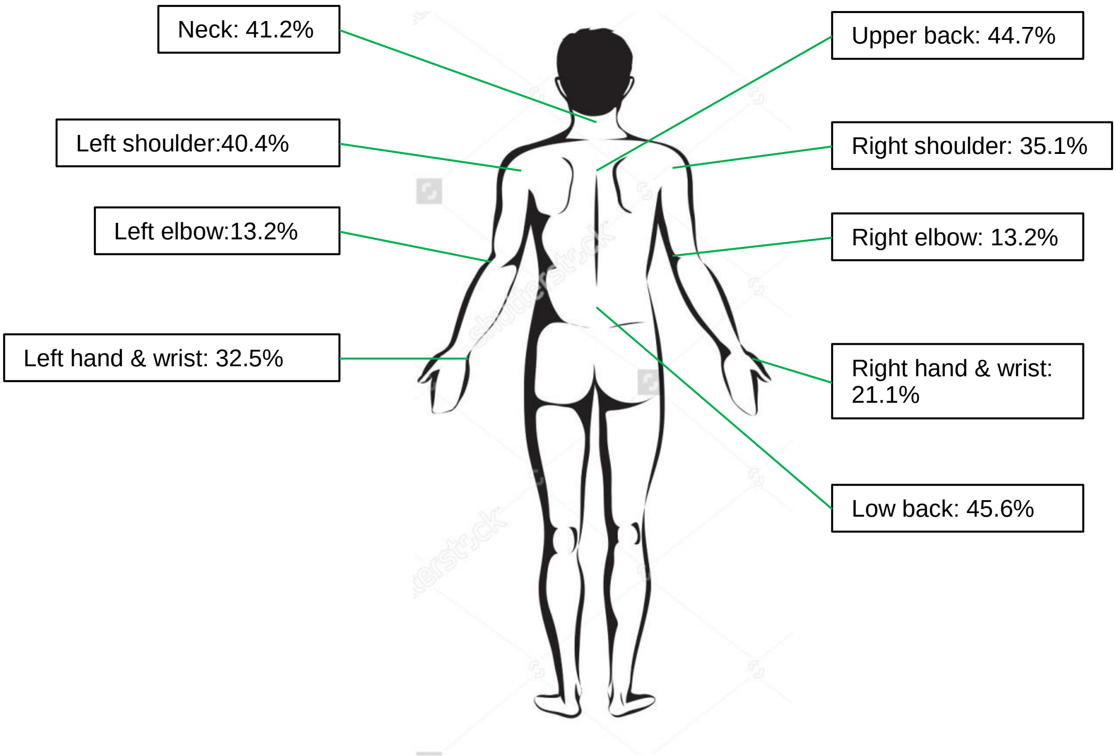


Figure 8.1: Anatomical distribution of PRMDs

The affected anatomic body region is directly proportional to the physical demands of playing the upper string instrument (Moraes and Antunes, 2012). From the results of the cross sectional study in Chapter 4, the prevalence of PRMDs is higher in the low back (45.6%), upper back (44.7%), neck (41.2%), left shoulder (40.4%), right shoulder (35.1%) and left wrist (32.5%). The biomechanical analysis results explained in Chapter 5, shows that the joint positions of the neck, trunk and shoulders puts the string player at risk of neck pain, low back pain and impingement problems in the shoulder. Exposure to the risk of developing musculoskeletal disorder as reported in Chapter 5 puts the violinist player at a low risk of developing musculoskeletal disorders.

Figures 8.2, 8.3 and 8.4 below illustrates the integration of the results of the cross sectional study in Chapter 4 and the biomechanical analysis in Chapter 5 as it informs the component and objectives of the exercise programme. The theoretical rationale for the specific exercise programme in each of the affected regions for the violinists are explained and discussed in the following section.

a. Cervical region

The cervical region was one of the most common areas of symptoms of musculoskeletal problems among string players (Leaver et al., 2011). From the results of the cross sectional study reported in Chapter 4, 41.2% of the string players had a history of musculoskeletal problem associated with playing a string instrument in the cervical region. Descriptors of musculoskeletal problems in this study are synonymous to the symptoms of overuse injuries (Dawson, 2001). In upper string playing, the neck mainly functions as a support structure in holding the violin/viola in position (Wilke et al., 2011). Figure 8.2 below illustrates the theoretical rationale of the selected exercises for the prevention musculoskeletal injuries in the cervical region for the violinist.

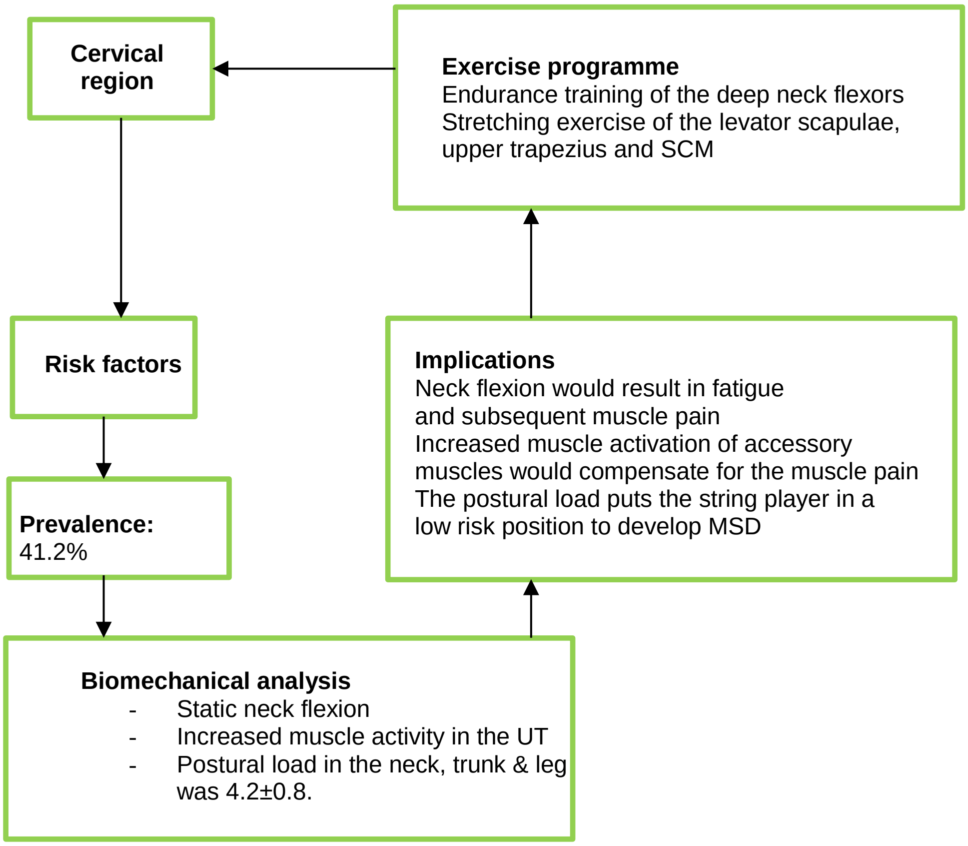


Figure 8.2: Theoretical rationale for the adapted exercise programme in the cervical region

As shown in Figure 8.2 above, the theory of the adapted exercise programme was based on risk factors identified from the biomechanical analysis of joint movement and the implications of the risk factors in the development of PRMDs. The results of the cervical range of motion of the violinists, puts the cervical in a relatively static position of 5^{o} left lateral flexion and 17^{o} flexion. During the course of performance, the neck position can be sustained in this awkward position (neck flexion with lateral flexion) for a prolonged time. Sustained neck flexion has been reported to be associated with neck pain and forward head posture (Chiu et al., 2002, Silva et al., 2009). Out of the six string instrumentalists in the biomechanical analysis study reported in Chapter 5, subjective postural evaluation showed forward head posture in two of the participants. The causative relationship between forward head posture and neck flexion has been associated with the short upper cervical extensor muscles (Burgess-Limerick et al., 2000). Upper cervical extension is complemented by a lower cervical flexion and a sustained cervical flexion will result in the upper cervical extensor to be sustained in an extended position (Burgess-Limerick et al., 2000). As a result of the sustained extension, the muscles could end up being fatigued which would eventually result in an increase in cervical flexion and subsequent forward head posture (Burgess-Limerick et al., 2000). Improving the strength and endurance of the deep neck flexors would reduce the onset of fatigue of the upper cervical extensors and possibly prevent forward head posture.

Apart from the sustained neck flexion that can predispose the violinist to cervical dysfunction, postural asymmetry of the cervical region could also contribute to neck pain. The static asymmetry position of the neck sustains muscle activity in the muscles stretched in neck flexion especially the upper trapezius and the sternocleidomastoid (SCM). Sustained muscle activity has been hypothesized to result in muscle damage (Visser and van Dieën, 2006). Muscle activation in painful major muscles is reduced and this results in increased muscle activation in the accessory neck muscles by a compensatory mechanism (Falla et al., 2004). The increased muscle activity in the accessory muscles would result in symptoms of overuse injuries (Falla et al., 2004). The results of the descriptors of PRMDs in the cross sectional study in Chapter 4 is consistent with the common symptoms of overuse injuries. Therefore, stretching exercises with the aim of improving muscle compliance and relaxation would be beneficial in reducing the risk of overuse injuries.

Postural asymmetry and increased muscle activity in the neck muscles (right upper trapezius most especially) are predisposing factors to neck pain (Ariëns et al., 2001, Yip et al., 2008). The demands of playing the violin and viola requires the sustained asymmetric position, however, endurance and strength training of the deep neck flexors could reduce the onset of muscle fatigue and subsequently prevent the forward head posture. Likewise, stretching of the neck muscles (SCM, upper trapezius, levator scapulae) could reduce muscle activity and improve muscle compliance.

From the extracted exercises in Chapter 7, endurance exercises of the deep neck flexors (longus capitis, longus colli, rectus capitis anterior and lateralis) (Abdel-aziem and Draz, 2016) and stretching exercise of the upper trapezius and pectoralis would be beneficial in preventing musculoskeletal problems associated with string instrument playing (Sihawong et al., 2013). The deep neck flexor endurance exercises and stretching exercises showed significant positive outcomes in the management of neck pain (Sihawong et al., 2013, Abdel-aziem and Draz, 2016).

The next section explains the rationale that underlies the content of the exercise programme in the shoulder region.

b. Shoulder region

The left and right shoulder function mainly, to support the instrument and in the bowing action respectively in violin and viola players (Wilke et al., 2011). From the results of the cross sectional study reported in Chapter 4, the prevalence of musculoskeletal problems in the left and right shoulder was 40.4% and 35.1% respectively. Figure 8.3 below is an illustration of the theoretical rationale of the adapted exercise programme for string players based on the identified risk factors.

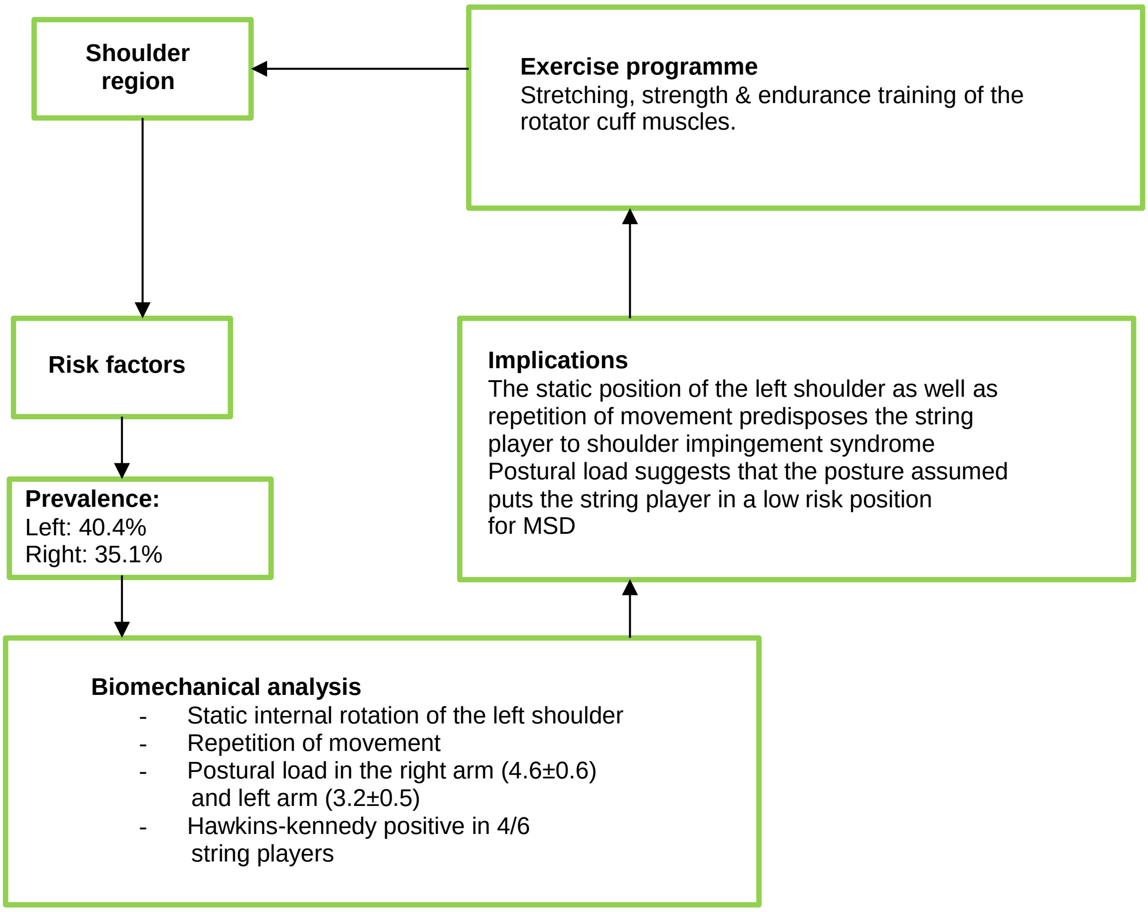


Figure 8.3: Theoretical rationale for the adapted exercise programme in the shoulder region for violinists

The inertial motion unit sensor measured movement in the shoulder and the scapula-thoracic joints (C7shoulder). The results as reported in Chapter 5 showed that in the right upper extremity, there was considerable movement in the shoulder joints in the coronal, sagittal and the transverse planes. The right shoulder was averagely in 17.1(8.8)^{o} abduction, 15.5(13.7)^{o} internal rotation and 20.1(14.9)^{o} flexion position while the left shoulder was averagely in 3.7(7.6)^{o} abduction, 10.9(14.9)^{o} internal rotation and 26.4(21.9)^{o} flexion position during violin performance.

The demands of the bowing arm (right arm) require repetition of quick movements which predisposes the string instrumentalists to overuse and possibly shoulder impingement syndrome (Moore et al., 2008). The bowing arm (right) was averagely positioned in about 15.5 degrees of internal rotation which puts a strain on the internal rotators and could result into impingement syndrome (Moore et al., 2008). Unlike the right shoulder joint, the left shoulder joint was held in a static position for upper string players in 3.7 degrees abduction, 10.9 degrees internal rotation and 26 degrees flexion. This static position is usually held throughout the duration of performance which results into constant contraction of the muscles involved in abduction, internal rotation and flexion. Shoulder impingement dysfunction has been reported as a common musculoskeletal problem among string players and the repetition of movement and static position has been reported to be risk factors (Moore et al., 2008, Rickert et al., 2012). From the results of the musculoskeletal integrity of the respondents in the biomechanical assessment reported in Chapter 5, four out of the six participants showed positive Hawkins and Kennedy test which indicates early signs of impingement syndrome in the participants. Maintaining the integrity of the rotator cuff muscles should be an important component of the exercise based injury prevention strategy. Smooth shoulder movement is often accompanied with scapula-thoracic movements (Phadke et al., 2009, Struyf et al., 2011). Therefore, scapular stabilisation exercises to improve stability and ensure smooth shoulder movements would be important in maintaining the integrity of shoulder movements.

From the results of the scoping review in Chapter 7, scapular stabilisation exercises of the scapula retractors was found to reduce pain intensity in participants with impingement syndrome (Bernhardsson et al., 2011). Posterior shoulder and pectoralis minor stretch as a component of an overall exercise based programme was effective in the prevention of shoulder disorders among construction workers (Ludewig and Borstad, 2003). Strengthening exercises (front raise, lateral raise, reverse flys and shrugs) of the shoulder muscles (Andersen et al., 2008, Häkkinen et al., 2008, Andersen et al., 2012, Zebis et al., 2014) and serratus anterior (Borstad et al., 2009) showed significant positive outcome in the management of shoulder dysfunction.

Therefore, strengthening and endurance exercises of the shoulder muscles in the sagittal, coronal and transverse planes would reduce the incidence of overuse related injuries in the shoulders. Scapular stabilisation exercises to improve support would improve endurance and stretching exercises of the rotator cuffs could reduce the strain on the rotator cuffs.

c. Thoracic and lumbar regions

The upper thoracic region and the lumbar region are normally support structures for the whole musculature during performance (Wilke et al., 2011). From the results of cross sectional study presented in Chapter 4, the prevalence of the musculoskeletal problems in the upper thoracic and the lumbar region was 44.7% and 45.6% respectively.

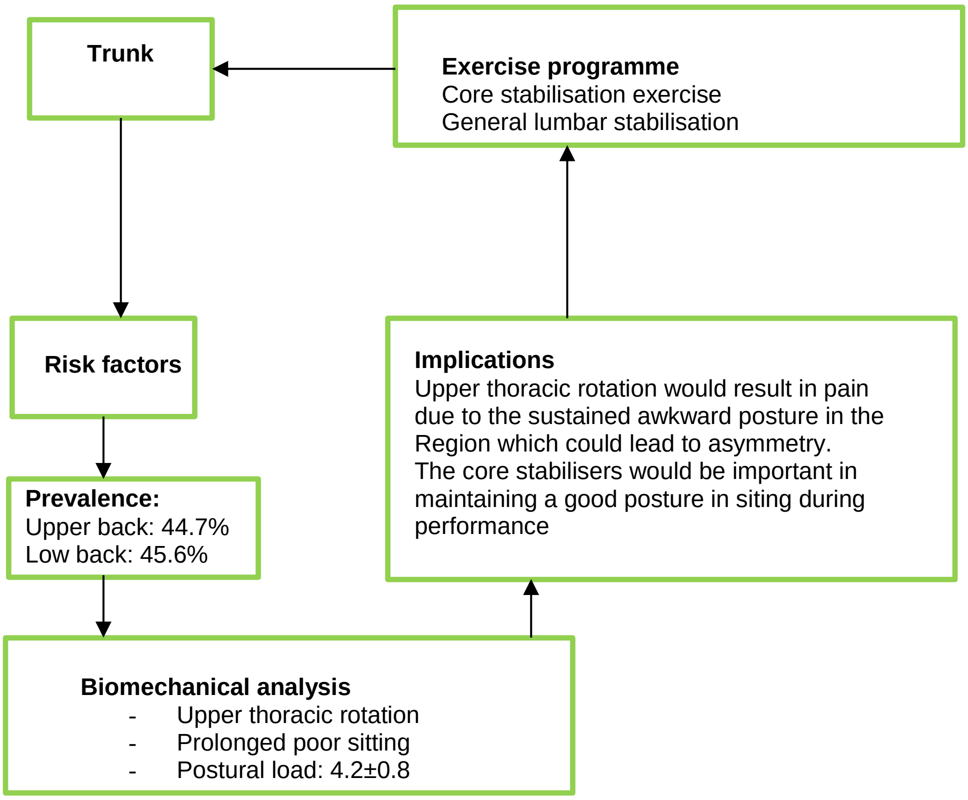


Figure 8.4: Theoretical rationale for the adapted exercise programme in the lumbar region

Low back pain is a common problem in the general population and musicians are not exempt from the activities of daily living that predisposes people to back problems (Van Tulder et al., 2000). Additionally, postural problems associated with playing a string instrument can predispose the string player to back problems (Eijsden-Besseling et al., 1993, Steinmetz et al., 2010, Ramella et al., 2014).

The result of the biomechanical analysis presented in Chapter 5 showed that only one violinist had weak core stabilisers. The role of the core stabilisers in maintaining posture is important in injury prevention and this has been included in several studies (Lederman, 2010). Muscle activity in the erector spinae reported % RMS MVC of 2.7±1.3 and 1.7±0.7

respectively. This suggests that the muscle activity in the lumbar region is reduced in comparison to the amplitude of muscle activity in the upper trapezius. The core stabilisers has been explored in several studies as a major contributor to the stabilisation of the lumbar region (Willson et al., 2005, Peate et al., 2007, Yang et al., 2010, Brandt et al., 2015).

The scoping review in Chapter six concludes that strength, endurance or core stabilisation exercises would be effective in the management of low back pain. However, feed forward activation of the stabilisers has a prophylactic effect in anticipating movement which has been suggested to reduce the risk of lumbar pain (Griffin, 2003, Smith et al., 2008). Therefore, stabilisation exercises of the lumbar region would be effective in reducing the risk of low back pain among string players. Core stabilisation exercise described by Inani and Selkar (2013) and general lumbar stabilisation exercises were adopted and included in the exercise programme.

d. Forearm and wrists

The left forearm functions to support the instrument while the wrist functions in the 'shifting' process of modulating the frequency on the strings (Wilke et al., 2011). Musculoskeletal problems in the left elbow and wrist were shown to be 13.2% and 32.5% respectively. The right forearm functions mainly in determining the force applied to the bow in sound generation and it works synchronously with the left hand (Rolland et al., 1986). The right wrist functions mainly in holding the bow. In this study, the prevalence of musculoskeletal problems in the right forearm and right wrist was 13.2% and 21.1% respectively. The movement at the right elbow was mainly in pronation, internal rotation and flexion while the position of the left elbow was static mainly in supination, external rotation and flexion in the violinists. This position can result into musculo-tendinous strains which are a common injury of musicians. Hence, strengthening and stretching exercises would improve endurance and relaxation respectively in the forearm.

Table 8.1: Developed exercise programme for violinists

Cervical and upper thoracic	
Exercise	Deep neck flexors endurance Upper trapezius stretch Shoulder shrugs
Shoulder	
Exercise	**Shoulder strengthening exercises (Dumbbell exercises)** **Serratus anterior stabilisation exercises:** Push up plus **Stretching:** Posterior capsule stretch and pectoralis minor stretch
Lumbar	
Exercise	**Progressive core stabilisation exercise training in three phases** - Facilitation of isolated local muscle activity with emphasis on continuation of normal breathing. - Applying low load to the muscles through controlled movements of the upper extremities (4 point kneeling, supine, sitting and standing). - Integrate low grade static contractions along with the normal static and dynamic tasks so that these contractions become involuntary. **General lumbar stabiliser training:** bird dog exercises
Forearm and wrist	Forearm and wrist strengthening exercises (Dumbbell exercises) Stretching exercises of the wrist extensors and flexors, supinators and pronators

As outlined in Table 8.1 above, the developed exercise programme was compiled based on the rationale of musculoskeletal injury risk factors associated with string players. The exercises were further validated by experts. The procedure of the validation of the exercise programme is explained in the next section.

8.3. Validation of the exercise programme

The face and content validity of the exercise programme was conducted with sports physiotherapists and bio-kineticists. Face validity is a subjective assessment of the validity of a measurement for a defined outcome (Bork, 1993). Content validity assesses whether the measure is based on theory and logical argument (Bork, 1993). The validation procedure and the results are presented in the section below. This phase of the study explains the methodology and the results of the validation of the developed exercise programme.

8.3.1. Aim of the study

The aim of the study was to evaluate the face and content validity of the developed exercise programme

8.3.2. Study participants

Physiotherapists and bio-kineticists with experience in sports or neuro-musculoskeletal system management and research were invited to participate in the study. The participants were identified through the sports interest group of the South African Society of Physiotherapy (SASP) and snowball sampling was used to recruit them. The bio-kineticists were recommended by the physiotherapists with whom they were working. Health of performing artists is a new field in South Africa and it would be extremely difficult to find clinicians with musician injury experience.

8.3.3. Procedure

The participants were approached to participate in the study. The aim and the procedure of the study were explained. The developed exercise programme was sent to the participants via emails and consultations were made with the participants. The developed exercise programme included a pattern of injury and a rationale for the selection of the exercise programme as outlined in Table 8.1 above. The participants made recommendations and suggestions on the included exercises and also on the procedure of conducting the exercises. The programme was updated after every consultation. Consultations continued till saturation was reached. The recommendations of the participants were categorised into themes and integrated into the overall exercise programme.

8.3.4. Results

8.3.4.1. Demographic of the participants

A total of 10 experts with mean years of experience of 10.8 ± 6.7 years participated in the study. It comprised of five males and five females. The demographic characteristics of the participants are outlined in Table 8.2.

Table 8.2: Demographic characteristics of the participants

Participant	Profession	Gender	Years of experience
1	Sport physiotherapist	Male	26
2	Sport physiotherapist (violinist)	Female	6
3	Sport physiotherapist	Female	14
4	Physiotherapist (NMS)	Female	7
5	Physiotherapist (NMS)	Male	13
6	Physiotherapist (NMS)	Male	9
7	Bio-kineticist (exercise therapy)	Male	16
8	Sports/NMS Physiotherapist	Female	6
9	Bio-kineticist (Orthopaedic rehabilitation)	Female	3
10	Bio-kineticist (Orthopaedic rehabilitation)	Male	8

Three of the physiotherapists have experience in the management of neuro-musculoskeletal system problems in the upper extremity, neck, lower limbs and back. One of the sports physiotherapists also play the violin and have experienced playing related injury management. The other two sport physiotherapists are mainly involved in the treatment of soccer related injuries both in the acute and the rehabilitation stage. The three bio-kineticists are involved in the exercise based rehabilitation of musculoskeletal injuries.

8.3.4.2. Face and content validity of the exercise programme

The developed exercise programme was evaluated for face and content validity by the participants. The face validity of the exercise programme was considered relevant and useful in the prevention of PRMDs among violin players. Further recommendations and suggestions based on theory and logical argument of the causative factors of PRMDs among violinists was considered. Based on the recommendations and suggestions of the participants, the exercise programme was modified. The recommended exercises were included and categorised based on the anatomic region. The procedure of the exercises was reviewed. Table 8.3 below outlines the recommendations from the experts.

Table 8.3: Recommendations from the consultations

Additional exercises		Procedure
Specific exercise	**Region**	
PNF	Shoulder	Thera-band for dumbbells
Neural mobilisation	ULNT1, ULNT2a and b	Dosage will be in line with basic exercise principles
General mobilisation to full range		
Mobilisation, strengthening and rotation	Thoracic region	Progression of strengthening exercises – resistance exercise training
Stretching	SCM	Order of exercises – stretching – mobs – strengthening exercises
Stabilisation exercises	Rhomboids	
Stretching exercises		Warm up and cool down

As outlined in Table 8.2, recommendations from the consultations were categorised into two namely additional exercises and procedure.

a. Additional exercises

PNF: Proprioceptive neuromuscular facilitation was suggested to be included in the exercise programme for shoulder exercises. The strength training exercise programmes were suggested to be performed putting into consideration the PNF patterns of shoulder movements. PNF has been recommended as a component of injury prevention programmes in sports (Soligard et al., 2008, Steffen, 2013b). A recent exercise programme developed for musicians also included proprioceptive training as a part of injury prevention programme developed generally for musicians irrespective of the instrument played (Chan et al., 2013a).

Neural mobilisation exercises: Neural mobilisation exercises of the median, radial and the ulnar nerve were proposed to be included as part of the exercise programme. The rationale of the inclusion was due to the static position of the cervical region in holding and supporting the upper string instruments could result into compression of the nerve roots of the brachial plexus. Therefore, the integrity of the neural structures using neuro-mobilisation exercises could be important in reducing nerve irritations and musculoskeletal injuries associated with compression neuropathy. Compressive neuropathy has been reported as a common problem among musicians (Lederman, 1993).

General mobilisation: An inclusion of general mobilisation exercises of the upper extremity and trunk to ensure full range of motion was also suggested. To maintain the physiological joint integrity, full range of motion is important.

Stabilisation exercises: the adapted exercise programme was focussed on stabilisation of the scapular stabilisers (serratus anterior) and the core stabilisers. Stabilisation exercises of the rhomboids were suggested to be included in the exercise programme. The scapular is important in supporting the violin and also in the excursion of shoulder movement. The shoulder is a complex joint and the integrity of the each of the joints that made up the shoulder complex is important in ensuring smooth movements.

Stretching: The adapted exercise programme was focussed on stretching the upper trapezius in the cervical region. The experts suggested gentle stretch exercises of the sternocleidomastoid. The rotation movement and position of the cervical region in holding the violin/viola could result into a strain on the right side and shortening on the left side. Therefore, the rationale of stretching of the sternocleidomastoid could be important in reducing cervical problems in the cervical region.

Thoracic rotation exercises: The prevalence of musculoskeletal problems in the thoracic region (upper back) was relatively high in the population studied (Chapter 4). Although, there was no exercises of the thoracic region extracted from literature. The experts in this study suggested thoracic rotation exercises as well as progressive strengthening exercises of the thoracic region. The rationale for the inclusion was due to the trunk rotation associated with playing the string instrument and also the high prevalence of musculoskeletal problems in the upper thoracic region.

b. Procedure

The dosage of the exercise programme was suggested to follow standard prescription practice with regards to strength and resistance training. Dumbbells for resistance training exercises were suggested to be replaced with Thera-bands due to the ease of carrying of the Thera-bands. The exercise regimen was suggested to be divided into three main categories which includes – warm up, exercises and cool down.

Warm up: Warm up exercises was suggested to include stretching exercises. These exercises include stretch of the upper trapezius, biceps, triceps, IP and MCPs.

Exercises: the exercises were categorised into general exercises and specific region exercises with a focus on neuro-musculoskeletal injury prevention.

Cool down: the importance of cool down exercises in injury prevention was emphasized by the experts. It was suggested that stretch exercises of the muscles susceptible to overuse and mobilisation exercises in the opposite direction of position normally sustained during performance should be performed after practice and performances.

Table 8.4 outlines the modified exercise programme with the inclusion of the opinions of the experts aggregated. The procedure of each of the exercises is outlined in Appendix L.

Table 8.4. Modified exercise programme for violinists

Exercise category	**Specific exercises**
Warm up and cool down exercises/breaks	Upper trapezius stretch Bicep and triceps stretch Fingers clenched and unclenched Wrist rotations Oppositional finger wrist press Hand/finger extensions Posterior capsule stretch Rotatory shoulder shrugs Hold and relax exercises of the upper trapezius (PNF) Pendulum arc exercises
General exercises	General active mobilisation exercise of the neck, trunk, shoulder, elbow, wrist and fingers to the end of range should be performed prior to the specific exercises. Postural education – proper posture as a component of activities of daily living
Cervical/thoracic region	Stretching – SCM, levator scapulae, upper trapezius Neuro-mobilisation – upper neural tension exercises Strength and endurance training of the deep neck flexors Thoracic rotation exercises
Shoulder	Stretching – posterior capsule stretch, pectoralis stretch, biceps and triceps stretch. Strengthening exercises – resistance exercises with Thera-band incorporated with proprioceptive neuromuscular diagonal patterns. Scapular stabilisation exercises – serratus anterior, rhomboids, middle and lower trapezius. Scapular strengthening exercises Shoulder shrugs – rotatory shrugs Pendulum arm exercises Rotator cuff exercises – Thumbs up and down
Elbow/wrist	Stretch – forearm stretch Strengthening exercises – resistance exercises with Thera-band incorporated with proprioceptive neuromuscular patterns Intrinsic hand muscle exercises – clench and unclench exercises and resistance against rubber band.
Lumbar region	Lumbo-pelvic stabilisation exercises Core stabilisation exercises Bird dog exercises

The exercises were further categorised into warm up exercises, pre-training exercises and stretches during breaks. The procedure of the exercises suggested the use of Thera-bands instead of dumbbells as resistance due to its easy availability and ease of carriage. The dosage of the various exercises was suggested to be in line with the basic principles of exercises prescription. The progression and order of the exercises was also suggested as shown in Figure 8.5 below.

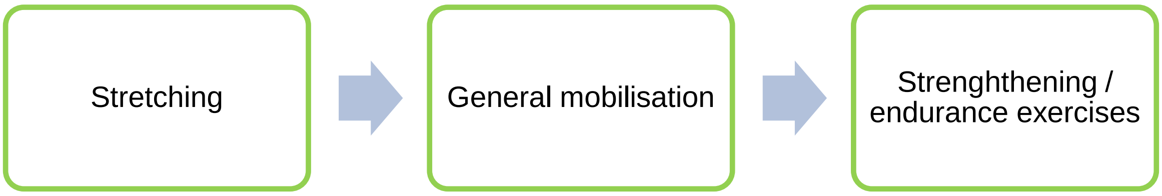


Figure 8.5: Progression and order of the developed exercises

The implementation strategy of the developed exercise programme was explored with musicians and music tutors. The methodology and the results of the study are explained in the next section.

8.4. Implementation strategy with musicians

The final phase of the exercise development and validation was focussed on exploring the opinion of musicians and music tutors on the usefulness and possible implementation strategies of the exercise based injury prevention programme. The consolidate criteria for reporting qualitative study (COREQ) (Tong et al., 2007).

8.4.1. Aim

The aim of this phase of the study was to explore the opinion of music instructors and musicians on implementation strategies of an exercise based injury prevention programme for string instrumentalists.

8.4.2. Objectives

- To explore the usefulness of the exercise programme with musicians
- To explore possible implementation strategies with musicians

8.4.3. Research team and reflexivity

8.4.3.1. Personal characteristics of the interviewer/facilitator

The interviewer was a male doctoral student of Physiotherapy. The participants were made familiar with the aim of the research and relationship was developed between the participants and the interviewer.

8.4.3.2. Study design

Methodology

Structured focus group discussion using an interview guide was used to explore the opinion of musicians on the implementation of the exercise based injury prevention programme. Focus group discussion can be used as a research design to explore predetermined themes and emerging themes (Gill et al., 2008, Onwuegbuzie et al., 2009). The component of the exercise programme and the potential effects were explained to the participants.

Sampling and sample size

A sample of convenience of music tutors and musicians were invited to participate in a focus group discussion. Participants were approached via email and telephone and consented participants were scheduled for a focus group discussion.

Study participants

Musicians and music teachers with experience in orchestra music were invited to participate in a focus group discussion.

Procedure

The researcher conducted the focus group discussions. The foundation of the study and the exercise development procedure was explained to the participants prior to their opinion on the potential usefulness of the exercise programme and implementation strategies. The participants were approached to participate in the study. The aim and the process of the study were explained. The focus group discussion (FGD) was conducted at the convenience of the participants and the discussion was facilitated using an interview guide (Appendix K). The focus group discussions were conducted at the workplace (music) of the participants (music schools). Focus group discussion continued till there were no emerging themes. The discussions were audio-taped, field-notes were taken and the researcher facilitated the discussions.

Maintaining rigor

Credibility was ensured through triangulation of data, peer debriefing to critique the data collection process and member checking of collected data peers and participants and by giving a rich description of the context and by utilising information from previous studies (Lincoln and Guba, 1999). Peer debriefing was done at the end of the sessions and member checking was done during the group discussions, participants' comments summarized and accuracy of the opinion was confirmed with the participants. Familiarity was developed by involving participants who are willing to genuinely take part in the FGD; probes were used during questioning to ensure honesty from the participants (Shenton, 2004). To ensure transferability, clear description of the methodology was provided to ensure that the study can be repeated (Guba, 1981). The raw record data were reviewed by constant comparison to ensure conformability. Dependability was ensured using in-depth methodological description.

8.4.4. Ethical implications

A clear description of the study was explained to the participants and they a copy of the research information sheet was handed over to each of the participants. Informed consent to make an audio tape recording was agreed to by all the participants. It was explained to the participants that confidentiality cannot be entirely guaranteed in a qualitative research but the researcher would ensure that identifiers would be removed from the transcribed document.

8.4.5. Data analysis and findings

Demographic characteristics of the participants were described using the descriptive statistics. Data were transcribed by the researcher and coded using directed content analysis (Hsieh and Shannon, 2005) and coded and new codes was given to emerging themes.

8.4.6. Results

Two focus group discussions were conducted with a total of eleven participants. The duration of focus group one and focus group two was 20 minutes and 44 minutes respectively. The demographics characteristics of the participants are outlined in Table 8.5 below.

Table 8.5: Demographic characteristics of the participants

Participant	Age	Gender	Profession	Experience
Focus group one				
1	26	Female	Violinist and music tutor	15 years of playing, 7 years of teaching
2	22	Male	Violinist	12 years
3	26	Female	Violinist	15 years – playing; 7 years – teaching
4	35	Male	Violinist	7 years of playing
5	19	Male	Bassist	6 years of playing
6	30	Male	Violinist	15 years of playing
7	20	Male	Violinist	9 years of playing
Focus group two				
1	31	Male	Cellist – player and teacher	16 years of playing
2	34	Male	Violin, Trombone, Music research and music tutor	17 years of playing, 8 years of teaching
3	36	Male	Pianist and music tutor	14 years of playing
4	31	Male	Guitarist and Music tutor	12 years of playing

The mean age and the mean years of experience of the participants was 28.2±6 years and 12.4±3.8 years respectively. The participants comprised of two females and nine males, eight of the participants play one of the string instruments while four play other instruments and teach music as shown in Table 8.5 above.

The transcribed report was coded into themes and subsequently categorised into broader themes based on the objectives of the study as shown in Table 8.6 below.

Table 8.6: Thematic content analysis of the study

Objectives	**Sub-theme**	**Theme**
To explore the usefulness of the exercise programme	Exercise programme will be beneficial in injury management	Injury prevention effect of the exercise programme
	I would like to understand how other players manage their injuries	Health promotion and education
	My injury affects my playing and performance	
To explore intervention strategies with musicians	We can follow up on the kids and ensure compliance and adherence	Compliance and adherence
	We can do some exercises before playing	
	I have only 30 minutes to teach my student	Time
	Workshops can be organised with tutors and students	
	We are open to learn the exercise programme and teach the programme.	Adoption of the programme
	Teach the young learners at an early age	

As outlined in Table 8.6 above, the themes from the two focus group discussion were categorised into subthemes and themes based on the objective of the study. The section below explains the themes of the results of the focus group discussion.

a. Usefulness of the exercise programme

Two main themes can be extracted from this objective. The first objective was the beneficial importance of the exercise programme and the participants believe that the exercise programme would be beneficial in reducing musculoskeletal injuries.

“I think it is going to benefit us a lot. I suffer from back and shoulder pain. I know it is a struggle for me to play, especially when we have a lot of work, concerts and tour. I get muscle spasm, it is a struggle to work and play. I definitely would be open to learn and teach the exercises” Participant 1 (FGD 1).

The second theme was focussed on the musician's willingness to understand the pathophysiology of the injury mechanism and possible intervention outcomes.

"I'd like to know how other players manage their injuries or how they come about make us feel better by playing". C (FGD1).

The musicians in this study do understand the beneficial effect of the exercise based injury prevention programme. Health education on the possible injury mechanism would be important in ensuring good compliance among musicians.

b. Intervention strategies

Compliance and adherence, time constraints and adoption of the programme were the three major themes identified from the discussion. The participants were willing to adopt the exercise programme and it was suggested that the exercise programme should be introduced to the musicians at the early stage when they are still acquiring motor skills needed to play a string instrument.

"As a teacher, it will also benefit the young ones, at an early age to help them grow and prevent injuries when they are still young" Participant 3 (FGD 2).

Time constraint in implementing the programme was considered by the participants. It was suggested that the teaching of the programme would be better implemented in music schools rather than one on one tutor due to the short time of teaching which is usually 30 minutes.

"It is beneficial to everyone, we might have to make arrangements and probably teach the students in batches and that way everybody gets a chance to learn the exercises. We can create time" Participant 5 (FGD1).

"We can organise workshops…..I think the workshop is best even if it's not for the teachers alone….you teach everybody and the teachers can follow up on the monitoring" (Participant 1 (FGD1).

Time constraint in implementing the programme was a major point of discussion. Implementing the exercise programme in a more structured setting – music schools, youth orchestra and professional orchestra might be more effective. Compliance and adherence with the exercise programme can be ensured by the music tutors and management.

The exercise based injury prevention programme for string players was generally considered important in preventing injury among string players and the participants showed willingness in understanding the components of the exercise programme as well as looking forward to implementing the programme. Due to the experience of playing related musculoskeletal problems experienced by a number of the participants, a preventative approach to their injuries was considered a good intervention.

8.4. Discussion

The aim of this study was to develop an exercise programme for the prevention of musculoskeletal problem among string players. The exercise development process involved exploring the biomechanical risk factors associated with injuries among string players which led to the extraction of reproducible exercises from exercise intervention of WRMDs. The developed exercises were based on the biomechanical demands of string playing which corresponds to the common anatomical areas of injury complaints among string players. The developed exercises were categorised into warm up and cool down exercises and region specific exercises for injury prevention in the neuro-musculoskeletal structure. The discussion is explained in two sections – components of the exercise programme and implementation strategies of the exercise programme.

a. Components of the exercise programme

The developed exercise programme was focussed on improving strength and endurance in the major muscles involved in performance, stretch muscles of the cervical, shoulder, forearm and wrist region. Stabilisation exercises of the lumbar and cervical region was an important component of the programme as well as neural mobilisation exercises of the radial, ulnar and median nerve. Stretching and relaxation exercises were a component of the warm up and cool down programme.

The exercise development and component in this study is comparable to an earlier study by Chan et al. (2013a), where a formative evaluation process was used to develop an exercise based programme for the management of PRMDs. The content of the exercise programme was aimed at improving strength and endurance of the deep neck flexors and shoulders, stabilisation exercises of the lumbo-pelvic region and the scapular stabilisers and motor control (Chan et al., 2013a, Chan et al., 2013b). Other exercise based intervention programmes have utilised strength and endurance, stabilisation exercises and stretching exercises in management of PRMDs (Ackermann et al., 2002b, De Greef et al., 2003, Kava et al., 2010). This study is the first study where the inclusion of neural mobilisation exercises as a key component of an exercise based injury prevention programme for musicians was considered.

Exercise based intervention for musicians has usually focussed mainly on improving strength and endurance as well as improving neuromuscular control and positive outcomes has been reported (Ackermann et al., 2002b, De Greef et al., 2003, Kava et al., 2010, Chan et al., 2013a, Chan et al., 2013b). In this study, postural asymmetry and the repetition of movement was suggested as probable risk factor for neural dysfunction. Tingling sensations in the upper limbs was one of the most common descriptors of PRMDs and this suggests nerve compression and compressive neuropathies are common problems among musicians (Charness et al., 1996).

Thoracic mobilisation exercises aimed at correcting and compensating for the awkward position of the upper thoracic region during performance was included in the overall exercise programme. The thoracic region has often been overlooked in several exercise based injury prevention programmes for musicians (Ackermann et al., 2002b, De Greef et al., 2003, Kava et al., 2010, Chan et al., 2013a, Chan et al., 2013b). This could be due to the broad exercise development aim for musicians irrespective of the instrument played. From the results of the cross sectional study to establish the burden of PRMDs among string players in South Africa reported in Chapter 4, the prevalence of musculoskeletal problems in the thoracic region (upper back) is high. The physical demands of playing the string instrument requires that the thoracic region is held in an asymmetric rotatory position or crouching for upper and lower string instrumentalists respectively (Rolland et al., 1986). Specific exercise programme to correct abnormal posture would have a positive outcome on musculoskeletal problems in the thoracic region.

The exercise programme was structured into a warm up and cool down session and pre-activity exercises. The warm up and the cool down exercises were stretching exercises aimed at improving muscle compliance before an activity and cooling down the muscles post activity respectively. Other exercise programmes have included warming up before playing and cool down exercises as a part of their exercise based injury prevention programme for musicians (Ackermann et al., 2002b, De Greef et al., 2003, Kava et al., 2010, Chan et al., 2013a, Chan et al., 2013b). McCrary (2016) compared the effects of four different warm up protocols on perceived exertion and muscle activity. The warm up protocols were cardiovascular warm up, core muscle strengthening, core muscle strengthening and musical warm up (McCrary, 2016). The results showed that perceived exertion and muscle activity were reduced in all groups, although, pre-post-test difference in muscle activity in the right upper trapezius and the right lower trapezius was significantly lower in the musical warm up group and core muscle strengthening warm up group (McCrary, 2016). Musical warm up is a common practice among musicians and it involves the playing of graduated scales (Paul, 2009, McCrary, 2016). Musical warm up has been suggested to prepare the mind and body for the psychological demands of performance and thereby important in reducing the risk of injury (Guptill and Zaza, 2010, Baadjou et al., 2016). In as much physical warm up by using stretching exercises would be important in improving muscle compliance and potentially prevent injury, the role of musical warm up in reducing injury should not be overlooked.

In the lumbar region, exercises aimed at improving the stability of the gross and intrinsic muscles of the lumbar region were included in the overall exercise programme. Core stabilisation exercises have been reported in literature to be effective in the management and prevention of low back pain (Ferreira et al., 2006). Previous exercise programme have included endurance training of the core muscles as a component of their exercise programme for musicians and positive outcomes have been shown (Ackermann et al., 2002b, De Greef et al., 2003, Kava et al., 2010, Chan et al., 2013a, Chan et al., 2013b) .

The shoulder in string players is prone to impingement problems bilaterally (Rickert et al., 2012). Exercises aimed at improving the strength and endurance of the rotator cuff muscles as well as stretching of the pectoralis minor and posterior capsules were included. The shoulder is a complex and the integrity of the scapula-thoracic joint is important to smooth shoulder movement patterns (Voight and Thomson, 2000). Stabilisation exercises of the serratus anterior and rhomboids were included in the study. Scapular stabilisation exercise was a component in only one study (Chan et al., 2013a). The exercise programme showed a significant reduction in PRMDs and perceived exertion (Chan et al., 2013a).

The forearm and wrist of both the right and left upper extremity are used in sound production, with the right involved mainly in the bowing action while the left is involved in the shifting action (Rolland et al., 1986). Both movements occur synchronously to produce sound in string playing. In the bowing arm, movement repetition at the elbow joint in flexion - extension as well as in pronation – supination would predispose the string player to overuse. The left elbow is usually held in a more static position in supporting the instrument in violin/viola players. However, in this study the prevalence of injury is higher in the left wrist and hand. The prevalence of musculoskeletal problem in the left wrist and hand could be due to the shifting action of the left hand. In order to modulate sound, the left wrist and hand shifts between the four strings repetitively as well as the thumb to support the head of the violin or viola. Strengthening exercises and stretching exercises of the forearm muscle groups and intrinsic muscles of the fingers were part of the exercise programme in this study. In comparison to earlier exercise based interventions, the wrist and the forearm were not included (Ackermann et al., 2002b, De Greef et al., 2003, Kava et al., 2010, Chan et al., 2013a, Chan et al., 2013b). Cooper et al. (2012) evaluated the effect of stretching exercises of the forearm and wrist on perceived discomfort during rehearsals. The intervention group reported significantly lower discomfort when compared with the control group (Cooper et al., 2012). An exercise programme targeted at improving strength and muscle compliance could reduce the overall level of discomfort among musicians.

b. Implementation of the developed exercise programme

The results of the focus group discussions showed that the musicians were willing to adopt the programme as part of their training schedule. The musicians in this study were convinced about the beneficial effect of the exercise programme. However, time constraints in administering and teaching of the programme were considered a barrier. Adherence to exercise programme is important to the effectiveness of the programme in management and injury prevention (Chan et al., 2013b, Chan et al., 2014). A study by Chan et al. (2013b) showed that compliance to home use exercise programme among musicians was 15%. Exercise designed for the work place was shown to have better positive outcomes in comparison to exercises performed at home (Jakobsen et al., 2015a). Supervision of the exercises and group therapy effect could be responsible for the better adherence and eventual reduction in pain.

The duration of an exercise programme is important in ensuring adherence. An intervention strength training programme implemented with four different groups showed that the group with seven minutes training three times a week showed significant improvement when compared with other groups and compliance was better in comparison to other groups (Dalager et al., 2015). The longer the exercise programme, the less likely participants would adhere to the programme. The study by Chan et al (2014) showed that the significant difference between the exercise intervention group and control group was not statistically significant. The outcome could be as a result of reduced adherence and compliance to the exercise programme. Cooper et al. (2012) in their study to evaluate the effect of 15 minutes stretching exercise on musculoskeletal problems during rehearsals showed reduced perceived exertion and a reduction in self-reported symptoms.

Understanding the concepts of injury mechanism and risk factors is an important consideration in ensuring good adherence and compliance. Knowledge on the pathology of the musculoskeletal dysfunction and associated risk factors would improve the adherence and compliance. Health promotion with the focus of educating musicians on injury mechanisms, risk factors and implementation strategies would be effective in ensuring better compliance.

In conclusion, the content and the exercise programme for the prevention of musculoskeletal injury among string players was focussed on improving strength and endurance and improving muscle compliance in the commonly affected anatomic regions. Health education as well as postural education integrated into the exercise programme would improve compliance and adherence. The implementation strategy suggested by music tutors and string players in the focus group discussions was focussed on educating the both the instructors and the students. The instructors also suggested that monitoring and implementation of the exercise programme can be done by them.

8.5. Summary of chapter

This chapter was aimed at explaining the exercise development process. The exercise developed was aimed at strengthening and maintaining the integrity of the neuromuscular bundle. The implementation of the exercises would require evaluation of the duration of the whole programme. Inclusive training with string players incorporating health promotion as well as teaching and supervision of the exercise programme in music schools should be considered for implementation. The next chapter is a summary of the overall study and recommendations for future studies.

CHAPTER 9

9. CONCLUSION AND RECOMMENDATIONS

9.1. Overall summary of the research

The aim of this study was to develop an exercise based injury prevention programme for string instrumentalists. The research was conducted in four main studies. A cross sectional study to establish the burden of musculoskeletal problems among string instrumentalists in South Africa was conducted. This was followed by the biomechanical analysis of string playing study which sought to evaluate the joint angle positions, muscle activity and postural loading during performance. Two separate scoping reviews were conducted with the aim of reviewing exercise based interventions for musculoskeletal problems and to extract reproducible exercise programme from work related musculoskeletal problems. Based on the extracted exercise programme and the theoretical approach of injury prevention, the extracted exercise programme was adapted for violinists. The face and content validity of the exercise programme was conducted and implementation strategies with music tutors were explored. The summary of the procedure and key outcomes of each study is outlined below based on the research questions of the study. Figure 9.1 outlines the key outcome, limitations and contribution of each study to the overall aim of the thesis.

Burden of PRMDs among string instrumentalists in South Africa

Key outcomes
- PRMD is a problem string instrumentalists in South Africa.
- PRMD is associated with activity limitation and participation restriction.
- There are racial differences in the prevalence of PRMDs and this should be explored.
  - Blacks reported less PRMDs compared to whites
- The upper extremity and the trunk are the mot affected areas of PRMDs

Limitations
- Sampling bias
- Mode of questionnaire administration
- Non-music related factors that could predispose the musician to musculoskeletal problems.

Contribution to the overall aim of the thesis
This phase of the thesis established the pattern of injury among string instrumentalists in South Africa. The anatomic regions mainly affected were used to develop the exercise programme in Chapter 8.

Biomechanical analysis of string playing

Key outcomes
- Postural load during performance puts the violinists and the cellists at low and moderate risk for musculoskeletal problems.
- The neck position is relatively static in left lateral bending (3.5±2.4)o and flexion (17.5±1.3)o during violin performance.
- The range of motion in the right shoulder could predispose the violinist to impingement problems.
- There is increased muscle activity in the upper trapezius muscle.

Limitations
- Sample size
- Inability to evaluate other string instruments – double bass and viola (cello).

Contribution to the overall aim of the thesis
This phase of the study shows the physical demands of performance puts the violinist at risk for musculoskeletal problems. The movement pattern was used to develop an exercise based injury prevention programme in Chapter 8.

Scoping review 1 and 2

Key outcomes
- Exercise based interventions have been shown to reduce musculoskeletal problems and reduce perceived exertion .
- The component of current exercise programmes are: Strength,, endurance, core stabilisation exercises and stretching exercises, Proprioception and neuromuscular control
- Implementation, adherence and compliance
- Exercise reduces musculoskeletal problems and perceived exertion.
- Exercises was mainly to strengthen the muscles in the region with a high prevalence of musculoskeletal injuries which are the back, neck and shoulder regions.
- There is no specific exercise programme for musicians.
- Exercises extracted were stretching, endurance, strengthening, core stabilisers.

Contribution to the overall aim of the thesis
This phase of the thesis provided the foundation for the adapted exercises used in Chapter 8.

Exercise development process

Key outcomes
Exercises were adapted based on the integration of the results of study 1 and 2 and the key outcomes of the developed exercise programmes are listed below:
- Specific exercises were adapted based on the demands for the cervical region, shoulder region, lumbar, forearm and wrist.
- The validated exercise programme included general mobilisation, neural mobilisation and stabilisation of the rhomboids.
- Musicians believed that the exercises would be useful for them in managing injuries.
- Musicians are willing to implement the programme, however time constraints seems to be considered a challenge.

Limitations of the thesis
- The inability to develop specific exercise programmes for other string instrument (cello, double bass and viola players)
- The participants in the validation programme (physiotherapists with experience with managing PRMDs could have provided another insight to the exercise programme.

Strengths of the thesis
The major strength of this thesis was the biomechanical + pathoanatomical approach used in developing an exercise based injury prevention programme for violinists.

Contribution to the field
The exercise programme developed in this thesis can be used to prevent PRMDs among violinists. It also provides evidence for an instrument specific approach in preventing PRMDs in other instrument groups.

Figure 9.1: Summary of the key outcome, limitations and contribution of each study to the overall aim of the thesis.

9.1.1. Burden of PRMDs among string instrumentalists in South Africa

A cross sectional study of string instrumentalists in professional and youth orchestra in South Africa was conducted to determine the prevalence, severity and distribution of PRMDs as well as disability associated with PRMDs. A total of 114 string instrumentalists from 11 orchestras participated in the study. Of the overall sample, 67% were females and 62% play the violin. The median age of the participants was 28 years. The prevalence of musculoskeletal problems among string players in South Africa was high, 77% of the string players reported musculoskeletal problems in one or more anatomic region. The prevalence, distribution and severity of PRMDs in this study were similar to earlier studies (Chan et al., 2000, Abreu Ramos and Micheo, 2007). However, the key outcomes from this study were the racial differences and the impact of PRMDs on disability with respect to activity limitation and participation restriction.

Racial comparison of the prevalence of PRMDs showed that white string instrumentalists (62.1%) reported significantly higher lifetime prevalence than black (31.6%) string instrumentalists. This study was the first study to compare racial differences between string instrumentalists. The increased skeletal muscle mass of the black race could be responsible for the differences (Silva et al. (2010). The distribution of the PRMDs reported by the two races showed that 52.2% and 50.7% of the symptoms of PRMDs in the white race was in the neck and upper back respectively. In the neck and upper back regions, the black race reported a prevalence of 31.6% and 34.2% respectively. The prevalence of PRMDs in the low back is similar for both races. The major differences between the races are associated with regions mainly involved in postural stability of supporting the upper string instruments during performance (Moraes and Antunes, 2012). This difference could be further explored in future studies to determine what could be specifically responsible for these differences. The theory of WRMD by Karsh (2006) outlined an interaction between work environment, social cultural context, physical and psychological demands of the work as predisposing the worker to musculoskeletal injury. Therefore, future studies should explore the interaction of the factors discussed by Karsh (2006) in determining the risk factors associated with PRMDs in the South African population.

The impact of PRMDs as an impairment on activity and participation was an important result from this study. Other studies have reported an association between disability and PRMDs (Barton et al., 2008, Akel et al., 2016), however this study was the first study to explore disability according to the ICF guidelines – an interaction between impairment, activity limitation and participation restriction (World Health Organisation, 2001a). In this study, the severity of PRMDs was reported as mild – moderate, 54.5% of the string instrumentalists reported affectation in more than three anatomic regions. The postural adaptation and the repetition of movements over a prolonged period of time have been suggested to be responsible for the multiple anatomic regions often injured in string instrumentalists. The Quick DASH and the NDI were the instruments used to measure disability in this population and the median Quick DASH score and NDI was 6.8 and 10 respectively. However, the median activity limitation and participation score of the Quick DASH was 10.4 and 12.5 respectively. In string instrumentalists with more than four affected anatomic regions, the activity limitation and participation restriction score was 18.8 and 25 respectively. This result further defines the burden of PRMDs as affecting activities of daily living. An increase in disability scores is associated with an increase in the severity of musculoskeletal problems (Gay et al., 2007) (Fan et al., 2008, Niekel et al., 2009).

The results of this study represents a larger population of string instrumentalists in South Africa comapred to previous studies with small sample sizes (Hohls, 2010, Barnes et al., 2011, Ajidahun and Phillips, 2013b). Although, the results should be interpreted with caution due to the sampling bias and mode of questionnaire adminstration which are limitations of the study. Also, psychosocial and non music related factors such as other work demands that could predispose the string instrumentalists to muscloskeletal problems was not controlled for.

In conclusion, the burden of PRMDs among string instrumentalists in South Africa is high and it impacts on activity and participation. Also, racial differences were found in this study, these differences should be explored further in order to understand the positives and negative of the biological differences between races as a risk factor for PRMDs. Future studies should explore the integration of the theory of work related musculoskeletal disorders by Karsh (2006) in evaluating the risk factors associated with PRMDs among musicians in South Africa.

The conceptual framework utilised in this thesis was to establish the burden of string instrumentalists in South Africa and develop an exercise programme based on the physical demands (biomechanical) of performance and the distribution of PRMDs among string instrumentalists. The affected anatomic regions presented in this study were the neck, upper back, low back, right and left shoulders. The next phase of the study was to evaluate the biomechanical demands of playing the string instrument. The summary of the methodology and key outcomes of the biomechanical demands of playing the string instrument is explained in the next section.

9.1.2. Biomechanical analysis of string playing

This study evaluated the kinematic, electromyography and postural load of string players during performance. A sample of convenience six string instrumentalists (5 violinists and one cellist) volunteered for this study. The volunteers were required to be able to play the first movement (allegro) of the Eine kleine Nachtmusik by Mozart. During the performance, the joint range of motion, electromyography of selected muscles and postural load were recorded using the Xsens MVN Biotech, Labchart® and the RULA respectively. Prior to the musical performance, musculoskeletal assessment of the string instrumentalists was conducted. The key outcomes from the biomechanical analysis of performance were 1) the postural load associated with playing the violin and the cello and the 2) joint position of playing the violin.

The postural load was measured using the RULA and the grand RULA score of the string instrumentalists in this study for the right and left upper extremity was 4.8±0.5 and 3.8±0.5 respectively. This score is considered to place the worker in a low risk position and change may be considered (Middlesworth, n.d.). The cellist reported a higher grand RULA score in comparison to the violinists which puts the cellist in medium risk position. Inter individual differences and postural flaws is common among musicians (de Araújo et al., 2009) therefore, the postural load of the cellist could not be generalised. Likewise for the violinists, the sample size is not representative of the population and should be interpreted with caution. However, the RULA scores are indicative of a low – medium risk of musculoskeletal injury for string instrumentalists. The art of string playing is an age long skill and the likelihood of altering playing technique might not be feasible in the short term but an intervention programme in conditioning the body to the demands of the profession as well as ergonomic support would have positive outcomes in reducing the risk of musculoskeletal problems among string instrumentalists (Rickert et al., 2013, Rickert et al., 2014b, Rickert et al., 2014a).

The kinematic results showed that considerable movement was recorded in commonly injured anatomic regions, the neck, right and left shoulder. The neck was held in a static position in 17.5^o flexion and 3.5^o left lateral bending during performance for violinists. The left shoulder was positioned in flexion – extension, abduction – adduction and rotation with a mean joint angle of 31±11^o, 13±6^o and 22±10^o respectively. The right shoulder was in an increased abduction – adduction position (17.1±8.8)^o in comparison to the left shoulder (3.7±7.6)^o. In the elbow, the range of motion left elbow (68.4±12.8)^o was higher than in the right elbow (57.2±8.9)^o. Although, the minimum and maximum joint angle in elbow flexion shows that the left elbow joint was held in a reduced range with a difference of 21.2^o in comparison to the right elbow joint in a wider range, with a difference of 60.5^o.

The results of this study compared to the findings by Shan and Visentin (2003) which measured arm kinematics in violin performance by using a nine camera motion capture system. The average range of motion in the left upper extremity in this study using the inertial motion sensors showed a reduced range of motion in all the segments measured when compared with the study by Shan and Visentin (2003). This study showed an increased joint angles in the left shoulder joints when compared to the study by Shan and Visentin (2003). The kinematic characteristics of the right, left and the trunk in violin performance showed considerable movement in the neck, right, left and trunk and these are the most common regions of musculoskeletal problems in violin players. The neck position is static in an awkward position with the back trying to compensate for the awkward neck position and the bowing action of the right hand and PRMDs from the repeated strain. The findings in this study showed increased muscle activity in the right upper trapezius in comparison to the left which is similar to the results of muscle activity among professional violin and viola players (Berque and Gray, 2002, McCrary et al., 2016). The %MVC in this study for was highest in the right (10.9±9.1) and left upper trapezius (5.8±3.9). In these studies, the participants reported increased muscle activity in the right upper trapezius in comparison to the left upper trapezius with an increase in the difficulty of the music piece (Berque and Gray, 2002, McCrary et al., 2016). A study by Park et al. (2012), showed contradicting results where muscle activity in the left upper trapezius during performance was increased in comparison to the right upper trapezius. The difficulty of the music piece might be responsible for the differences in the results. Overuse syndrome is often associated with muscle activity (Berque and Gray, 2002). Low load (10% of MVC) with duration of activity are significant factors associated with overuse (Visentin and Shan, 2004).

The role of the upper trapezius in support and providing stability during violin performance has been reported in literature (Press and Levy, 1992). In all the muscles evaluated, the upper trapezius showed an increased muscle activity in comparison to the other muscles and this further confirms the load demand on the upper trapezius during violin performance as well as the muscle involved in the synchronised bowing activity of the right upper extremity. In the left upper extremity, which similarly acts as a support for the violin, the left elbow flexors also show an increased muscle activity, 6.9(9.9) which relates to an increased load in the static position during the course of the performance.

The biomechanical analysis of string playing showed that the most commonly injured anatomic regions are often related to the physical demands of performance. The back and the neck are mainly used for postural support in violinists. The right and left shoulders which are mainly used for the bowing and support in violinists respectively (Rolland, 1986). The study showed that the postural load during performance puts the string instrumentalists in a low – medium risk position for developing musculoskeletal injury (Middlesworth, n.d.). In the string instrumentalists studied, three out of six were positive for shoulder impingement problems bilaterally and this could have influenced the results of the biomechanical analysis. Muscle pain is associated with a reduction in muscle activity (Falla et al., 2004) and this could result in a reduction in range of motion. Due to the small sample size, a comparison between the significant effects of shoulder problems could not be ascertained but it is plausible that pain in the shoulder would result in a reduction in range of motion (Almeida et al., 2013). This study concludes that the joint position, range of motion, muscle activity, postural load are risks of developing musculoskeletal injury shoulder be considered in developing an exercise based injury prevention programme. The exercise programme should focus on the commonly injured anatomic regions putting into consideration the physical demands of playing the violin.

9.1.3. Development and validation of an exercise programme

As illustrated in Figure 9.1 above, two scoping reviews were conducted with the aim of 1) evaluating existing literature on the components and implementation of exercises for musicians and 2) extracting reproducible exercise programme used in the management of WRMDs. A scoping review method developed by Arksey and O'Malley (2005) was used in this study. The results of the scoping reviews were used in the development of an exercise based injury prevention programme for violinists.

The results of the first objective of the scoping review showed that, the components of the exercise intervention programmes was focussed on warm up, stretching, neuromuscular control exercises, strengthening and endurance exercises. The results of the scoping reviewed showed that the focus of injury prevention programmes among musicians has shifted from primarily improving skills to a more holistic approach of physical conditioning as it relates to performance (Chan et al., 2013a, Chan et al., 2014). Chan et al. (2013b), further evaluated compliance to the exercise programme among professional orchestra members and they reported that compliance was poor and participants with poor compliance reported a higher incidence of musculoskeletal injury.

The results of the second objective of the scoping extracted exercises from existing studies on injury prevention and management of work related musculoskeletal disorders were extracted from literature. The extracted exercises were categorised according to the anatomic regions – cervical, lumber, shoulder, elbow and forearm. The extracted exercises were adapted based on theoretical, logical and clinical rationale of the development of PRMDs among violinists.

The exercises were adapted based on the physical demands of performance for each affected region. The components of the exercise programme was focused on improving strength and endurance in the cervical region, shoulder strengthening and stabilisation exercises, core stabilisation exercises and strengthening and stretching exercises as outline in Table 8.1. The content and face validity of the developed exercise programme was conducted with physiotherapists and biokineticists and the exercise was modified based on clinical reasoning and the nuance demands of playing the violin as outlined in Table 8.4. The modified exercise programme was categorised into warm up, cool down, break time and conditioning exercises.

The developed exercise programme was focussed on improving strength and endurance in the cervical region, shoulder, lumbar and forearm as well as core stabilisation exercises. The developed programme based on the theory and results from Study 1 and 2 was validated. The face validity of the developed exercise programme was considered useful to violinists by the experts. Although, a review of the exercise programme by experts showed that the following exercises should be included – proprioceptive neuromuscular facilitation, neural mobilisation, thoracic mobilisation, general mobilisation exercises, rhomboids stabilisation exercises and additional stretching exercises. Proprioceptive neuromuscular facilitation was suggested as an important component of the left and right shoulder exercises based on the pattern and demands of the bowing arm especially. Tingling is a common symptom of PRMDs (Bragge et al., 2006) and it was suggested that this could be due to nerve compression of the median, radial or ulnar nerves, therefore neural mobilisation exercises should be included. The position of the cervical region during performance also suggests a possible compression of the nerves. Thoracic rotation exercises as well as progressive strengthening exercises of the thoracic region were included as a part of the exercise programme. The rationale for the inclusion was due to the trunk rotation associated with playing the string instrument and also the high prevalence of musculoskeletal problems in the upper thoracic region. Stabilisation exercises of the rhomboids were suggested to be included in the exercise programme. The scapular is important in supporting the violin and also in the excursion of shoulder movement. The shoulder is a complex joint and the integrity of the each of the joints that made up the shoulder complex is important in ensuring smooth movements. General mobilisation exercises of the upper extremity and trunk to ensure full range of motion was also suggested aimed at maintaining the physiological joint integrity, full range of motion is important.

The exercise programme was modified and an exercise based injury prevention programme was developed for violinists as outlined in Table 8.4. The developed exercise programme is comparable to the exercise programme developed for musicians by Chan et al. (2013a), although their programme was focused more on rehabilitation than prevention. The components of the exercise programme are similar in some aspects especially the shoulder proprioceptive neuromuscular facilitation exercises, deep neck flexor exercises and core stabilisation exercises. Also their exercise programme was categorised into warm up, main exercises and cool down exercises. In this study, the developed exercise programme was more preventive than rehabilitation and the programme was categorised into warm up, main exercises, cool down and exercises during breaks. Stretching during breaks has been shown to reduce perceived discomfort and eventual musculoskeletal injury in string instrumentalists (Cooper et al., 2012). The inclusion of neural mobilisation exercises in this exercise programme is important as one of the most common symptoms of PRMDs is tingling sensation. Tingling is often caused as a result of nerve compression and specific exercises to improve neuro-mobilisation and reduce compression could reduce the incidence of PRMDs. Other studies have overlooked nerve compression in the cervical region as a possible risk factor for PRMDs (Brandfonbrener, 1997, Ackermann et al., 2002b, Chan et al., 2013a). The consistent static position of the neck during violin performance could result into nerve compression C5, C6, C7, C8 and T1 nerve roots.

Exercise based injury prevention exercise programme was first reported in literature two decades ago (Brandfonbrener, 1997). Evidence on the components and the effectiveness of exercise as an injury prevention and management for musicians has been explored and evaluated in several studies (Brandfonbrener, 1997, Ackermann et al., 2002b, Chan et al., 2013a). Chan et al. (2013a) developed an exercise programme for musicians by utilising a formative evaluation approach.

This study was the first study to develop an exercise based injury prevention programme for violinists using the patho-anatomical pathway of injury and the demands of performance. The anatomic regions commonly affected are synonymous to the demands of performance Therefore, the biomechanical demands of performance was evaluated as a primary risk factor for the development of PRMDs. The exercise programme developed in this study was specific to violin players as an injury prevention strategy.

In conclusion, the content and the exercise programme for the prevention of musculoskeletal injury among violin was focussed on improving strength and endurance in the commonly affected anatomic regions. Health education as well as postural education integrated into the exercise programme would improve compliance and adherence. The implementation strategy suggested by music tutors and string players in the focus group discussions was focussed on educating the both the instructors and the students. The instructors also suggested that monitoring and implementation of the exercise programme can be done by them. The developed exercise programme can be adaptable for violists due to the similar pattern of holding the instrument with the violinists, although, the weight and the length of the viola in comparison to the violinists should be considered in the adaptation process. The exercise programme could be adapted for other string instrument groups, although, the demands of the specific instrument needs to be explored and evaluated in modifying the exercise programme for the cellist and the double bassist especially. Further research needs to be conducted in implementing the exercise programme. Compliance and adherence to exercise programme is a challenge. The cultural beliefs of musicians could also be an impediment to the implementation of the programme. Therefore, it would be important to implement a holistic health promotion programme which involves health education, risk factors, injury prevention and management.

9.2. Strength and limitations of the thesis

This study developed an exercise based injury prevention programme specific to violinists. The biomechanical demand of playing the violin was evaluated and the clinical reasoning approach was used to address the symptoms of PRMDs in the anatomic regions commonly affected. Early exercise programmes have only adapted exercises based on the basic demands of playing a musical instrument and the focus of the exercises is not instrument specific. The developed exercise programme in this study was modified specifically for the demands of violin performance.

Neural mobilisation was included as a component of the exercise programme due to the static left lateral bending position of the neck in supporting the violin during performance. The experts in this study suggested a likelihood of nerve compression in the nerve roots of C7-T1 as a result of the awkward position. The results of the cross sectional study showed that pins/needles and tingling were reported in 15.8% and 13.2% of the string instrumentalists surveyed. Tingling is a commonly reported symptom of PRMDs (Bragge et al., 2006) and it suggests a symptom of nerve compression. Thoracic mobilisation exercise was included as a component of the exercise programme during exercise validation phase due to the mean joint angle results of the thoracic region. The upper thoracic region mean joint angle was in 3.26 (1.91) degrees during violin performance and the upper back were commonly reported as the site of musculoskeletal problems in 44.7% of violinists. Thoracic mobilisation exercise could reduce the discomfort associated with posture among violinists.

The procedure of the exercise programme was categorised into warm up and cool down, conditioning exercises and exercises during breaks. Stretching exercises of the upper extremity was included in the study with the aim of reducing perceived discomfort and eventual overuse syndrome. Overuse is a common problem among string instrumentalists and repetitive bowing action of the right upper extremity predisposes the string instrumentalists to overuse injury. Cooper et al (2002), in their study showed significant positive results in reducing perceived exertion and PRMDs among string instrumentalists when performed during breaks.

This study integrated the biomechanical demands, patho-anatomical pathway to develop and exercise based injury prevention programme. However, the study has its own limitations. The selected experts for validation did not have experience in managing musicians; therefore, the developed exercise programme could have been biased towards a more general preventative approach although the experts were provided with the results of the biomechanical demands of performance. The small sample for the biomechanical analysis resulted in an inability to evaluate the differences between the biomechanical demands of playing the various string instruments. Also, significant differences between injured and uninjured violinists could have further evaluated the impact of PRMDs on the bio-kinematic results reported. Despite these limitations, the developed exercise programme could be piloted, adapted for other string instrumentalists and implemented, although the developed exercise programme is best suited for violinists.

9.3. Contribution to the field of research

Injury prevention in performing artists has progressed from only surveillance to prevention over the last three decades. Earlier studies exercise based injury prevention studies were focussed on the overall management of musicians without consideration of the difference demands of required to play the musical instrument (Brandfonbrener, 1997, Ackermann et al., 2002b, Chan et al., 2013a). This study would be the first study in literature to develop an instrument specific exercise based injury prevention programme. A trend in exercise based injury prevention could be set whereby the specific biomechanical demands of playing the various instrument is evaluated in the exercise development process. Specific exercise based injury prevention could result into a significant reduction in the problems associated with playing the musical instrument.

9.4. Recommendations for future research

The developed exercise programme should be piloted among violinists and possible modification for other string instrumentalists. A longitudinal intervention study to test the effect of the specific programme in the prevention of PRMDs among violinists would be conducted. Subsequently, further research related to the biomechanical analysis (physical demands) of playing the cello and double bass would be important in adapting this programme. A process of face and content validation of the adapted programme would be important. The specific effect of each exercise on the anatomic region should be evaluated. Education of musicians in South Africa on the associated risk factors and health promotion should be integrated as a component of music education training in South Africa.

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APPENDIX A: MODIFIED SELF - ADMINISTERED QUESTIONNAIRE

Musculoskeletal Injury Profile Questionnaire for String Players in South Africa

Thank you for your participation in this study. The aim of the study is to develop an exercise program to prevent playing related musculoskeletal disorder among string instrumentalists in South Africa. Please tick in the box where appropriate and **FILL IN THE SPACES PROVIDED ON QUESTIONS WITHOUT BLANKS.** All information on this survey is confidential and will be used for research purposes only. It takes about 8 minutes to complete the questionnaire. Thank you.

1. What is your age? ___________________ years
2. Gender:

   Male ☐ Female ☐
3. Which province do you reside in? Tick (✓) as appropriate

   Gauteng ☐ Western Cape ☐ Free state ☐

   Mpumalanga ☐ Eastern Cape ☐ KZN ☐

   North West ☐ Northern Cape ☐ Limpopo ☐
4. Race (for statistical purpose only):

   White ☐ Black ☐ Coloured ☐

   Asian ☐ Others ☐
5. What is the highest level of education you have attained?

   Postgraduate degree ☐ Bachelor's degree ☐

   Conservatory diploma ☐ Others ☐

   Matric ☐

   Please specify _________
6. Which is your dominant arm?

   Right ☐ Left ☐ Both ☐
7. Which is your major string instrument?

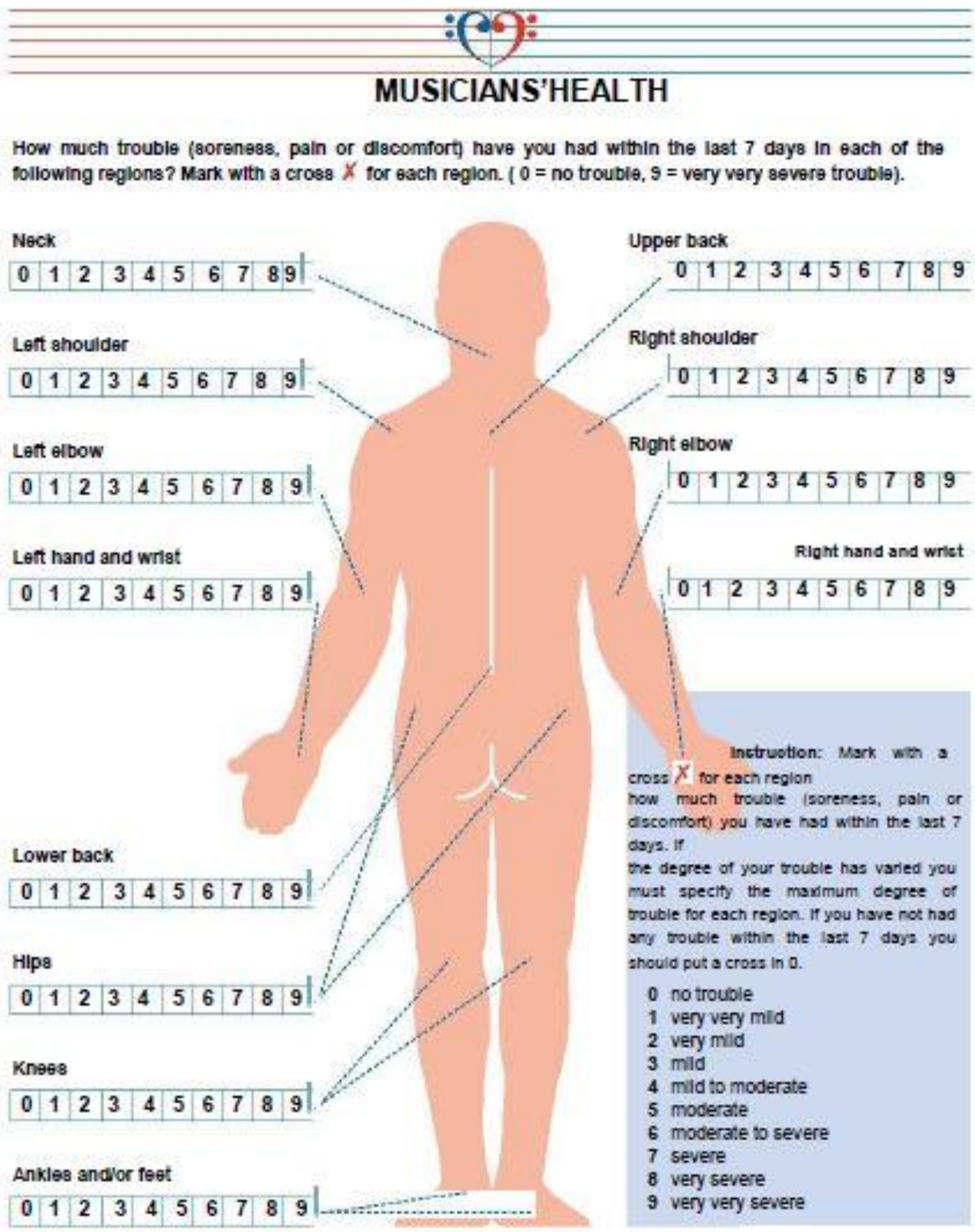
   Violin ☐ Viola ☐ Cello ☐ Double bass ☐
8. When playing, what position do you normally assume?

   High sitting ☐ Low sitting ☐ Standing ☐
9. For how many years have you played your instrument? _______________ years
10. For how many years have you played professionally in an orchestra /band?___________years

11. On average, how many hours per week do you spend playing your instrument in the orchestra (this includes rehearsals, performances, recordings)? __________________ hours per week
12. Do you presently have any musculoskeletal condition not related or due to you playing your musical instrument? Yes ☐ No ☐
13. If 'Yes' to Question 12, kindly explain____

    ____
14. Have you ever had pain/problems that have interfered with your ability to play your instrument at the level to which you are accustomed? Yes ☐ No ☐
15. Currently (in the past 7 days), do you have pain/problems that interfere with your ability to play your instrument at the level to which you are accustomed?

    Yes ☐ No ☐
16. How much trouble (soreness, pain or discomfort) have you had within the last 7 days in each of the following regions



17. Please tick ALL words that you would use to describe your discomfort or pain:

Tightening		Fatigue		Pins/needles		Cramping	
Tingling		Weakness		Burning		Radiating	
Aching		Dull		Sharp		Chronic	
Localized		Numb		Soreness		Diffuse	

APPENDIX B: NECK DISABILITY INDEX

Neck Disability Index

Office Use Only

Name ______________________________

Date ______________________________

This questionnaire has been designed to give us information as to how your neck pain has affected your ability to manage in everyday life. Please answer every section and **mark in each section only the one box that applies to you.** We realise you may consider that two or more statements in any one section relate to you, but please just mark the box that most closely describes your problem.

Section 1: Pain Intensity

☐ I have no pain at the moment
☐ The pain is very mild at the moment
☐ The pain is moderate at the moment
☐ The pain is fairly severe at the moment
☐ The pain is very severe at the moment
☐ The pain is the worst imaginable at the moment

Section 2: Personal Care (Washing, Dressing, etc.)

☐ I can look after myself normally without causing extra pain
☐ I can look after myself normally but it causes extra pain
☐ It is painful to look after myself and I am slow and careful
☐ I need some help but can manage most of my personal care
☐ I need help every day in most aspects of self care
☐ I do not get dressed, I wash with difficulty and stay in bed

Section 3: Lifting

☐ I can lift heavy weights without extra pain
☐ I can lift heavy weights but it gives extra pain
☐ Pain prevents me lifting heavy weights off the floor, but I can manage if they are conveniently placed, for example on a table
☐ Pain prevents me from lifting heavy weights but I can manage light to medium weights if they are conveniently positioned
☐ I can only lift very light weights
☐ I cannot lift or carry anything

Section 4: Reading

☐ I can read as much as I want to with no pain in my neck
☐ I can read as much as I want to with slight pain in my neck
☐ I can read as much as I want with moderate pain in my neck
☐ I can't read as much as I want because of moderate pain in my neck
☐ I can hardly read at all because of severe pain in my neck
☐ I cannot read at all

Section 5: Headaches

☐ I have no headaches at all
☐ I have slight headaches, which come infrequently
☐ I have moderate headaches, which come infrequently
☐ I have moderate headaches, which come frequently
☐ I have severe headaches, which come frequently
☐ I have headaches almost all the time

Section 6: Concentration

☐ I can concentrate fully when I want to with no difficulty
☐ I can concentrate fully when I want to with slight difficulty
☐ I have a fair degree of difficulty in concentrating when I want to
☐ I have a lot of difficulty in concentrating when I want to
☐ I have a great deal of difficulty in concentrating when I want to
☐ I cannot concentrate at all

Section 7: Work

☐ I can do as much work as I want to
☐ I can only do my usual work, but no more
☐ I can do most of my usual work, but no more
☐ I cannot do my usual work
☐ I can hardly do any work at all
☐ I can't do any work at all

Section 8: Driving

☐ I can drive my car without any neck pain
☐ I can drive my car as long as I want with slight pain in my neck
☐ I can drive my car as long as I want with moderate pain in my neck
☐ I can't drive my car as long as I want because of moderate pain in my neck
☐ I can hardly drive at all because of severe pain in my neck
☐ I can't drive my car at all

Section 9: Sleeping

☐ I have no trouble sleeping
☐ My sleep is slightly disturbed (less than 1 hr sleepless)
☐ My sleep is mildly disturbed (1-2 hrs sleepless)
☐ My sleep is moderately disturbed (2-3 hrs sleepless)
☐ My sleep is greatly disturbed (3-5 hrs sleepless)
☐ My sleep is completely disturbed (5-7 hrs sleepless)

Section 10: Recreation

☐ I am able to engage in all my recreation activities with no neck pain at all
☐ I am able to engage in all my recreation activities, with some pain in my neck
☐ I am able to engage in most, but not all of my usual recreation activities because of pain in my neck
☐ I am able to engage in a few of my usual recreation activities because of pain in my neck
☐ I can hardly do any recreation activities because of pain in my neck
☐ I can't do any recreation activities at all

Score: ___/50 Transform to percentage score x 100 = %points

Scoring: For each section the total possible score is 5: if the first statement is marked the section score = 0, if the last statement is marked it = 5. If all ten sections are completed the score is calculated as follows: Example: 16 (total scored)
50 (total possible score) x 100 = 32%

If one section is missed or not applicable the score is calculated: 16 (total scored)
45 (total possible score) x 100 = 35.5%

Minimum Detectable Change (90% confidence): 5 points or 10 %points

NDI developed by: Vernon, H. & Mior, S. (1991). The Neck Disability Index: A study of reliability and validity. Journal of Manipulative and Physiological Therapeutics. 14, 409-415

APPENDIX C: QUICK DISABILITY OF THE ARM, SHOULDER AND HANDS QUESTIONNAIRE

Please rate your ability to do the following activities in the last week by circling the number below the appropriate response.

	NO DIFFICULTY	MILD DIFFICULTY	MODERATE DIFFICULTY	SEVERE DIFFICULTY	UNABLE
1. Open a tight or new jar.	1	2	3	4	5
2. Write.	1	2	3	4	5
3. Turn a key.	1	2	3	4	5
4. Prepare a meal.	1	2	3	4	5
5. Push open a heavy door.	1	2	3	4	5
6. Place an object on a shelf above your head.	1	2	3	4	5
7. Do heavy household chores (e.g., wash walls, wash floors).	1	2	3	4	5
8. Garden or do yard work.	1	2	3	4	5
9. Make a bed.	1	2	3	4	5
10. Carry a shopping bag or briefcase.	1	2	3	4	5
11. Carry a heavy object (over 10 lbs).	1	2	3	4	5
12. Change a lightbulb overhead.	1	2	3	4	5
13. Wash or blow dry your hair.	1	2	3	4	5
14. Wash your back.	1	2	3	4	5
15. Put on a pullover sweater.	1	2	3	4	5
16. Use a knife to cut food.	1	2	3	4	5
17. Recreational activities which require little effort (e.g., cardplaying, knitting, etc.).	1	2	3	4	5
18. Recreational activities in which you take some force or impact through your arm, shoulder or hand (e.g., golf, hammering, tennis, etc.).	1	2	3	4	5
19. Recreational activities in which you move your arm freely (e.g., playing frisbee, badminton, etc.).	1	2	3	4	5
20. Manage transportation needs (getting from one place to another).	1	2	3	4	5
21. Sexual activities.	1	2	3	4	5

	NOT AT ALL	SLIGHTLY	MODERATELY	QUITE A BIT	EXTREMELY
22. During the past week, *to what extent* has your arm, shoulder or hand problem interfered with your normal social activities with family, friends, neighbours or groups? *(circle number)*	1	2	3	4	5

	NOT LIMITED AT ALL	SLIGHTLY LIMITED	MODERATELY LIMITED	VERY LIMITED	UNABLE
23. During the past week, were you limited in your work or other regular daily activities as a result of your arm, shoulder or hand problem? *(circle number)*	1	2	3	4	5

Please rate the severity of the following symptoms in the last week. *(circle number)*

	NONE	MILD	MODERATE	SEVERE	EXTREME
24. Arm, shoulder or hand pain.	1	2	3	4	5
25. Arm, shoulder or hand pain when you performed any specific activity.	1	2	3	4	5
26. Tingling (pins and needles) in your arm, shoulder or hand.	1	2	3	4	5
27. Weakness in your arm, shoulder or hand.	1	2	3	4	5
28. Stiffness in your arm, shoulder or hand.	1	2	3	4	5

	NO DIFFICULTY	MILD DIFFICULTY	MODERATE DIFFICULTY	SEVERE DIFFICULTY	SO MUCH DIFFICULTY THAT I CAN'T SLEEP
29. During the past week, how much difficulty have you had sleeping because of the pain in your arm, shoulder or hand? *(circle number)*	1	2	3	4	5

	STRONGLY DISAGREE	DISAGREE	NEITHER AGREE NOR DISAGREE	AGREE	STRONGLY AGREE
30. I feel less capable, less confident or less useful because of my arm, shoulder or hand problem. *(circle number)*	1	2	3	4	5

DASH DISABILITY/SYMPTOM SCORE = $\left[\left(\frac{\text{sum of n responses}}{n}\right) - 1\right] \times 25$, where n is equal to the number of completed responses.

A DASH score may not be calculated if there are greater than 3 missing items.

WORK MODULE (OPTIONAL)

The following questions ask about the impact of your arm, shoulder or hand problem on your ability to work (including homemaking if that is your main work role).

Please indicate what your job/work is:__________________________

p I do not work. (You may skip this section.)

Please circle the number that best describes your physical ability in the past week. Did you have any difficulty:

	NO DIFFICULTY	MILD DIFFICULTY	MODERATE DIFFICULTY	SEVERE DIFFICULTY	UNABLE
1. using your usual technique for your work?	1	2	3	4	5
2. doing your usual work because of arm, shoulder or hand pain?	1	2	3	4	5
3. doing your work as well as you would like?	1	2	3	4	5
4. spending your usual amount of time doing your work?	1	2	3	4	5

SPORTS/PERFORMING ARTS MODULE (OPTIONAL)

The following questions relate to the impact of your arm, shoulder or hand problem on playing *your musical instrument* or *sport* or *both*.
If you play more than one sport or instrument (or play both), please answer with respect to that activity which is most important to you.

Please indicate the sport or instrument which is most important to you:_

o I do not play a sport or an instrument. (You may skip this section.)

Please circle the number that best describes your physical ability in the past week. Did you have any difficulty:

	NO DIFFICULTY	MILD DIFFICULTY	MODERATE DIFFICULTY	SEVERE DIFFICULTY	UNABLE
1. using your usual technique for playing your instrument or sport?	1	2	3	4	5
2. playing your musical instrument or sport because of arm, shoulder or hand pain?	1	2	3	4	5
3. playing your musical instrument or sport as well as you would like?	1	2	3	4	5
4. spending your usual amount of time practising or playing your instrument or sport?	1	2	3	4	5

SCORING THE OPTIONAL MODULES: Add up assigned values for each response; divide by 4 (number of items); subtract 1; multiply by 25.

An optional module score may not be calculated if there are any missing items.

APPENDIX D: MUSCULOSKELETAL ASSESSMENT SHEET

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

Musculoskeletal assessment sheet

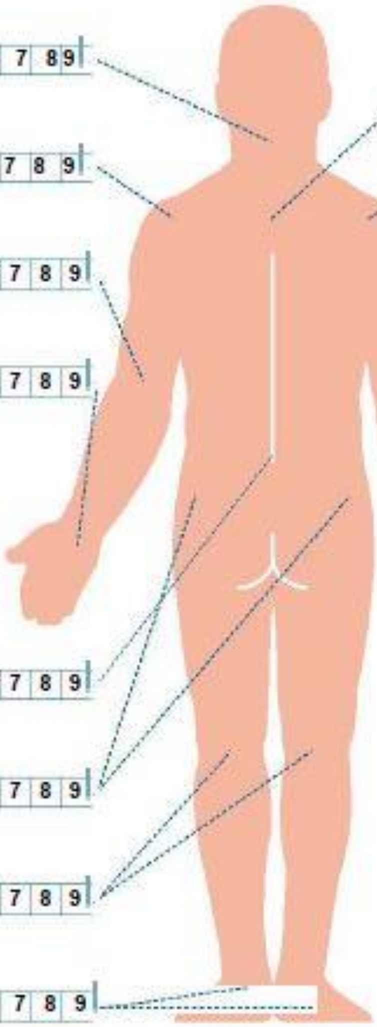
Name: **Participant ID:**

Date of assessment: **Name of assessor:**

	Socio-demographics	
1.	What is your gender?	
2	How old are you?	
3	What string instrument do you play?	
4	How many years have you played your instrument?	
5	On the average, how many hours per week do you spend playing your instrument in the orchestra (this includes rehearsals, performances, recordings)?	
6	Have you ever had pain/problems that have interfered with your ability to play your instrument at the level to which you are accustomed?	
7	Currently (in the past 7 days), do you have pain/problems that interfere with your ability to play your instrument at the level to which you are accustomed?	
8	Handedness (right, left or both)	
9	Weight (in kg)	
10	Height (in meters)	
11	Foot size	
12	Arm span	
13	Ankle height	
14	Hip height	
15	Hip width	
16	Knee height	
17	Shoulder width	
18	Shoe sole height	

MUSICIANS'HEALTH

How much trouble (soreness, pain or discomfort) have you had within the last 7 days in each of the following regions? Mark with a cross ✗ for each region. (0 = no trouble, 9 = very very severe trouble).



Neck

0 1 2 3 4 5 6 7 8 9

Upper back

0 1 2 3 4 5 6 7 8 9

Left shoulder

0 1 2 3 4 5 6 7 8 9

Right shoulder

0 1 2 3 4 5 6 7 8 9

Left elbow

0 1 2 3 4 5 6 7 8 9

Right elbow

0 1 2 3 4 5 6 7 8 9

Left hand and wrist

0 1 2 3 4 5 6 7 8 9

Right hand and wrist

0 1 2 3 4 5 6 7 8 9

Lower back

0 1 2 3 4 5 6 7 8 9

Hips

0 1 2 3 4 5 6 7 8 9

Knees

0 1 2 3 4 5 6 7 8 9

Ankles and/or feet

0 1 2 3 4 5 6 7 8 9

Instruction: Mark with a cross ✗ for each region how much trouble (soreness, pain or discomfort) you have had within the last 7 days. If the degree of your trouble has varied you must specify the maximum degree of trouble for each region. If you have not had any trouble within the last 7 days you should put a cross in 0.

0 no trouble
1 very very mild
2 very mild
3 mild
4 mild to moderate
5 moderate
6 moderate to severe
7 severe
8 very severe
9 very very severe

Postural assessment (Subjective evaluation)

Postural assessment	Normal	Mild asymmetry	Sig. asymmetry
Shoulder symmetry			
Shoulder roundness			
	Chin poke	Forward head	Neutral
Cervical spine			
	Increased	Normal	Decreased
Thoracic kyphosis			
Lumbar lordosis			
	Normal	Anterior Tilt	Posterior Tilt
Pelvic Tilt			

Shoulder and scapular assessment

Kiblers test (lateral slide test)	Right	Left
Shoulder in neutral		
Shoulder at 40-45 degrees of coronal plane abduction with hands resting on hips		
shoulder at 90 degrees abduction with the arms in full internal rotation		

Impingement	Right	Left
Hawkins - Kennedy test		
Painful arc test		
Neer’s test		

Gross muscle strength

MUSCLE STRENGTH	Right	Left
Hand grip		

Hypermobility	Right	Left	Total
Passive dorsiflexion of the little fingers beyond 90 degrees (1 point for each hand)			
Passive apposition of the thumbs to the flexor aspects of the forearm (1 point for each hand)			
Hyperextension of the elbows beyond 10 degrees (1 point for each elbow)			
Hyperextension of the knee beyond 10 degrees (1 point for each knee)			
Forward flexion of the trunk with the knees fully extended so that the palms of the hands rest flat on the floor.			
TOTAL			

Upper crossed syndrome

Component	**Right**	**Left**
Cervical flexion		
Push up		
Shoulder abduction		
Summary		

Stabilisation systems

	Right	**Left**
Serratus anterior		
Transversus abdominis		
Multifidus		
Summary		

APPENDIX E: MUSCULOSKELETAL ASSESSMENT PROCEDURE

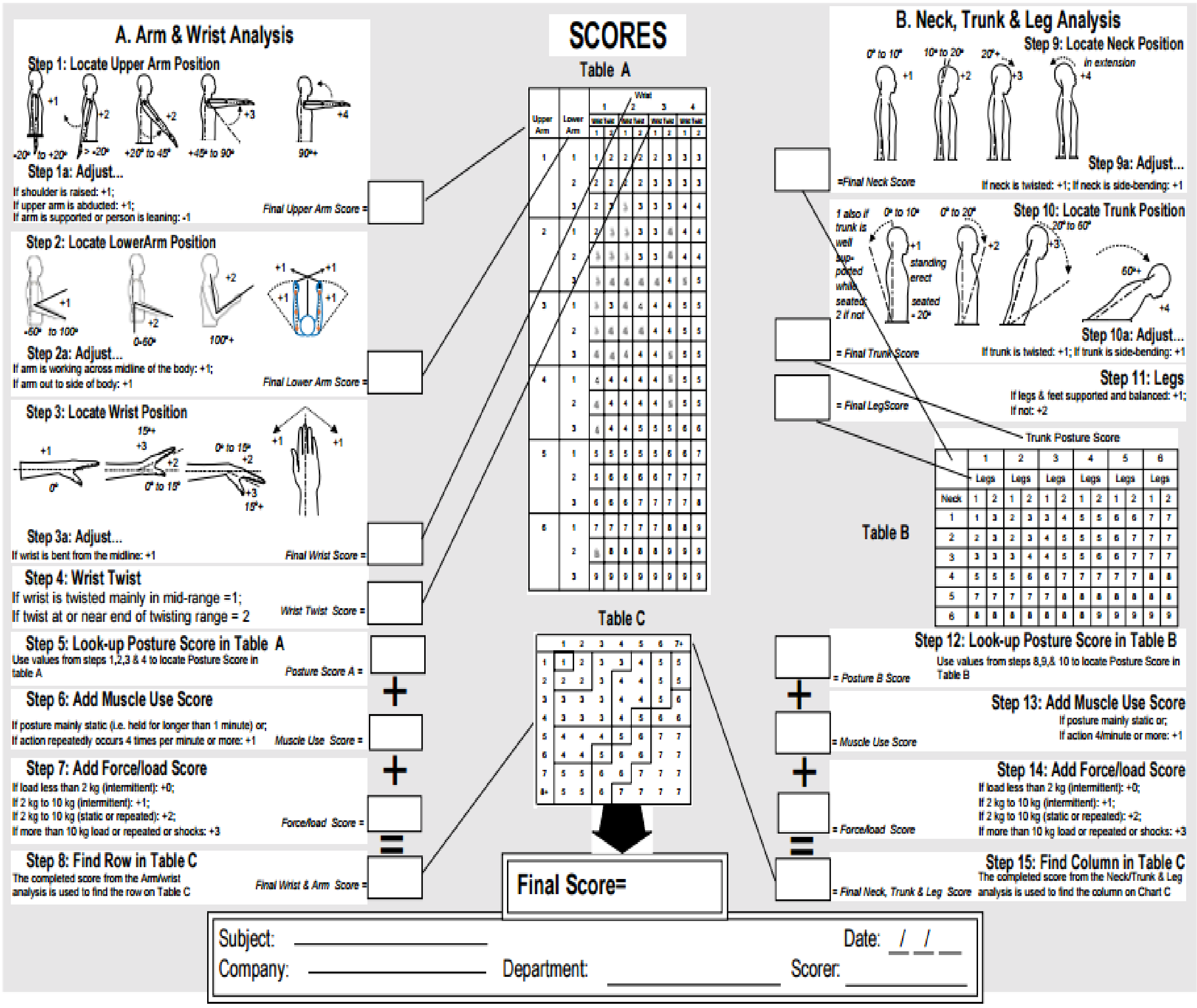
Test	Procedure	Implication
Muscle imbalance	Cervical flexion: • Participant in sitting • Active forward neck flexion Push up • Patients stand in front of a wall • Arms elevated at 90 degrees • Elbow extended and the participant is asked to do a push up on the wall. Shoulder abduction: • Patient in sitting • Patient is instructed to abduct the arm • Physiotherapist supports the inferior angle of the scapula •	Cervical flexion Implication • Prominence of the SCM at mid to distal insertion • Forward head posture • Increased angle (>90 degrees) between the chin and the neck • Impaired respiration Push up Implication: • Increased internal rotation of the arms • Nipples that face out superiorly and laterally (in males) • Scapula winging and tipping Shoulder abduction Implication: • Forward head with protracted shoulder • Gothic shoulder • Levator notch • Scapular winging and tipping
Lumbo-pelvic stabilisation	The modified lumbo-pelvic stabilisation palpation test described by Steinmetz et al. (2010) was used in this study. TrA • Participant in supine • Assessor palpates the insertion of the abdominal muscles on the anterior superior iliac spine • The patient is instructed to suck in the abdomen and a gentle deep tension should be felt under the fingers equally on each side MF • Participant in supine • Assessor places one in the vertebrae and the participants were asked to press their spine against the hand of the assessor	A change to the tension indicates increased activation of the superficial and global rather than independent contraction of the TrA. The test is also positive if the patient loses the resting the resting lumbar lordosis.
Scapular stabilisation (serratus anterior)	• Patients stand in front of a wall • Arms elevated at 90 degrees • Elbow extended and the participant is asked to do a push up on the wall.	Normally the scapular should adduct. Test is positive if the scapula loses contact with the chest wall.

Test	Procedure	Implication
Hand grip strength	Participant were seated, the elbow at 90 degrees. The dynamometer was calibrated for male and female separately. Participants were asked to grip the dynamometer as much as possible using the second rung. Three trials were recorded and the mean of the three trials was finally recorded for analysis.	n/a
Neer's test	• Patient in sitting position • Therapist stabilizes the scapula to prevent scapula rotation. • Therapist then moves the shoulder into maximal forward flexion.	The test is positive if the participant reports pain in this position.
Painful arc test	• Participant in standing • Participant was instructed to abduct the arm and to report if there was pain around the gleno-humeral region	A positive test is considered when the patient reports pain between 60 and 120 degrees which subsides in the range after 120 degrees
Hawkins-Kennedy test	• Participant in standing • Patients shoulder is flexed to 90 degrees and stabilized • The shoulder is then passively moved into internal rotation	Pain on internal rotation is considered positive for impingement problems.
Beighton's hypermobility test	Passive dorsiflexion of the 5th metacarpophalangeal joint (bilateral testing) Passive hyperextension of the elbow (bilateral testing) Passive hyperextension of the knee (bilateral testing) Passive apposition of the thumb to the flexor side of the forearm (bilateral testing) Forward flexion of the trunk with the knees straight:	Total score of <5 suggests hypermobility
Kibler's test	This test involves measuring the distance from the inferior angle of the scapula to the nearest vertebral spinous process using a tape measure or goniometer in three positions: shoulder in neutral, shoulder at 40-45 degrees of coronal plane abduction with hands resting on hips, and the shoulder at 90 degrees abduction with the arms in full internal rotation.	A difference of <1.5cm between the right and left measurement is considered as scapular asymmetry.

APPENDIX F: RULA ASSESSMENT WORKSHEET

RULA Employee Assessment Worksheet

Complete this worksheet following the step-by-step procedure below. Keep a copy in the employee's personnel folder for future reference.



FINAL SCORE: 1 or 2 = Acceptable; 3 or 4 investigate further; 5 or 6 investigate further and change soon; 7 investigate and change immediately

Source: McAtamney, L. & Corlett, E.N. (1993) RULA: a survey method for the investigation of work-related upper limb disorders, Applied Ergonomics, 24(2) 91-99.

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APPENDIX G: APPROVAL OF TITLE

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

Private Bag 3 Wits, 2050
Fax: 027117172119
Tel: 02711 7172076

Reference: Mrs Sandra Benn
E-mail: sandra.benn@wits.ac.za

20 March 2017
Person No: 709213
TAA

Mr AT Ajidahun
P O Box 1442
Enuwa
Ile-Ife
South Africa

Dear Mr Ajidahun

Doctor of Philosophy: Change of title of research

I am pleased to inform you that the following change in the title of your Thesis for the degree of **Doctor of Philosophy** has been approved:

From:	**The effect of a structured exercise programme on playing related musculoskeletal disorders among string instrumentalists**
To:	**Development of an exercise based injury prevention programme for string players**

Yours sincerely

UBenn

Mrs Sandra Benn
Faculty Registrar
Faculty of Health Sciences

APPENDIX H: ETHICAL APPROVAL

HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)

CLEARANCE CERTIFICATE NO. M130836

NAME: (Principal Investigator)	Mr Adedayo T Ajidahun
DEPARTMENT:	Department of Physiotherapy Medical School
PROJECT TITLE:	The Effect of a Strucutred Exercise Program on Playing Related Musculoskeletal Disorder (PRMD) among String Instrumentalist
DATE CONSIDERED:	30/08/2013
DECISION:	Approved unconditionally
CONDITIONS:	
SUPERVISOR:	Dr Witness Mudzi
APPROVED BY:	Professor PE Cleaton-Jones, Chairperson, HREC (Medical)

DATE OF APPROVAL: 27/09/2013

This clearance certificate is valid for 5 years from date of approval. Extension may be applied for.

DECLARATION OF INVESTIGATORS

To be completed in duplicate and **ONE COPY** returned to the Secretary in Room 10004, 10th floor, Senate House, University.
I/we fully understand the conditions under which I am/we are authorized to carry out the above-mentioned research and I/we undertake to ensure compliance with these conditions. Should any departure be contemplated, from the research protocol as approved, I/we undertake to resubmit the application to the Committee. **I agree to submit a yearly progress report**.

Principal Investigator Signature M130836Date

APPENDIX I: PERMISSION TO CONDUCT STUDY AND APPROVAL

Study title: The development of an exercise programme for the prevention Playing Related Musculoskeletal Disorders (PRMD) among string players

Good day Sir/Madam

Introduction:

I am a PhD student at the Department of Physiotherapy, University of Witwatersrand and I am doing a study to determine the effect of exercise on musculoskeletal disorders associated with playing string instruments. Studies have shown string instrumentalists report injuries such as pain most especially in the arms, hands and neck and several risk factors have been associated to be a cause of these complaints. The overall aim of this study is to develop an exercise programme for the prevention of PRMDs among string instrumentalists. The objective of this phase is to determine the prevalence, distribution, symptoms, severity of Playing Related Musculoskeletal Disorders among string instrumentalists in South Africa. I am inviting you to take part in this study. Participants will volunteer to complete a self – administered questionnaire with questions such as demographics, practice habits and injury profile. It takes about 30 minutes to complete the questionnaire.

Benefits

Participants get to have a clearer understanding about musculoskeletal disorders associated with their occupation.

Participation in this study is voluntary and refusal to participate has no negative effects.

Participants may discontinue participation at any time.

The participant will be given pertinent information on the study while involved in the project and after the results are available.

There will be reimbursements for out of pocket expenses such as travel allowances to the site of study.

Confidentiality

Efforts will be made to keep personal information confidential. Absolute confidentiality cannot be guaranteed. Personal information may be disclosed if required by law.

Organisations that may inspect and/or copy your research records for quality assurance and data analysis include groups such as the Research Ethics Committee. If results are published, may lead to individual / cohort identification.

Contact details of researcher/s – for further information / reporting of study related adverse events
Adedayo Tunde Ajidahun
Department of Physiotherapy,
University of Witwatersrand,
Johannesburg
0781781423
adajidahun@aol.com

Contact details of REC administrator and chair – for reporting of complaints / problems.
HREC (Medical) Secretary:
Anisa Keshav
E-mail: anisa.keshav@wits.ac.za
(011) 717-1234
(011) 717-1224

HREC (Medical) Chairperson
Prof. Cleaton Jones
E-mail: peter.cleaton-jones@wits.ac.za
(011) 717-2635

APPENDIX J: INFORMED CONSENT FORMS

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

Informed consent form for cross sectional study

I…………….. ……………………………………………….. *(Full names of participant)* hereby confirm that I understand the nature of the research project, and I consent to participating in this study.

Questionnaires will be coded and there will be no identifiers.

I understand that I can withdraw from the project at any time, should I so desire.

Signature Participant **Date:**

____

UNIVERSITY OF THE
WITWATERSRAND,
JOHANNESBURG

Informed consent form for biomechanical analysis

I…………….. ……………………………………………….. *(Full names of participant)* hereby confirm that I understand the nature of the research project, and I consent to participating in this study.

Questionnaires will be coded and there will be no identifiers.

I consent that my picture can be taken and it must be used solely for the aim of the research and must be blinded if it's published.

I understand that I can withdraw from the project at any time, should I so desire.

Signature Participant **Date:**

____

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

Informed consent form for focus group discussion

I…………….. ……………………………………………….. *(Full names of participant)* hereby confirm that I understand the nature of the research project, and I consent to participating in this study.

Questionnaires will be coded and there will be no identifiers.

Confidentiality cannot be assured in a Focus Group Discussion.

I understand that I can withdraw from the project at any time, should I so desire.

Signature Participant **Date:**

____

APPENDIX K: INTERVIEW GUIDE FOR FOCUS GROUP DISCUSSION

Question 1

What is your opinion about the usefulness of the specific exercise programme for string players?

Question 2

Would you be willing to implement this programme with your students?

Question 3

How do you think adequate implementation can be achieved?

APPENDIX L: PROCEDURE OF THE SPECIFIC EXERCISES

Cervical / thoracic region

Upper trapezius / levator scapulae stretch

- Sit on a chair
- Hold the edge of the chair with one hand
- If holding the chair with your right hand, lean your head to the left drop your head forward and turn your chin to the right.
- Add pressure with the contralateral hand
    - For levator scapulae, turn your neck 45 degrees and pull your head towards the contralateral knee.

Hold relax exercises of the upper trapezius

- Sit on the chair
- Hold the chair on both sides and shrug the shoulder to 40-45% MVC
- Hold for 10 seconds and relax

Upper limb neural gliding exercises

Median nerve gliding exercises

- Wrist straight with fingers and thumb flexed
- Wrist straight, fingers and thumb extended or straight
- Thumb neutral, fingers and wrist extended
- Wrist, fingers and thumb extended
- Same position as above, add forearm supination
- Same as position above, gently stretch thumb with the other hand
    - Stretch only until you feel a gentle tension not pain.

Ulnar nerve gliding exercises

- Arm extended in front of body with elbow straight and wrist flexed
- Move wrist and fingers into extension while keeping elbow straight
- Bend the elbow while keeping wrist and fingers extended
- Move arm out to the side then gently flex the wrist
- Rotate the arm towards the neck
- Gently tip your head to the opposite side

Radial nerve gliding exercises

- Stand with body relaxed
- Add shoulder depression
- Internally rotate and flex the wrist
- Add lateral cervical flexion

- Flex wrist as shoulder is extended

Deep neck flexors

- Patient in supine lying with the knee flexed
- Chin retracted and kept in this position for 20 seconds
- With the chin retracted, subject lifts the head up and maintains this position for as long as possible.

Thoracic rotation exercises

- Sit upright in a chair
- Rotate your body around to one side
- Then rotate around to the other side to the end of range of motion

Lumbar region

Core stabilisation exercises in three phases

a. **Activation phase (activation of the transversus abdominis and multifidus)**

b. **Skill precision: Improve task**

- Co-activation of deep muscles
- Coordination with breathing
- Progression to static functional position
- Progression to light dynamic task

c. **Integrate activation of the core stabilisers with dynamic movements in the upper extremity**

- Subjects sit on a chair
- The co-activation of the deep muscles is held for 30 seconds
- Subjects is asked to move the shoulder/elbow in the biomechanical direction of movement (abduction/adduction, flexion/extension, internal rotation/external rotation)
- Repeat 10 times

Bird dog exercises (general lumbar stabilisation training)

- Patients in quadruped position with elbow locked straight and head in neutral position.
- Patients pull in the belly button and lift one leg off the floor so that the limb is in line with the trunk and then opposite side arm is lifted off the ground.

Shoulder region

Pectoralis minor stretch

- Locate a corner or doorway
- Place one hand on each side of the corner at shoulder height
- Lean your chest forward into the corner so you feel a stretch in your upper chest

Posterior capsule stretch

- Reach arm across your body
- Place your hand over the opposite shoulder
- Use your opposite hand on your elbow to pull your arm towards your body
- Increase the stretch across the back of your shoulder

Shoulder strengthening exercises

- Use resistance elastic band
- Sit on chair.
- Alternate arm fixates the elastic band
- The other arm moves the shoulder in the diagonal proprioceptive pattern with resistance

Scapular stabilisation exercises

- Push up plus
- Subject stand against the wall
- Arms approximately shoulder width apart
- Subjects pushed against the wall until elbows are fully extended and the scapulae are protracted as far as possible

Shoulder shrugs

- Subject stands
- Arms by the side
- Subjects lifts up the shoulder
- Subjects adds shoulder rotation forwards and backwards

Rotator cuff exercises (thumb up and down)

- Subject sits/stands
- Abducts arm to about 30 degrees
- Thumb points up
- Shoulder is rotated actively to full internal rotation and then external rotation

Pendulum exercises

- Subjects lean on the chair for support
- The contralateral arm is left hanging in about 20 degree abduction
- Swing backwards and forwards

Elbow and wrist region

Finger exercises

- Clench and unclench fist
- Finger extension against resistance (elastic bands)

Biceps stretch

Begin with your back and neck straight and your arm supported behind you on a bench or table. Gently lower your body, allowing your arm to move further behind you until you feel a mild to moderate stretch pain-free. Hold for 15 seconds and repeat 4 times.

Triceps stretch

- Actively reach right hand down back and give gentle assistance with left hand, exhale and hold stretch for 2 seconds
- Actively reach left hand up back as high as possible and give gentle assistance with right hand, exhale and hold stretch for 2 seconds
- Repeat for prescribed number of repetitions, then switch hands and repeat

Intrinsic hand muscle exercises

- Clench and unclench exercises and resistance against rubber band.