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EFFICIENCY OF MOVEMENT  
IN VIOLIN BOWING

by

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for the Degree of Master of Music

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## **DECLARATION**

This work has not been previously submitted in whole, or in part, for the award of any degree. It is my own work. Each significant contribution to, and quotation in, this dissertation from the work of other people has been attributed, and has been cited and referenced.

Signature: \_\_\_\_\_

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Figure 43: The position of the right hand playing at the tip of the bow .....	57
Figure 44: The position of the right hand playing at the middle of the bow .....	58
Figure 45: The position of the right hand playing at the nut .....	58
Figure 46: Flexion of the fingers on the bow.....	59
Figure 47: Extension of the fingers on the bow .....	60
Figure 48: Lifting the bow, before straightening the wrist .....	61
Figure 49: Lifting the bow, after straightening the wrist.....	61
Figure 50: Ball balancing on strings .....	65
Figure 51: Left hand pizzicato .....	66

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# CONTENTS

LIST OF FIGURES .....	iii
ACKNOWLEDGEMENTS .....	v
ABSTRACT .....	vi
CHAPTER ONE: INTRODUCTION .....	vi
1.1 BACKGROUND .....	1
1.2 STATEMENT OF THE PROBLEM .....	5
1.3 PURPOSE OF THE STUDY .....	6
1.4 METHODOLOGY .....	6
1.5 LIMITATIONS OF THE STUDY .....	11
1.6 CHAPTER OUTLINE .....	11
CHAPTER TWO: THE APPLICATION OF SCIENTIFIC THEORIES TO THE ART OF BOWING .....	13
2.1 INERTIA AND MOMENTUM IN BOWING .....	13
2.2 REACTION IN BOWING .....	15
2.3 SLOW-CONTROLLED AND REPETITIVE MOVEMENTS .....	17
2.4 THE RIGHT ARM AS A SYSTEM OF LEVERS .....	20
2.5 MOVEMENT ANALYSIS .....	20
2.5.1 Computer enhanced photography .....	21
2.5.2 Cyclegraphs and graphs .....	29
2.5.3 Movement analysis using graphs .....	39
2.6 CONCLUSIONS OF THE GRAPHICAL MOTION STUDY .....	43
CHAPTER THREE: POSTURE, BALANCE AND FLEXIBILITY .....	46
3.1 INTRODUCTION .....	46
3.2 POSTURE .....	46
3.3 DRAWING THE FIRST BOW STROKE .....	51
3.4 THE RIGHT ARM .....	53
3.4.1 The bow hold .....	53
3.4.2. Flexibility in the bow hold .....	56
3.4.3 Flexibility of the shoulder .....	62
3.3 THE LEFT ARM .....	63
3.3.1 Holding the violin .....	63
3.3.2 Placement of the elbow .....	66
CHAPTER FOUR: SUMMARY AND CONCLUSIONS .....	67
APPENDIX A .....	69
APPENDIX B .....	70
APPENDIX C .....	71
REFERENCES .....	72
FURTHER BIBLIOGRAPHY .....	74
INTERVIEWS .....	75

# LIST OF FIGURES

Figure 1: Schema of videographic biomechanical data acquisition and resultant photograph..	7
Figures 2 and 3: Cyclegraphs of non-linear and linear movement .....	8
Figures 4a and b: Non-linear and linear experimental set-ups .....	9
Figures 5 and 6: Flashing cyclegraphs of non-linear and non-linear bowing.....	9
Figure 7: Example of a graph created from raw kinematic data.....	10
Figure 8: The fulcrum of the balanced arm movement.....	16
Figure 9: Diagram of Rolland's tapping board.....	17
Figure 10: Non-linear movement – swift détaché.....	22
Figure 11: Linear movement – swift détaché .....	23
Figure 12: Non-linear movement – détaché string crossing .....	24
Figure 13: Linear movement: – détaché string crossing.....	25
Figure 14: Non-linear movement – legato .....	26
Figure 15: Linear movement – legato.....	27
Figure 16: Non-linear movement – détaché.....	28
Figure 17: Linear movement – détaché .....	28
Figure 18: Cyclegraph of non-linear wrist movement – swift détaché.....	30
Figure 19: Cyclegraph of non-linear elbow movement – swift détaché.....	30
Figure 20: Cyclegraph of linear wrist movement – swift détaché.....	31
Figure 21: Cyclegraph of linear elbow movement – swift détaché .....	31
Figure 22: Cyclegraph of non-linear wrist movement – détaché string crossing .....	32
Figure 23: Cyclegraph of non-linear elbow movement – détaché string crossing .....	32
Figure 24: Graph non-linear elbow movement – détaché string crossing .....	33
Figure 25: Cyclegraph of linear wrist movement – détaché string crossing.....	33
Figure 26: Cyclegraph of linear elbow movement – détaché string crossing.....	34
Figure 27: Cyclegraph of non-linear wrist movement – legato .....	34
Figure 28: Graph of non-linear wrist movement – legato.....	35
Figure 29: Cyclegraph of non-linear elbow movement – legato .....	35
Figure 30: Cyclegraph of linear wrist movement – legato .....	36
Figure 31: Cyclegraph of linear elbow movement – legato.....	36
Figure 32: Cyclegraph of non-linear wrist movement – détaché.....	37
Figure 33: Cyclegraph of non-linear elbow movement – détaché.....	37
Figure 34: Graph of non-linear elbow movement – détaché .....	38
Figure 35: Cyclegraph of linear wrist movement – détaché.....	38
Figure 36: Cyclegraph of linear elbow movement – détaché .....	39
Figure 37: Flashing cyclegraph of non-linear wrist movement – swift détaché.....	40
Figure 38: Flashing cyclegraph of linear wrist movement – swift détaché .....	41
Figure 39: Graph of linear and non-linear hand and bow velocities.....	42
Figure 40: Graph of linear and non-linear hand and bow accelerations .....	43
Figure 41: The path of the hand playing the open D- to open A-string in one bow .....	51
Figure 42: Bow hold practised on a pencil .....	56

# ABSTRACT

This dissertation presents a study and critical analysis of violin bowing technique. The works of some of the great twentieth century violin pedagogues were studied and their ideas on efficiency of movement, posture and balance in violin playing are highlighted.

Motion analyses comparing linear and non-linear bowing styles were conducted using digital motion-tracking techniques. The movements have been analysed, using principles of kinaesiology, physics and mathematics, to determine what factors contribute to energy consumption and efficiency.

Posture, balance and flexibility are also identified as key elements for efficient right-arm technique and their attributes leading towards efficient right-arm technique are discussed.

Data from this study suggest that non-linear bowing styles are more energy efficient than linear styles. In addition, players employing non-linear technique should benefit from reduced incidence of repetitive strain injury and improved endurance through conservation of energy.

The study aims to create an awareness of efficiency of motion in contemporary violin pedagogy and hopes that it be included in the early stages of violin instruction.

# CHAPTER ONE

## INTRODUCTION

### *1.1 BACKGROUND*

The question of what distinguishes a good violinist from a mediocre one has fascinated me since the start of my tertiary education. Significant changes in my own technique brought a new richness to my violin performance. I was taught to play and teach the violin with the understanding that music, science and kinaesiology are all inter-related. I was also encouraged to question the efficiency of movements in my playing.<sup>1</sup> These ideas have stayed with me and my passion now is to learn how and why these movements are both so effective and so efficient.

My work over the last decade as a professional musician and violin teacher has stimulated me to critically analyse violin technique. This dissertation aims to define the factors that form the basis of efficient and sound violin technique. Many authors identify efficiency of movement and 'naturalness' as being key factors in good technique. I aim to demonstrate which movements are efficient and why they are beneficial.

#### *1.1.1 Literature survey*

Over the past hundred years there have been numerous books, papers and journal articles published concerning different methods of violin technique and violin teaching (Palac, 1992: 30–34). Roos, in her dissertation on the freedom of movement in violin playing, states that in the last thirty years violin pedagogy has moved towards developing a natural playing posture that is free of excessive tension. This is due to the fact that there has been immense development in the fields of science and physiology.

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<sup>1</sup> Movement that is efficient fulfils a specific purpose with economy of movement resulting in the least amount of energy expended. The performer needs adequate strength, endurance, flexibility, stability and co-ordination. The posture and overall balance of the body need to be adapted to suit the movement, be it simple or complex, symmetrical or asymmetrical. To have complete control and accuracy one needs to know the body's position in space, and be able to judge the distance, height, depth and path of the movement. One also needs the ability and the tools to be able to adapt to quick changes for accuracy of movement (Galley & Forster, 1987: 127).

Roos talks about the importance of a good posture and a good lifestyle (2001: 1-1) which leads to freedom of movement and 'naturalness' in violin playing. She concentrates on the well-being of the violinist as a whole. In the present dissertation the importance of posture and naturalness is also discussed in detail as they play an important part in the development of efficient movement.

In her work on violin technique, Bennell (2004) proposes a need for a secure and balanced posture. She speaks about the need for an environment that promotes a state of muscular balance in which to develop the fine motor skills of left-hand technique. She discusses posture, position of the violin, position of the left arm, position of the left wrist, position of the left hand and position of the left thumb and fingers. These are all factors of left-hand technique and are discussed as key elements in providing the most suitable posture for optimum sensorimotor development. In this dissertation however I will focus on the position and movement of the right arm, which need to be both natural and balanced in order to promote efficient movement.

The interdisciplinary field known as cognitive neuroscience investigates the higher cognitive processes including language, memory and perception, and gives understanding of how the brain functions (Edwards, 1999: xxiii). Playing the violin is made possible through complex neurological, physiological and creative processes. It is probably the most complex of all human neuromuscular activities (Norris 1993: 91). Ackerman and Sylvester state that the act of playing the violin represents one of the most complex forms of sensorimotor integration known to man (1995: 7). Szende and Nemessuri were of the same opinion, and wrote that violin playing belongs to the most complicated of human movements (1971: 19).

Because violin playing is recognised as such a complex neuromuscular activity, it is important to realise that these instrumental movements belong to the broad domain of human motion. It is therefore crucial to utilise common movements, thereby creating a greater ease in learning. It is also significant to realise the close connection that human movement studies have with science. The work of Isaac Newton<sup>2</sup> is relevant to kinaesiology and the study of

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<sup>2</sup> Sir Isaac Newton, British physicist and mathematician, 1642–1727. Before the age of 30 he had formulated the basic concepts and laws of motion, discovered the law of gravitation, and invented calculus. His contributions to physical theories dominated scientific thought for two centuries and remain important today (Serway, 1996: 108).

movements and the forces that cause them. Newton's laws enable one to understand the physics of bowing from the working of general laws. An example the first law of motion is the law of 'momentum and inertia', and Newton's third law of motion states that for every action there is an opposite and equal reaction (Serway, 1996: 114). These two laws of motion can be applied to violin bowing, enabling the violinist to play with more economy of movement.

Movement can also be studied through mathematical theories and graphs. Basmajian and MacConaill suggest that there is a need for new ways of investigating movements, saying that mathematics is needed to establish these theories (1969: 8).

### *1.1.2 Paul Rolland*

In the string teaching fraternity, Paul Rolland is a pioneer in the amalgamation of science and violin technique. His primary aim as a teacher was to find the essential aspects of playing that enable a violinist to play the instrument with ease. Influenced by the teachings of Waldbauer and Rados, he was convinced that the movements in producing beautiful tone on the violin had to be in balance and free from static tensions. He summed up the purpose of his teaching method in a single word – 'naturalness'.

At the heart of Rolland's method is the use of efficient human movement. He sourced scientific evidence from the fields of physics and kinaesiology, which influenced his teaching methods greatly. He refined his teaching methods by applying Newtonian principles of motion to the human body as a violin-playing machine (Perkins, 1995: 92).

Rolland worked on developing the theory of upper arm rotation in violin playing. The scientist Steinhausen had first advocated this principle of arm rotation in 1903.<sup>3</sup> He suggested the use of pronation and supination of the forearm to add or take away sound. Carl Flesch also discussed arm rotation in bowing. He stated that the distribution of the weight of the bow is 'extremely unequal'. To overcome this unevenness he suggests that the bow needs to be pressed down upon the strings at the point and be slightly raised at the nut (Flesch, 1939, 53). The pressing at the point he paired with pronation and the pressing at the nut with supination, thereby agreeing with Steinhausen's theory of forearm rotation. Flesch suggests, however,

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<sup>3</sup> FA Steinhausen *Die Physiologie der Bogenführung auf den Streich-Instrumenten*. Leipzig, Breitkopf & Härtel. First Edition, 1903; Third Edition, 1916.

that this rolling of the forearm should not in fact be thought of as pronation and supination, but should rather focus on the pressure of the first finger at the point, producing tone, and the fourth finger at the nut, preventing too much pressure (ibid.).

Rolland disagrees with Flesch's idea of using pressure from the first finger to acquire tone at the point. He states that this action localises the pressure in the hand and short-circuits the forces of tone production. He suggests rather the release the natural weight of the arm into the bow. The fingers and thumb need only resist the collapse of the bow hold. The thumb supports the bow upward, so the right arm must also offer upward support to the bow whilst releasing downward weight onto the string. This is only possible through rotary movement. Rolland did however recognise the further advantage of using rotary action of the upper arm to create a greater tone production by means of a more powerful and more reliable movement (Rolland, 2000: 35).

Rolland wanted to confirm scientifically that humeral rotation results in improved quality of playing. In 1970 Basmajian, in a letter to Rolland, wrote that it is difficult to show how these circular movements are scientifically more sound. Basmajian therefore concentrated rather on showing which movements are habitual, and suggested to Rolland to do the same. Rolland therefore teaches the use of movements that fall into the category of habitual or natural patterns, which include rotary components and circular motion (2000: 209).

Rolland was greatly influenced by the writings of Percival Hodgson who also studied the science of human movement in violin playing. Hodgson's work was groundbreaking in his time. Hodgson photographed the actual movements that are described by the bow, taking thousands of cyclegraphs of circular bowing movement, which were published in the first edition of his book in 1934. He found that it was essential to take the photograph from the correct angle, allowing the picture to reflect the most accurate non-linear pattern. The results of his study show the naturalness of non-linear bowing. By photographing the actual movements, Hodgson confirmed Steinhausen's theories of non-linear movement by showing that the bow moves in curves (Hodgson, 1958: xi). He suggested that one should teach the actual movements of the bow rather than describing imaginary ones. By demonstrating that the actual pattern of 'good' technique consisted of non-linear movement, Hodgson advocated the teaching of curved motion. He showed that the figure of eight and the ellipse are two natural types of limb-swinging movements. This point is now recognised in almost every branch of physical activity (Hodgson, 1958: 11).

With the development of science, and the integration of science and music, the most efficient movements in violin playing can be studied (Basmajian and MacConaill, 1969: 8). A more detailed discussion of the literature of violin pedagogy appears in Chapter 3.

### *1.1.3 WL Nelson*

In a pioneering article written in 1984, Nelson describes some elementary principles regarding constraints on skilled movements and the 'costs' that these movements are subject to. He theorises that skilled movements are subject to certain 'costs' which affect the economy of these actions. These 'costs' are: movement time, distance, peak velocity, energy, peak acceleration and rate of change of acceleration (jerk). The impulse-cost is proportional to the total impulse occurring during the movement. The jerk-cost is proportional to the rate of change of acceleration (Nelson, 1983: 136).

Nelson studied arm movements during violin bowing, and jaw movements during speech, and discusses the ways in which these skilled movements are influenced by considerations of physical economy or 'ease' of movement. He formulated mathematical models (equations) in terms of the abovementioned costs for minimising energy in skilled movements. With these models Nelson was able to draw graphs predicting which velocity patterns represent efficiency of movement. He writes that velocity-time graphs are 'a useful framework for discussing and analysing the constraints and objectives of skilled movements' (Nelson, 1983: 139).

Nelson discovered that the input power (muscle energy) requirement for muscles is proportional to the square of the muscle force output. This force output is proportional to the acceleration (impulse-cost and jerk-cost). He thus implies that energy efficiency is closely related to minimising the impulse-cost and jerk-cost of these movements (Nelson, 1983: 138).

## **1.2 STATEMENT OF THE PROBLEM**

A wide variety of teaching methods exist in parallel to each other. These methods do not all focus on natural movements and physical awareness of the body. Neither do they all focus on the idea that movement in violin playing can be modified to be more efficient. There are few detailed studies of efficiency of bowing in violin technique. Paul Rolland is one of only a handful of teachers who have amalgamated a knowledge of science and string pedagogy to create a technique that is both efficient and successful.

### ***1.3 PURPOSE OF THE STUDY***

The purpose of this study is to verify that non-linear motion in violin bowing is significantly more efficient than linear bowing. To achieve this it is important for the teacher to understand the basic anatomy of the body and the physics of motion (Roos, 2001: 4–5). This new understanding will lead to a technique based on the natural movements and balance of the body. This dissertation will illustrate how a combination of the study of physics, mathematics and violin playing can produce a technique that results in economy of movement. This efficiency translates into creating sound with less effort and with reduced incidence of injury. The dissertation will therefore also discuss correct posture and sense of balance. Flexibility of the shoulder, arm and fingers will also be discussed. These aspects will all be brought together to demonstrate the most efficient right arm technique.

### ***1.4 METHODOLOGY***

The images in this study were created from two different mediums. Firstly, a series of cyclegraphs were created using a light emitting diode (LED) in a darkened room. The second medium was the video recording of movements, after which the images were downloaded – using two different methods – for computer analysis.

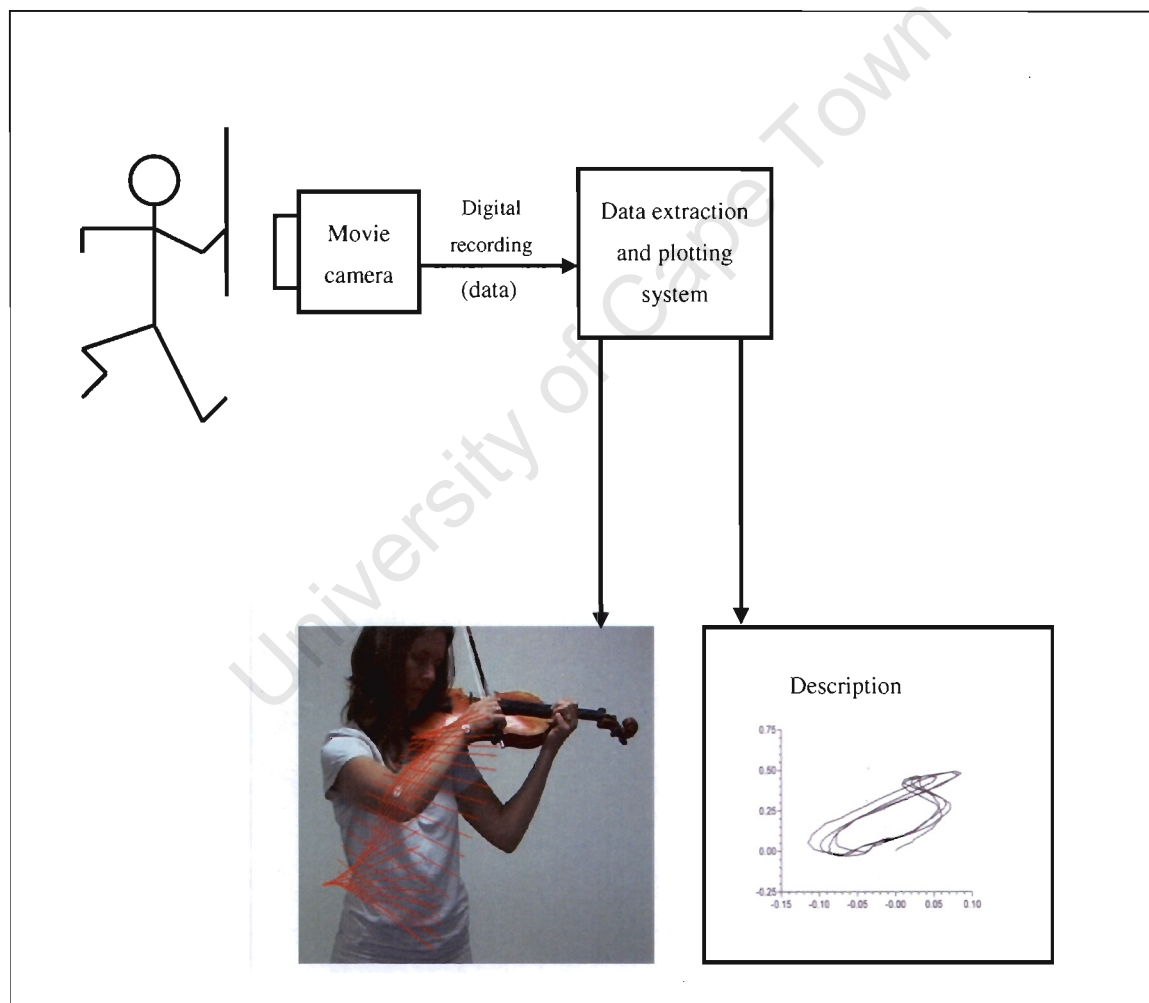
In order to compare linear and non-linear bowing movements in this study, the two movements studied (non-linear and linear) had to fulfil the same performance objectives. Theoretically, this equates to the two different styles of bowing producing a comparable sound. Movements of the same frequency (tempo) and bow excursion were therefore compared, to minimise bias in the results. With fixed distance and time constraints imposed on bowing movements, the varying ‘costs’ of velocity and acceleration were analysed. It is subtleties of the latter two factors that are likely to determine the efficiency of the movement.

A video recording of the author’s bow arm movements was made at the Sport Science Institute of South Africa with the help of two sports analysts, namely Sebastian Prim and Dr Michele van Rooyen. Two markers were placed on the author’s right arm, one on the wrist and one on the elbow. The violinist was then positioned in front of the video camera and – to obtain objective scientific results – did not change her angle or distance from the camera. The first recordings were done on a Sony DV video camera (DSR-PDX10P).

Using the video recording, photographs of the movements that were performed were obtained. This was done by placing a marker line joining the wrist point to the elbow point. A series of lines were plotted on the photograph showing the movement of the arm. After the movements were recorded, the video was downloaded onto a computer programme designed to plot the points of the movement of the elbow and wrist separately. The result was different graphs, with the movements plotted, showing easily recognisable circular and straight lines in the bow-arm movements. These graphs depict results similar to those of the cyclegraphs to follow. (The graphs are plotted with distance in metres on both the  $x$  and  $y$  axes of the graph.)

This process is described pictorially in Figure 1.

Figure 1: Schema of videographic biomechanical data acquisition and resultant photograph

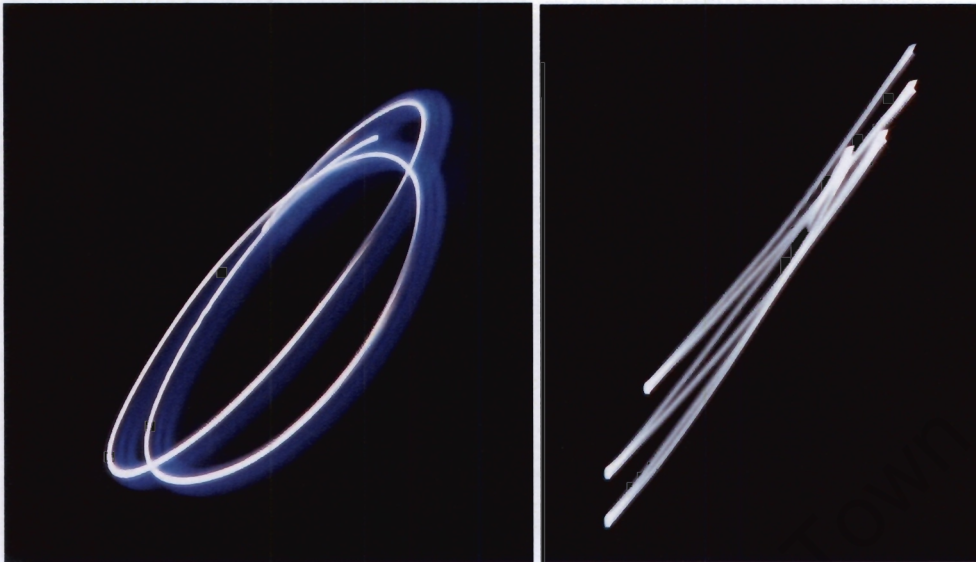


The images shown in Figure 2 and Figure 3 are called *cyclegraphs*. To create these images an LED was placed either on the fifth metacarpophalangeal joint or on the elbow, and

photographed at slow shutter speeds in a darkened room. The slow exposure of the camera captures the exact line of movement made by the arm.

*Figure 2: Cyclegraph of non-linear movement*

*Figure 3: Cyclegraph of linear movement*



These examples of bowing show clearly that the non-linear movements follow curved, circular or elliptical paths, and in the linear bowing they show the straight lines produced by the hand or elbow.

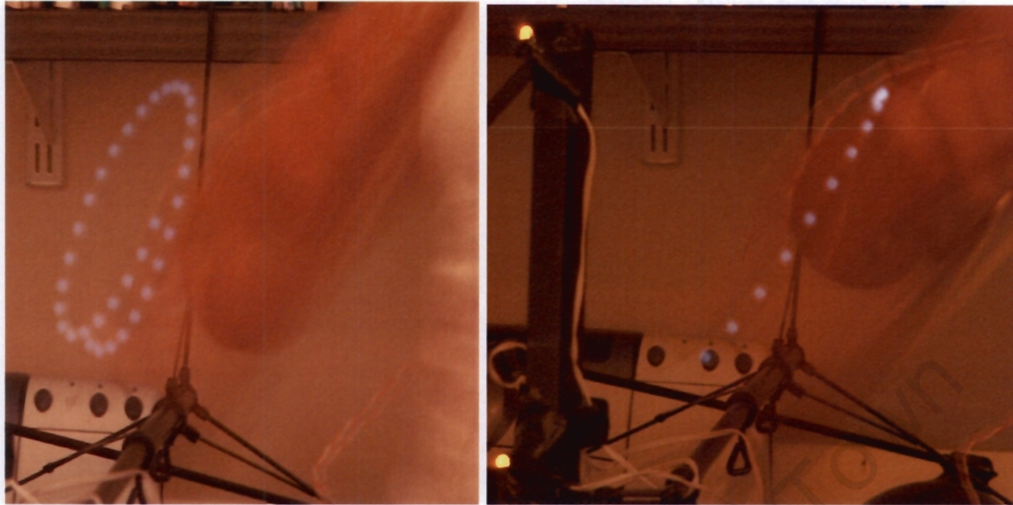
In attempting a mathematical analysis, the modified cyclegraphs shown in Figure 4 were created. This type of analysis was not encountered in any of the literature reviewed.

In order to ascertain the speed of the moving bow-arm, an oscillation circuit was built and connected to an LED. The circuit allowed the author to control the LED to flash at varying speeds, in order to find the most suitable time interval to notate into graph format.

The photographs in Figure 4 show how the experiment was conducted. The LED was again placed on the medial aspect of the fifth metacarpophalangeal joint of the right hand. The light diode was adjusted to flash at a speed of 52 Hz, and the different movements were recorded. Two stationary light sources, the vertically orientated orange LEDs, were placed in fixed positions 200 mm apart, to calculate accurately the distances between the dots made by the flashing diode. The room was then darkened and the photographs were taken with an aperture of 0.5 seconds for the non-linear bow strokes and 0.25 seconds for the linear bow strokes. The reason for the different shutter speeds is that it takes half a second to complete one bow cycle of a down and up bow. To record a non-linear bow stroke, as shown in Figure 4a, the

photograph needs to capture the entire cycle, but in the linear example, shown in Figure 4b, the camera captures movement in only one direction because the return stroke follows the same path. This also overcomes the problem that

*Figure 4a: A non-linear experimental set-up Figure 4b: A linear experimental set-up*



the image would be difficult to interpret if the dots were superimposed over one another. The “aperture” of the camera is therefore set to a quarter of a second, thereby capturing only one bow stroke or half a cycle. The images were recorded with a Konica Minolta Dimage Z3 digital camera. The photographs were then downloaded onto the computer where they could be analysed. Figures 5 and 6 are ‘flashing cyclegraphs’. They are open aperture photographs, taken in a darkened room, of an LED, flashing at 52 Hz, attached to the player’s right hand, and taken with a shutter speed of 0.5 seconds.

*Figure 5: Flashing cyclegraph of non-linear bowing Figure 6: Flashing cyclegraph of linear bowing*

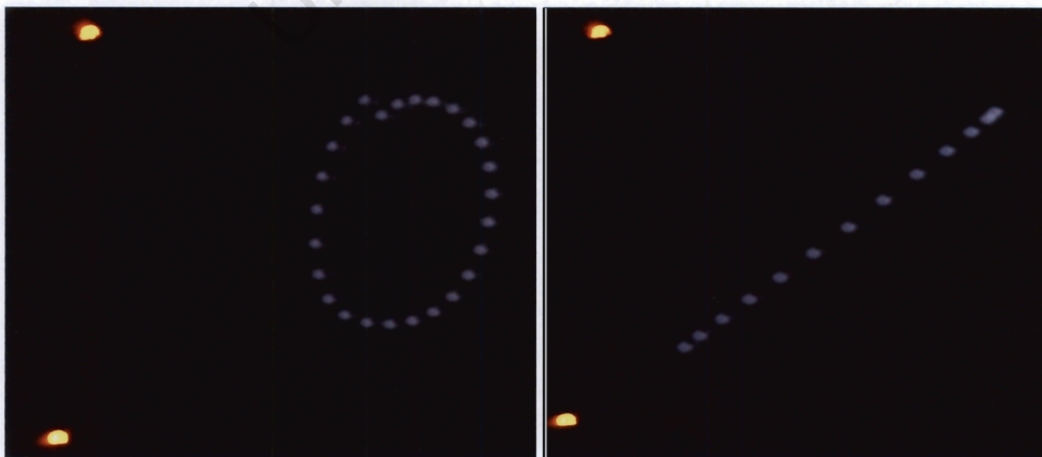
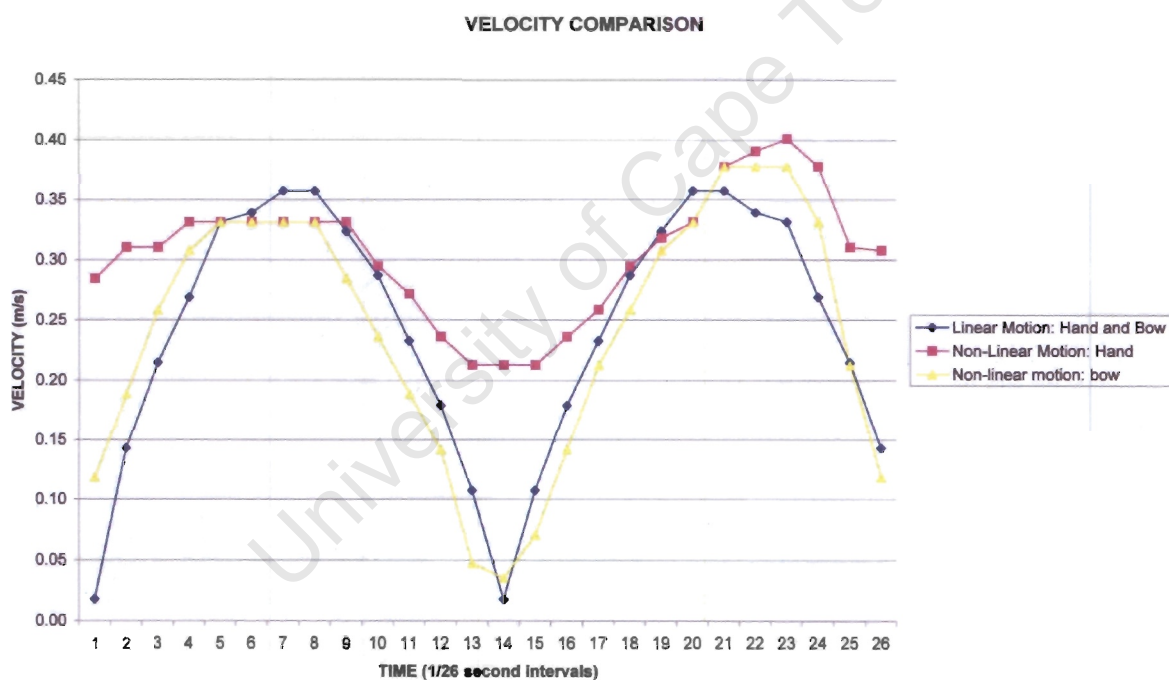


Figure 7 is a graph obtained from processing the raw kinematic data. To create the graphs, images of the flashing cyclegraphs were printed on plain paper. The distances between each

pair of dots were measured and converted to millimetres using a scaling factor, calculated using the known distance between the orange LEDs (200 mm). These values were entered into a spreadsheet (see Appendices). The average velocity (distance/time) was then calculated for each interval, using formulae entered into the spreadsheet.<sup>4</sup> The average acceleration was similarly calculated as the change in velocity ( $v_2 - v_1$ ) divided by the time elapsed ( $t_2 - t_1$ ).<sup>5</sup> Using the graph-creating feature in Excel, graphs were drawn, selecting different values from the raw kinematic data.

In this way data from the flashing LED was converted into comparative studies of velocity and acceleration for both linear and non-linear bowing techniques. In the example shown in Figure 7, velocities of the bow and the hand in both linear and non-linear movements are compared. A discussion of this graph follows later in the text.

Figure 7: Example of a graph created from raw kinematic data



4 Velocity is the distance covered in an interval of time, divided by the time interval.

5 Acceleration is the change in velocity in an interval of time, divided by the time interval

## ***1.5 LIMITATIONS OF THE STUDY***

A difficulty that arose in this study was that the movements were recorded in a two-dimensional medium from one angle only. The movements made by the arm are however three-dimensional. Therefore when the traces of the bow-arm were made they could not capture the movement of the bow when it moved away from the camera. The results of the movement analysis study are therefore not always a true reflection of the entire movement, since the hand and arm may be moving away from or towards the camera, resulting in a falsely linear picture. The wrist and elbow create different patterns on many different planes. Hodgson encountered this same problem in his cyclegraphs.

My initial aim was to quantify mathematically the degree of efficiency of non-linear bowing patterns. Despite approaching an academic mathematician and physicist this proved impossible. Equations for linear motion are relatively easy to create. As non-linear bowing does not repeat the same shapes, these paths cannot easily be described using mathematical equations. Using the closest appropriate shape (an ellipse) would assume that there is constant velocity of the hand, which is not the case.

In non-linear bowing there is only a very slight decrease in speed as the hand reaches the point at which the direction changes. Other factors such as gravity, friction, and centrifugal and centripetal forces make mathematical analysis very difficult. It should also be noted that the 'inertial' energy expenditure is nil, since the arm returns to its original position. This is a conservative system, and thus no net work is done over a complete cycle.<sup>6</sup> This does not, however, mean that no muscular effort has been expended, and I have therefore concentrated on explaining energy efficiency through biokinetic principles.

## ***1.6 CHAPTER OUTLINE***

**Chapter One** introduces the concept of efficiency of movement and its relevance to violin bowing. It discusses the work of authors who have researched and theorised about movement analysis with regard to violin playing. The chapter details the methodology of the study,

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<sup>6</sup> The work done by a force is equal to the force itself multiplied by the distance over which it is applied.

explaining how the raw data of the dissertation was acquired using computer-aided digital technology. The chapter ends by discussing the limitations of the study.

**Chapter Two** discusses the relevance of Newton's laws of motion to violin bowing. The factors influencing work done and energy conserved are governed by these laws. The first law is the law of inertia, which states that in order to move an object one needs a force, to overcome the inertia. To bring a moving body to a stop one needs a force to change the momentum. These laws suggest that continuous movements, those without stops and starts, are more efficient. In violin playing, these continuous movements would take the form of circular, figure-of-eight or elliptical paths.

Newton's third law of reaction can also be applied to violin playing when executing repetitive movements, such as *detaché*. These movements create elliptical-type patterns, which only exert energy once per cycle (Hodgson, 1958: 11).

The study then shows how certain movements that are continuous are efficient. This is done through the study of graphs, photographs and cyclegraphs.

**Chapter Three** analyses the importance of good posture and balance in violin playing. It discusses how the function of the upper limb depends primarily on a stable posture. It also examines the interconnectivity of the segments of the body through the kinetic chain, as well as how these segments balance each other to create a stable base on which to play.

The chapter goes on to discuss the ideal way for the violinist to hold the bow and the violin. This is looked at with special reference to Paul Rolland and Ivan Galamian. Rolland and Galamian have been chosen because of their extensive research into naturalness and science in violin playing.

**Chapter Four** gives a summary and presents conclusions.

# CHAPTER TWO

## THE APPLICATION OF SCIENTIFIC THEORIES TO THE ART OF BOWING

This chapter illustrates how the use of non-linear movements in violin bowing saves energy. This will be discussed with reference to Newton's laws of inertia and reaction, using graphs, photographs and cyclegraphs to assist in the understanding and analysis of the movements made.

### 2.1 INERTIA AND MOMENTUM IN BOWING

*A body continues in a state of rest or of uniform motion unless an unbalanced force acts upon it.* (Newton's Second Law)

In violin playing, both the left and right arms can be used with either linear or circular movements. Less energy is needed to change the direction of a moving object if the object is still moving than if the object is brought to a complete stop before it is moved in the new direction (Morehouse and Miller, 1959: 79–80). If one were to execute sequential linear bow strokes – which have a beginning and an end – both the bow and the arm would have to come to a complete stop at the point and again at the nut.

The property that causes an object to stay in a state of rest or of motion in a straight line is called inertia, and, to overcome inertia, energy must be expended. This means that, with linear bowing, the body needs to expend energy to start and then to accelerate each stroke, and again needs to decelerate and stop it – overcoming the inertia in the state of rest and then decreasing the momentum in the state of motion. This (unnecessary) energy expenditure is repeated for each linear bow stroke. This repetition of motion between two points is known as simple harmonic motion.

Simple harmonic motion is the type of motion in which an object oscillates between two spatial positions for an indefinite period of time, with no loss of mechanical energy. In real mechanical systems, however, retarding forces are always present. Whenever force acting on a particle is linearly proportional to the displacement and is acting in the opposite direction to

the motion, the particle moves in simple harmonic motion (Serway, 1997: 361, 365). A heavy mass bouncing on the end of a spring and a mass swinging at the end of a pendulum are both examples of simple harmonic motion.

In simple harmonic motion there is a cyclic interchange of energy. At each end of a movement there is a momentary stop. Consider the model of a mass bouncing on a spring: energy is stored in the spring and then released again into the mass. The momentary stop at the bottom of the cycle is when the spring stores the maximal potential energy, which is then converted to kinetic energy as the mass is accelerated upwards. With a pendulum, the bob has maximum kinetic energy at the lowest point of the swing.

Kinetic energy is the energy of a mass due to its motion. There is a constant transfer of energy in harmonic linear motion. This energy transfer requires effort, which is provided by the spring and, in the case of the pendulum, by the force of gravity. (The gravitational force is always directed towards the centre by gravity and is therefore constant. This can be seen in a planet in orbit (Greene, 2006 – interview).) For a body moving along an elliptical path there is no start or stop to the motion, therefore there is no energy exchange as the body is constantly moving.

In the human body, the chemical energy used to produce a muscle contraction is transformed into mechanical energy and heat. This mechanical energy can take the form of potential or kinetic energy. The potential energy of the bow-arm would be maximum at the point and the nut – where the bow must come to a complete stop in order to change direction. Here the muscular change requires real effort. Each time a muscle exerts a force, a chemical interchange is needed. An arm bowing in a straight line would have this constant exchange of energy, in the same way as a mass on the end of a spring (Galley & Forster, 1987: 66).

Efficient energy exchanges are characterised by smooth movements. Energy added to a body by positive work at one point in time is conserved, and very little of this energy is lost by muscles doing 'negative' work. Jerky movements have a steady succession of starts and stops, and each of these bursts of positive and negative work has a metabolic cost (Winter, 2005: 134).

Rolland states that, when coming to the end of a bow stroke, the arm must not be suddenly stopped, instead the motion should be reversed with a curved or pendulum-like movement. If one used a circular, elliptical or figure of eight movement to create continuity in the bow-arm

movement, one would expend less energy. These movements allow a smooth, flowing, and continuous stroke. Every motion flows without a break into the next (Rolland, 1979: 33). The momentum of the movement does not have to be broken.

The most essential technical requirement of violin performance is fluency in the change of bow direction. This is jeopardised if breaks are allowed between strokes. The smooth execution of movement is not promoted by any sort of pause or stop in the bow stroke. The fact that the stopping and starting of the bow uses up additional energy determines the need for the smooth, continuous movements. The stop-start is an acyclical motion which begins and ends repeatedly. In non-linear cyclical motion the movement will not come to any sort of a stop and is therefore preferable, since the movement has no end (Szende & Nemessuri, 1971: 16, 21).

## **2.2 REACTION IN BOWING**

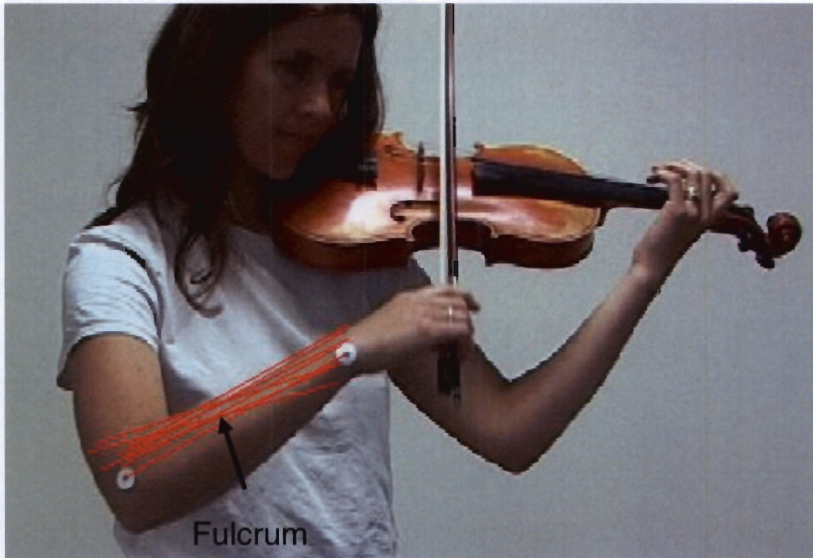
*For every action there is an equal and opposite reaction.* (Newton's Third Law).

When a force is applied to an object, the object will 'push back' with equal force (Luttgens and Hamilton, 1997: 352). The magnitude of this reaction force will be the same as that of the applied force, but will act in the opposite direction.

In the repetitive movements of *detaché*, *spiccato*, *sautillé*, *vibrato* and *tremolo* the player will need to apply energy consciously only once per cycle (Hodgson, 1958: 11). Rolland points out that when a group of two notes is played with only one action impulse the arm and hand will coast back without a superfluous action impulse on the return bow (*ibid.*, 2000: 36).

Rolland explains that these balanced movements resemble the action of a seesaw in the arm, with the fulcrum between the elbow and the wrist, as shown in Figure 8. When upper arm rotary movement is combined with the flexion–extension of the forearm or hand, a balanced movement occurs. The hand and elbow move in opposite directions, making the movement balanced. These repetitive actions of the hand and elbow are circular in character.

Figure 8: The fulcrum of the balanced arm movement

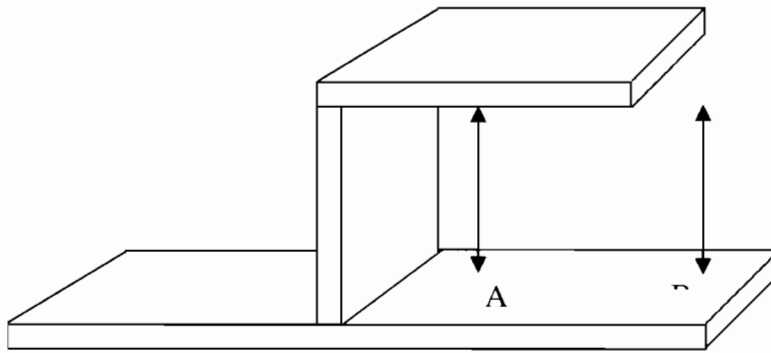


The photograph in Figure 8 represents the balanced bow action used in swift *detaché*. The red lines are the traces made by the arm in this reciprocal bow pattern. The return of the reciprocal stroke is a reaction rather than an impulse.

Clapping hands and knocking on a door are examples of everyday movements that would be categorised as repetitive movements. Such everyday habitual movements can be incorporated into violin playing thereby creating greater ease of learning. Szende and Nemessuri state that reciprocal and rhythmical movement is the simplest form of motion. All cyclic motion is reciprocal, and these movements repeat themselves in a sequence, unbroken in both rhythm and continuity. This makes them quicker and easier to master and automatise (1971: 26).

Rolland explains the simple form of repetitive motion using the apparatus shown in Figure 9. He asks the player to tap at point A on a board, tapping at the top and the bottom of the board. The energy used to tap this point at high speed is evident. He then asks the player to tap at point B. The player will see that much more effort is required to create the fast notes at point B because they are only tapping the lower section of the board. At point A the stick sounds notes at double this frequency. The same applies to the repetitive movements of *detaché*, *spiccato*, *sautillé* and *tremolo*. Here the player will feel as though the movement is in one direction, giving it a single downward impulse and allowing it to return automatically to the starting point (2000: 36).

Figure 9: Diagram of Rolland's tapping board



### **2.3 SLOW-CONTROLLED AND REPETITIVE MOVEMENTS**

Two groups of bowing movements will be discussed in relation to Newton's laws. They are the slow controlled bowing and the faster repetitive motions. Rolland seeks to acquire balance in both the slow controlled movements and the faster repetitive movements. He advocates balance in all aspects of violin technique. This is seen in his theory of establishing total body balance. Good body balance is based on a correct stance, which extends to the arms. Rolland states that for a well co-ordinated motion the whole arm must be supple and sensitively balanced so that it can swing freely in any direction (1979: 35). The body and the arms can function more efficiently when they are brought into a balanced relationship (Rolland, 2000: 32).

#### **2.3.1 Slow-controlled movements**

The 'slow-controlled movement' requires the muscles to work in opposition to each other. The light tension caused by these opposing muscles must be well regulated in order to achieve the most beautiful tone (Rolland, 2000: 36). To play the slow-controlled motion using straight line bowing one would have to stop and start the arm after each bow stroke. The abrupt reversal of direction of the motion of the arm requires a complete stop before the arm returns along the same path. Rolland suggests that the motions should rather be reversed with a curved motion from the hand in the form of an ellipse or figure of eight. This will ensure a smooth, flowing, continuous stroke. The arm will not come to a stop and each movement will be gently deflected into the next stroke (1979: 33). When analysed, the curves and loops that appear in the bow movement also appear in that of the upper arm, thus showing that the upper arm leads in the slow strokes (1979: 33, 35).

Rolland points out the importance of starting the arm motion with a slight anticipation, in which the upper parts lead, while the lower parts, and finally the bow, follow. He writes that, to overcome inertia in violin playing, one should anticipate movements. The reason for this is that a minute anticipation of the upper arm overcomes the inertia of the resting arm. A lack of this anticipation results in hasty and 'jerky' tone beginnings.

In ideally smooth bow releases, bow changes and string crossings, the movements of the arm are not sudden or convulsive. Smooth follow-up movements at the end of a stroke expend kinetic energy of the arm and bow as the movement ends. In the absence of follow-through movements, the antagonist muscles bring the motion to a halt too abruptly (Rolland, 2000: 38). The use of a follow-through movement and sequential actions bring about a smooth continuity of action and tone during bow changes. Steinhausen discusses this sequence of action in the arm, pointing out that the larger members of the body lead, and the smaller ones follow. The upper arm changes direction first, followed by the forearm, hand, fingers and finally the bow. In this chain the follow-through of the hand, fingers and bow continue the motion for a fraction of a second while the upper arm turns and starts the new direction (Rolland, 2000: 39). This indicates the importance of flexibility in the shoulder, the hand and the fingers.

Roos discusses the importance of the follow-through action in motion. According to her, the whole body should be part of this continuation of movement (2001, 4-4). This idea stems from Polnauer's statement that in violin playing the body moves as a whole (Polnauer and Marks, 1964: 1). Luttgens and Hamilton affirm that the forces generated by the musculature in one area of the body may be passed from one segment to another. This sequential transfer of motion can be seen in violin playing where an impulse is generated in the trunk and transferred through the upper arm, forearm, hand and finally to the bow to produce the tone (1997: 357). This transfer can be seen in rapid upper limb movements where the *transversus abdominis* is activated prior to the upper limb moving. It has also been noted that the postural muscles of the lower limb are activated before the arm moves, thus adding to the stable base on which the upper limb can function. This integrated action of postural activation in the pelvis and leg muscles, prior to arm movement, is an important prerequisite for the production of a co-ordinated action of the upper limb function (Trew & Everett, 2005: 203). This relationship and interplay between each segment of the body is known as a kinetic chain (Trew & Everett, 2005, 202).

### 2.3.2. Repetitive movement

*For every action there is an equal and opposite reaction.* (Newton's Third Law)

Repetitive actions in violin playing will be discussed with reference to Newton's Third Law, according to which there is an equal and opposite reaction to every action. One can apply this law to repetitive motions in violin playing such as vibrato, trilling, détaché, sautillé and tremolo bowings. This study will focus on the détaché bow stroke.

A common problem resulting from fast repetitive movements in linear bowing technique is that when the action is executed using only the smaller muscles such as triceps and biceps – which open and close the forearm – the movement can cause tension or even damage the joint through an overuse injury<sup>7</sup> (Rolland, 2000: 36). The cause of sustained overuse injury of small muscles is the fact that they are not designed to do these repetitive motions.

Repeated flexion and extension of the elbow can damage the ulnar nerve that passes through the two heads of the flexor *carpi ulnaris* in the cubital tunnel (Tubiana & Amadio, 2000: 84). The wrist joint is also flexible and able to execute these movements. The danger in this regard is that repetitive wrist flexion can cause carpal tunnel syndrome (Norris, 1993: 63). These movements should rather be played from the shoulder, with the impulse in a single direction, creating a balanced movement in the arm, thus saving energy.

Louis Krasner wrote a letter to Paul Rolland in 1969 in which he discussed Rolland's study of arm balance, saying that Rolland's ideas were among the most important and most critical of violin investigations. Krasner said that Flesch had pinpointed a mystery concerning détaché and string crossing and suggested further research in this field (Rolland, 2000: 204). Flesch noted that the détaché movement comes from the shoulder. He stated that for détaché in the lower third of the bow the use of the shoulder joint in vertical directions is required (Flesch,

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<sup>7</sup> An overuse injury is a condition that occurs when biological tissue is stressed beyond its physical limit. 'While runners and dancers frequently sustain stress or fatigue fractures, musicians more commonly develop tendonitis.' (Norris, 1993: 1) Overuse injuries can be chronic or acute. Acute overuse injury occurs following a specific incident of stressing the tissue beyond its limits. Chronic overuse injury takes place in a more significant way over a longer period of time. The tendonitis starts out as a mild discomfort that becomes progressively severe over the course of weeks or months. One of the factors causing chronic tendonitis is errors in technique, the most common of which is playing with excessive tension, causing the muscles to work extra hard. 'Modern scientific techniques, such as motion analysis, which have been used to elevate the technique of professional and Olympic athletes, may also become widely available in music field, leading to better understanding of bowing and fingering techniques. Motion analysis, along with studies of muscles involved in actions such as vibrato, is already available in some performing arts medicine centres' (Norris, 1993: 3).

1939: 55). Rolland suggests a theory in which the violinist uses arm balance from the shoulder when executing the *detaché* in the lower half of the bow (2000: 36).

#### **2.4 THE RIGHT ARM AS A SYSTEM OF LEVERS**

A lever by definition is a rigid bar that rotates about a fixed point when force is applied to it. The human body is made up of a complex system of levers (Galley & Forster, 1987: 68). Considering the arm as a system of levers helps us to understand how movements are created with it. Hodgson accepted the arm to be a system of levers. One part of the arm is attached to the shoulder while the rest is free to move from this fixed point. The shoulder is a ball and socket joint which allows the arm to move freely in any direction. The shoulder joint also allows more movement than the smaller joints namely the elbow and the wrist (Hodgson, 1958: 6). The elbow can only flex and extend whilst the shoulder can flex and extend, abduct and adduct, rotate and circumduct (Faiz & Moffat, 2002: 163). When an object acting as a lever moves in an arc about an axis, the movement is known as rotary motion.

The muscles controlling the movements of the upper arm are principally the *pectoralis major* and *minor*, *trapezius*, *supraspinatus*, *infraspinatus*, *latissimus dorsi*, *teres major* and *minor*, and the deltoid. Many of these muscles are bigger than those within the forearm, and collectively they are more powerful. It is therefore physiologically beneficial to use this well equipped lever to initiate and execute the bulk of all arm movement in bowing.

In violin playing the upper right arm is the dominant lever for the bow. 'After locating the *fulcra* and *power* of the most important levers in the arm, it becomes obvious that the whole limb is fundamentally governed by the body' (Hodgson, 1958: 8). Another system of levers supports the body, i.e. the legs, so that in tracing these levers back we discover that the true source of support to be the ground on which we stand (Hodgson, 1958: 8).

#### **2.5 MOVEMENT ANALYSIS**

Violin movements happen rapidly and the human eye has difficulty in analysing small nuances in each different movement. Recording these movements photographically and videographically captures motion patterns that are otherwise invisible to us. These images can be studied and manipulated in order to analyse the motion.

'Whilst experienced observers can obtain a substantial amount of subjective information about human movement, they do not have the ability to observe and remember all the

complex multijoint movement patterns that occur in even the simplest functional activities. The unassisted eye functions at the equivalent of  $\frac{1}{30}$ <sup>th</sup> of a second exposure time and can only see details of slow motion, the brain too despite its amazing ability has a limit on the amount of information it can absorb and remember. As a consequence, when observing complex movement only a limited amount of the detail is actually seen' (Trew & Everett, 2005: 139).

The movement analysis for this study was done by photographing two different playing styles. The first style was playing with a non-linear action in the bow-arm movement. The second style was with the bow-hand following a straight path which had a start and stop at each end. For each of these styles, four different movements are discussed: repetitive action of swift detaché, detaché over two strings, slow controlled movement, and detaché on one string.

### ***2.5.1 Computer enhanced photography***

The following photographs were made by video recording the subject during bowing, thus capturing the exact movement of the forearm. Markers were placed on the elbow and the wrist, and a line connecting them was recorded by the computer every five frames. These lines were then superimposed onto a still frame of the subject at the beginning of the movement. The composite image shows the orientation of the forearm at multiple timeframes during bowing. This is an exact representation of the positions held by the forearm during play.

The photographs taken from the video footage are discussed here separately as they depict a more accurate image of the movements, through the superimposed red lines. The movements, directions and changes of directions of the wrist and elbow can be analysed together or individually. The important difference between the video footage and that of the photographs is that the computer-enhanced video pictures show how the upper arm is leading the movements. This is seen through the different changes in angles of lines. The cyclegraphs and graphs in the next section however only show that the patterns of the elbow are similar to the patterns of the wrist. From the cyclegraph analysis we can conclude that one part follows another without showing which part is actually leading. It is important to know that the elbow is the leading point as this shows that the upper arm whose movements are controlled by the muscle around the shoulder leads the movement.

### 2.5.1.1 Non-linear movement: Swift détaché

Figure 10: Non-linear movement – swift détaché



Figure 10 shows the violinist playing continuous bow strokes at the speed of four semi-quavers per second. The movement of the arm is a 'seesaw' pattern with the fulcrum between the elbow and the wrist at point A. This shows how the arm is free to oscillate at the shoulder joint, allowing the upper arm to rotate. This movement is efficient because of the balance used in the arm to sustain the movement. In the image of swift détaché in Figure 10, the balance within the right forearm can be seen. As the wrist moves upwards, so the elbow is moving downwards, rotating in a three-dimensional see-saw pattern around the fulcrum. This seesaw action is seen in Rolland's basic principles of balance and leverage where he describes how balanced objects can be moved with minimum effort around an axis (2001: 32). This contrasts with linear strokes which originate at the elbow, as described in the next subsection.

### 2.5.1.2 Linear movement: Swift *detaché*

Figure 11: Linear movement – swift *detaché*



The violinist shown in Figure 11 is again playing continuous bow strokes at the speed of four semi-quavers per second. This picture depicts swift *detaché* played using a linear motion. The movement originates at the elbow at point A. The elbow remains stationary whilst the wrist moves up and down in a straight line. The large forces required to reverse the bow-stroke act on the relatively small surface area of the elbow joint. This places increased strain on the elbow joint. The muscles used to flex and extend the elbow are the triceps and the biceps. In addition there is no conservation of momentum as is the case in non-linear motion. This makes this movement more energy-intensive.

The difference between the positions of the bow in the non-linear picture and the linear picture is because in the non-linear photograph the violinist has just completed the up-bow. In the photograph of the linear movement the violinist has just completed the down-bow. This discrepancy is due to the fact that to time the photograph of the movement of a single bow stroke at such high speed is very difficult. Both pictures show a complete cycle of the bow, but they start at different points of the bow stroke.

### 2.5.1.3 Non-linear movement: *Detaché* string crossing

Figure 12: Non-linear movement – *detaché* string crossing

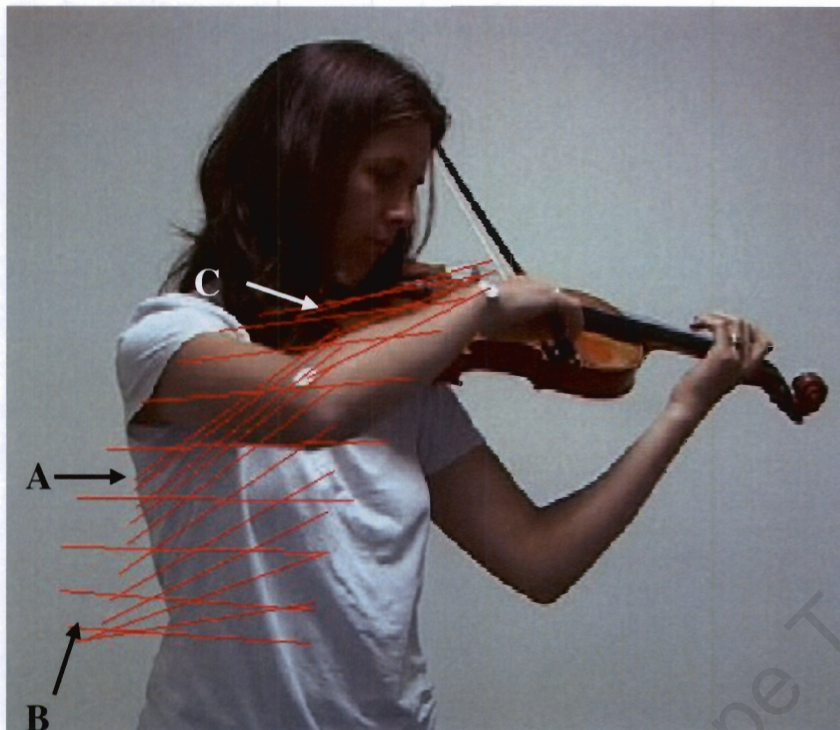


Figure 12 shows string crossing from D-A strings and returning A-D strings in a continuous pattern. The speed here is two quavers per second. The photograph represents one full bow-stroke cycle. Point A is the start of the bow cycle and also the start of the elbow position. The initial downward movement of the elbow is due to the first string crossing from the D- to the A-string. At point B the elbow has changed direction but the wrist still continues down. This indicates that the wrist is following through with the movement whilst the elbow begins to lead the arm back. On the return stroke the elbow still leads, until point C where it starts to prepare the down bow-stroke again. At each end of the stroke the elbow will initiate the change of direction whilst the wrist finishes off the stroke. This movement and crossover seen in Figure 12 show the follow through of the movements, which maintain the smoothness and continuity. This follow-through motion is important and is discussed in section 2.3.1, with reference to Rolland, as being important in allowing each bow stroke to be fused smoothly together to the following one (2000: 38). This follow through is efficient as the larger stronger body parts are leading the movement.

#### 2.5.1.4 Linear movement: *Detaché string crossing*

Figure 13: Linear movement: – *detaché string crossing*

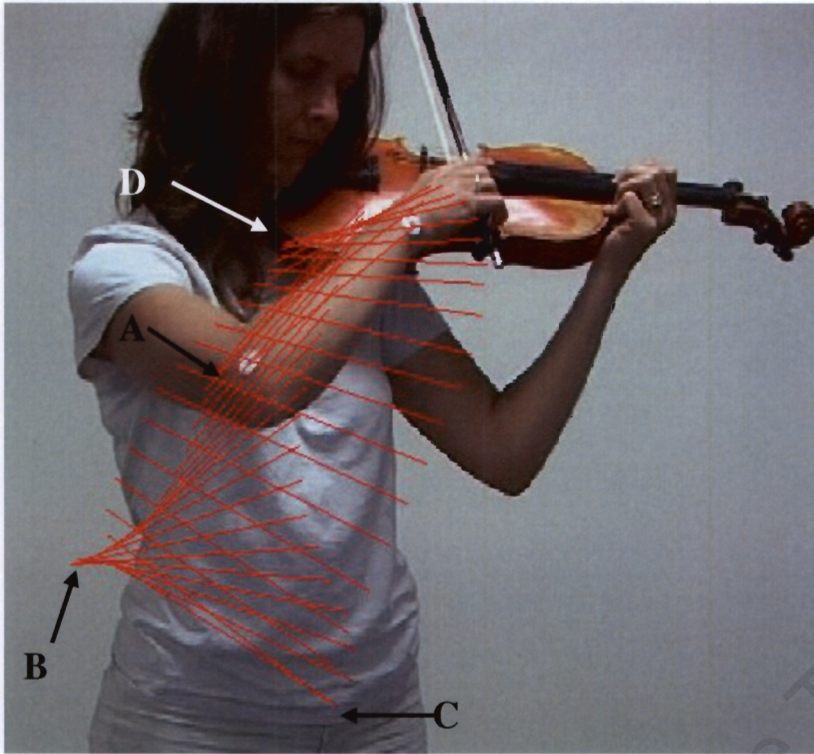


Figure 13 shows the same bowing pattern as the non-linear *detaché* string crossing. The string crossing is from the open-D to the open-A strings slurred and back. The speed is two quavers per second. Here the elbow leads only in the string crossing from point A to point B. The second half of the downward stroke and the first half of the upward stroke on the A-string are completed in the elbow joint. This is seen at point B where the elbow remains stationary and the four last lines cross over one another. The patterns are the same on both the up-and down-bow strokes showing that both the movements continue on the same path.

#### 2.5.1.5 Non-linear movement: *Legato*

Figure 14 is an example of slow *legato*, with non-linear bowing. The movement is a continuous *legato* bow stroke. The speed of the movement is one crotchet per second where each bow stroke is a semi-breve. Here the movement is again led by the upper arm. When executing the bow stroke, the elbow changes direction when the point of the stroke is reached. Here the hand continues the down-bow whilst the upper arm leads into the new stroke. This happens again at the nut where the upper arm changes direction first, leading the hand into the successive stroke.

Figure 14: Non-linear movement – legato



The start of the elbow movement is at point A. The elbow leads down until it reaches point B where, as in non-linear detaché string crossing, the elbow starts to change direction and begins the return stroke. The lines cross over one another, showing the movement of the elbow slowing and the movement of the wrist continuing. The wrist continues the follow through of the stroke until point C where it changes direction to follow the elbow and begins the up-bow stroke. The wrist follows the elbow again to point D, where the elbow changes direction whilst the wrist follows through. These follow-through movements of the wrist and hand ensure the continuity of the movement and of the sound.

#### 2.5.1.6 Linear movement: Legato

Figure 15 shows the same pattern of long minims on the A-string. The result is similar to linear detaché string crossing where the elbow leads down from point A to point B. At point B the forearm takes over and continues the stroke whilst the elbow remains at point B. The work of the second half of the stroke is again done from the elbow joint. On the return, the pattern is almost identical.

Figure 15: Linear movement – legato



The wrist leads in the first half of the up-bow. The upper arm pushes the bow back to the nut. At the nut the wrist must bend to ensure that the bow remains parallel to the bridge.

The total distance travelled by the wrist is much greater than the distance travelled by the elbow. This shows that the work done in the relatively small region of the elbow joint is great, placing increased strain on the elbow joint.

#### 2.5.1.7 Non-linear movement: *Detaché*

Figure 16 is of slow *detaché*, with non-linear bowing. It is similar to *detaché* string crossing but is executed on only the A-string. The speed of the stroke is two quavers per second. The start of the elbow movement is at point A. From here the elbow leads to point B, where it returns and the wrist continues the movement. The elbow leads on the up-bow until point C, where again the elbow changes direction and the wrist follows through. One can easily see the circular movement in the elbow from this picture. The distances travelled by the wrist and the elbow are the same. The wrist is however always following the elbow. Again the follow-through of the wrist ensures the smooth change of bow and the continuity of the movement and of the sound.

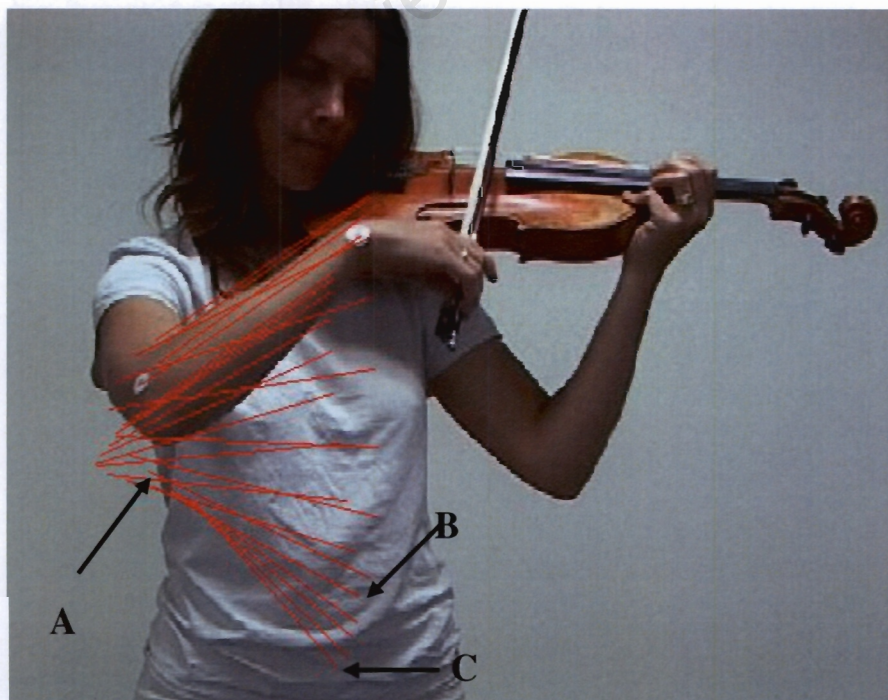
Figure 16: Non-linear movement – *detaché*



#### 2.5.1.8 Linear movement: *Detaché*

Figure 17 is again a linear example of slow *detaché*. The speed of the stroke is two quavers per second. The movement is similar to linear-style legato where the elbow initiates the downward stroke and the wrist continues the movement. Again the wrist leads in the second half of the down-bow and the first half of the up-bow, making the distance travelled by the

Figure 17: Linear movement – *detaché*



wrist far greater than the distance travelled by the elbow. This distance travelled by the wrist shows again that the forearm is doing more work than the upper arm. The stationary elbow can be seen at point A. Point B on the wrist carries on down to point C, showing the extra work done in the elbow joint. The pattern is the same on the up and down-bow stroke, showing that the movement follows a straight line.

### ***2.5.2 Cyclegraphs and graphs***

In 1934 Percival Hodgson employed a method of photographing a point light source attached to parts of the moving bow-arm. The two points he used on the right arm were the second finger and the elbow (1958: 58). This produces an image called a cyclegraph – a photographic record of the path followed by a moving object.

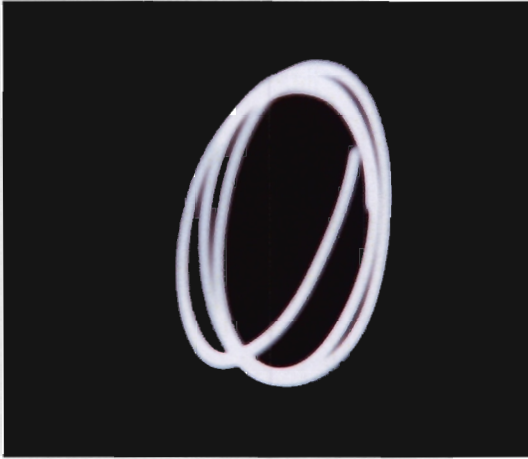
This section focuses on a series of cyclegraphs, based on the idea of motion analysis used by Hodgson to produce original images which can be used in the study of the movements made in violin bowing.

The bowing patterns that were videoed in the previous section were also photographed. These were slow controlled motions such as legato, and reciprocal motions such as détaché. In all of the non-linear photographs the size of the curves is determined by the boundaries of the adjacent strings, the speed of the stroke and the point of contact of the bow. Rolland indicates that it is advantageous to use larger curves in slow strokes because the longer stroke relieves restriction and allows freer movement. He also states that, when bowing faster, smaller movements should be used (1979: 34). This is seen clearly in the cyclegraphs where the slow détaché stroke has a long elliptical bow trace. The swift détaché stroke has a very much smaller elliptical bow trace, showing the smaller amount of movement used by the arm.

#### ***2.5.2.1 Non-linear movement: Swift détaché – wrist***

The movement shown in Figure 18 is a fast bow stroke in the middle of the bow, of four semi-quavers to the crotchet beat, where the beat is one crotchet per second. The pattern shows small ellipses, overlapping each other, showing the regularity of the pattern. The cyclegraph depicts a continuous cyclical motion without change of direction or stop.

Figure 18: Cyclegraph of non-linear wrist movement – swift détaché



#### 2.5.2.2 Non-linear movement: Swift détaché – elbow

Figure 19: Cyclegraph of non-linear elbow movement – swift détaché

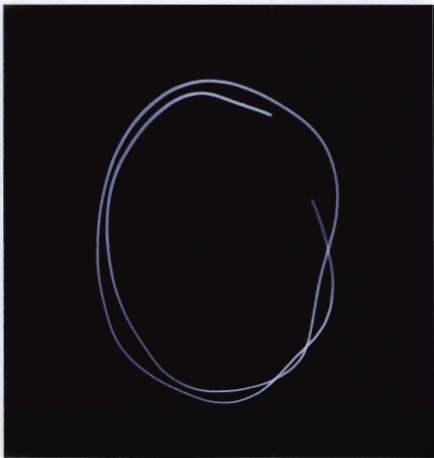


Figure 19 shows the movement of the elbow playing the same swift détaché motion. Here the movement is cyclical. It is played with a continuous motion from the shoulder, resulting in a circular motion at the elbow. The upper arm oscillates and rotates from the shoulder joint.

#### 2.5.2.3 Linear movement: Swift détaché – wrist

The cyclegraph in Figure 20 depicts a fast détaché stroke of two quavers per second. Here the path of the bow repeats itself in both the up-and down-bow strokes. The light is the duller at the middle of the bow stroke. This depicts that the speed at which the hand was travelling is much faster than at each end where the light is much brighter. The brightest points show where the hand has stopped in order to return along the same path. The arm rapidly accelerates at the start of the bow stroke and decelerates again towards the end of the stroke. This pause in movement creates more work for the arm, as energy is required to start and stop each successive stroke.

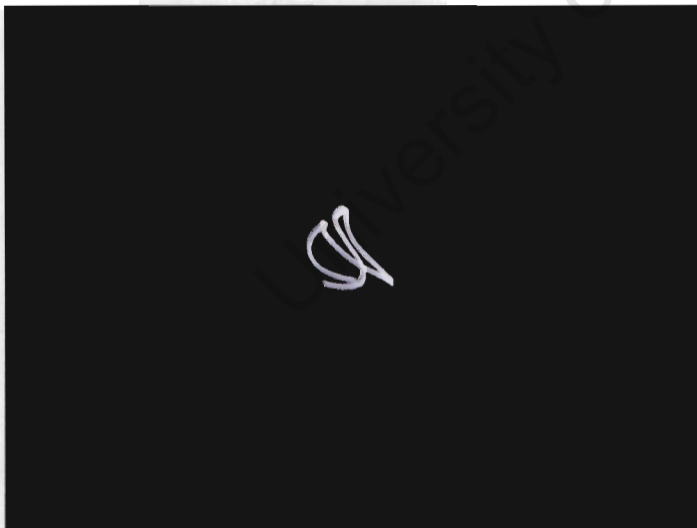
Figure 20: Cyclegraph of linear wrist movement – swift détaché



#### 2.5.2.4 Linear movement: Swift détaché – elbow

The trace of the elbow in Figure 21 is minimal, showing that the détaché movement originates in the almost stationary elbow. This shows that there is an increased force applied through the elbow joint resulting in significantly higher joint strain than in the gentle oscillations found in non-linear movement. The energy expenditure at each end of the stroke is great and the energy exchange from kinetic to potential energy is very quick.

Figure 21: Cyclegraph of linear elbow movement – swift détaché



### 2.5.2.5 Non-linear movement: *Detaché string crossing – wrist*

Figure 22: Cyclegraph of non-linear wrist movement – *detaché string crossing*

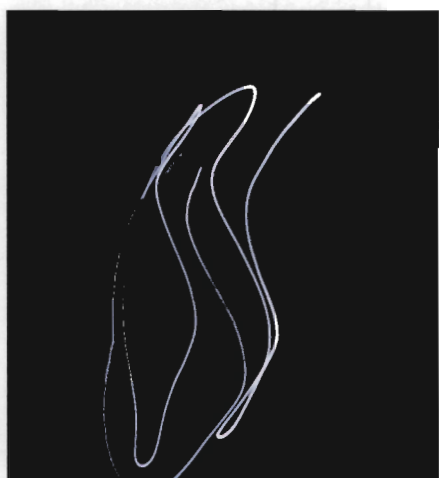


Figure 22 shows a string crossing movement. The pattern is open-D to open-A quavers slurred down-bow; followed immediately by open-A to open-D quavers slurred up-bow. The speed is two quavers per second. Here the cyclegraph reveals continuous movement of the hand. The bend in the upper half of the curve is caused by the action of changing strings. The trace is continuous at both the top and bottom of the trace. This represents the change of direction of the bow. This continuity maintains the flow and momentum.

### 2.5.2.6 Non-linear movement: *Detaché string crossing – elbow*

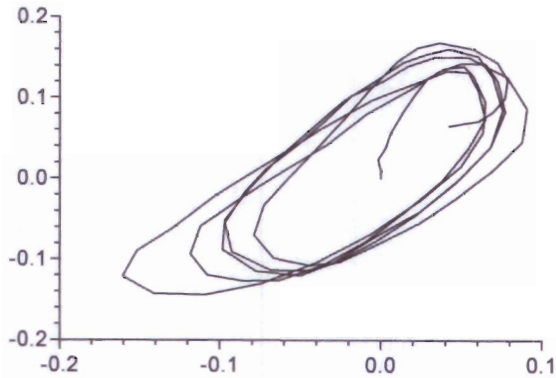
Figure 23: Cyclegraph of non-linear elbow movement – *detaché string crossing*



The shape of the elbow trace shown in Figure 23 is similar to the trace made by the wrist, showing that elbow and wrist follow each other in a reciprocal pattern. The wider curve at the bottom is created by the change of direction at the point – the hand has more space to move a

greater distance at the point. The smaller curve at the top of the figure shows the elbow returning to the nut of the bow. Here the curve is moving away from the camera.

Figure 24: Graph non-linear elbow movement – *detaché* string crossing



The 'xy-graph' shown in Figure 24 has been included to show how different camera angles view the same movement. It depicts an elliptical pattern. Both the cyclegraph and the xy-graph show the continuity of the motion.

#### 2.5.2.7 Linear movement: *Detaché* string crossing – wrist

Figure 25: Cyclegraph of linear wrist movement – *detaché* string crossing



Figure 25 shows the repetitive movement of the linear *detaché*, where both the down-bow and up-bow strokes move along essentially the same path. The light is brightest at each end of the stroke where the hand pauses to change direction. The tracing of the wrist follows a slight 'S' shape, which is due to the string crossing.

### 2.5.2.8 Linear movement: *Detaché string crossing – elbow*

Figure 26: Cyclegraph of linear elbow movement – *detaché string crossing*



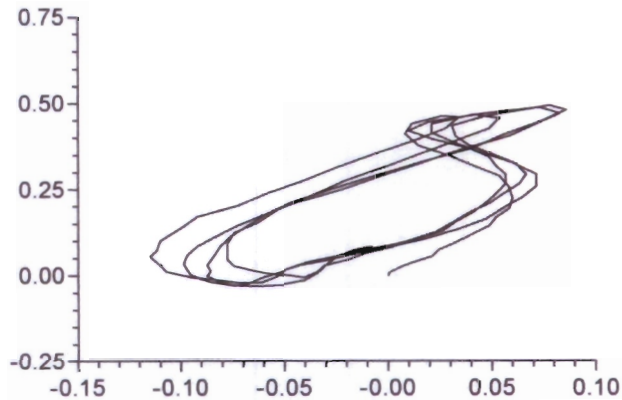
The deflection of the elbow joint in the linear *detaché*, shown in Figure 26, is again minimal, demonstrating that the movement originates at the elbow joint. The tracing in this cyclegraph has a sharp point of return at the bottom of the picture. The start and stop of each stroke reflects the energy expenditure at each end of the bow stroke. The elbow moves in a sideways arc depicting the movement across the two strings.

### 2.5.2.9 Non-linear movement: *Legato – wrist*

Figure 27: Cyclegraph of non-linear wrist movement – *legato*



Figure 28: Graph of non-linear wrist movement – legato



The bow stroke shown in Figure 27 is of continuous minims played at one crotchet per second. The *xy*-graph has been included because it shows the movement of the wrist clearly. The cyclegraph and the *xy*-graph clearly depict the figure of eight trace made by the wrist – showing the continuity of the movement made by the hand. This movement has a greater curve at the bottom of the cyclegraph where the bow changes direction at the point. The reason for this is again that there is more space for the arm to move when it is extended. The smaller curve at the top of the cyclegraph is where the bow changes direction at the nut. Here the curve is moving away from the camera and creating a curve on a different plane, as shown in the *xy*-graph. The continuous trace of the bow-arm shows the efficient nature of the movement. There is no energy used to stop and start each bow stroke, only to continue the motion in one direction.

#### 2.5.2.10 Non-linear movement: Legato – elbow

Figure 29: Cyclegraph of non-linear elbow movement – legato

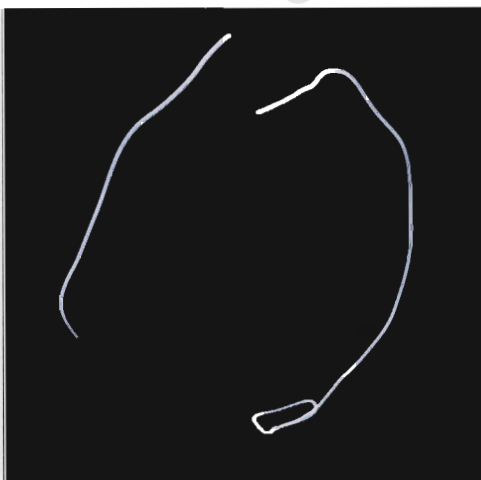


Figure 29 shows a circular trace with a loop at the one end. The small circle trace at the bottom of the cyclegraph is the movement of the elbow at the point. The reason for this is that the elbow leads the change of direction at the point. The elbow makes a small turn and leads the arm back to the nut, where it flows into the successive stroke, making the movement continuous.

#### 2.5.2.11 Linear movement: Legato – wrist

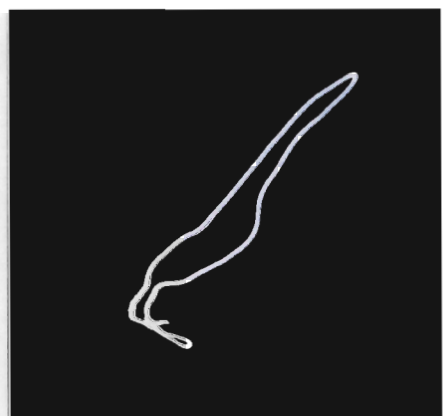
Figure 30: Cyclegraph of linear wrist movement – legato



The tracing of the hand shown in Figure 30 is linear and angular. The traced movement of the wrist turns almost exactly back on itself. In the original photograph it is clear that there is a pause at each end of the stroke. The beginning and the end of the stroke both have sharp angles at the point of change of direction and have a more intense light showing the momentary stop in the movement. This pause is not conducive to the conservation of energy.

#### 2.5.2.12 Linear movement: Legato – elbow

Figure 31: Cyclegraph of linear elbow movement – legato



The movement in the elbow shown in Figure 31 also has a sharp point of return. The slight bend in the trace is created by the second half of the bow where the upper arm extends outwards, enabling the bow to reach the point. The trace repeats its movement in each up and down stroke. This acyclic motion, where the movement begins and ends repeatedly, requires unnecessary use of energy.

#### 2.5.2.13 Non-linear movement: *Detaché* – wrist

Figure 32: Cyclegraph of non-linear wrist movement – *detaché*



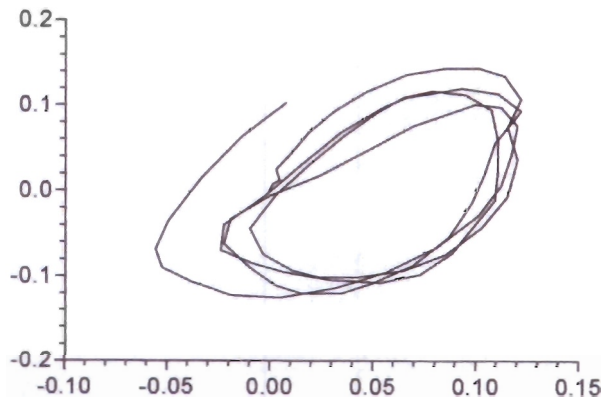
The cyclegraph in Figure 32 depicts *detaché* played on one string. The pattern is continuous quavers played on the A-string at one crotchet per second. Here the trace of the arm depicts an elliptical pattern, showing the continuation of movement at each change of direction. There is no bend in the ellipse such as that seen in non-linear *detaché* string crossing, since it is played on one string and thus has no string crossing. The motion of the arm is smooth and continuous, even at the changes of bow direction.

#### 2.5.2.14 Non-linear movement: *Detaché* – elbow

Figure 33: Cyclegraph of non-linear elbow movement – *detaché*



Figure 34: Graph of non-linear elbow movement – *detaché*



With non-linear *detaché* the elbow also creates a circular shape of continuous movement, as shown in Figure 33. Here the *xy*-graph (Figure 34) has again been included to clarify the motion of the elbow. Both graphs employ an efficient cyclic motion, with no stops within the bow stroke. This shows how the bow arm maintains momentum throughout the movement.

#### 2.5.2.15 Linear movement: *Detaché* – wrist

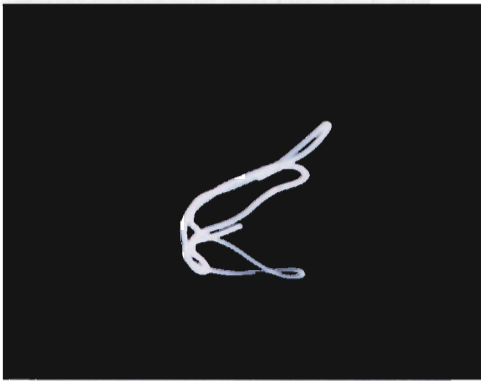
Figure 35: Cyclegraph of linear wrist movement – *detaché*



The movement in the wrist shown in Figure 35 is very angular. Here the shape is longer and straighter than the linear movement of *detaché* string crossing. The reason for this is that it is played on one string and has no string crossing. The pattern in the elbow is again similar to the linear movement *legato*, and is again angular at the beginning and end of each stroke, showing that is energy expended when stopping and starting each bow stroke.

### 2.5.2.16 Linear movement: *Detaché – elbow*

Figure 36: Cyclegraph of linear elbow movement – *detaché*



From Figure 36 we see that the trace made by the elbow in linear *detaché* is very small. Again, as in the previous *detaché* movements, the elbow is almost stationary as there is an increased amount of work done in the elbow joint, which can result in stress and tension in the joint.

These cyclegraphs all show that in the more effective movement of non-linear bowing the bow-arm never comes to a dead stop but always curves and loops into the next stroke, thus maintaining the momentum of the stroke. The body does not have to use energy to start and stop every bow stroke. The cyclegraphs also show how, in the non-linear movements, the elbow and hand movements create similar shapes. The circular movement in the elbow is created from the oscillation of the arm in the shoulder. This oscillation is fundamental in allowing the whole arm to move freely to create movement in a non-linear pattern.

### 2.5.3 *Movement analysis using graphs*

The next subsection focuses on the fast *detaché* stroke only. The pictures were taken with the LED flashing at 52 Hertz, and shutter speeds of 0.5 seconds for non-linear bowing and 0.25 seconds for linear bowing.

The trace in Figure 37 shows that the flashes are roughly an equal distance apart, indicating that the hand moved at a relatively constant speed throughout the bow stroke. This indicates that the hand moves at an almost constant speed in this non-linear movement. There is conservation of momentum which contrasts with the stop-start action of the bow-arm during linear motion.

Figure 37: Flashing cyclegraph of non-linear wrist movement – swift detaché

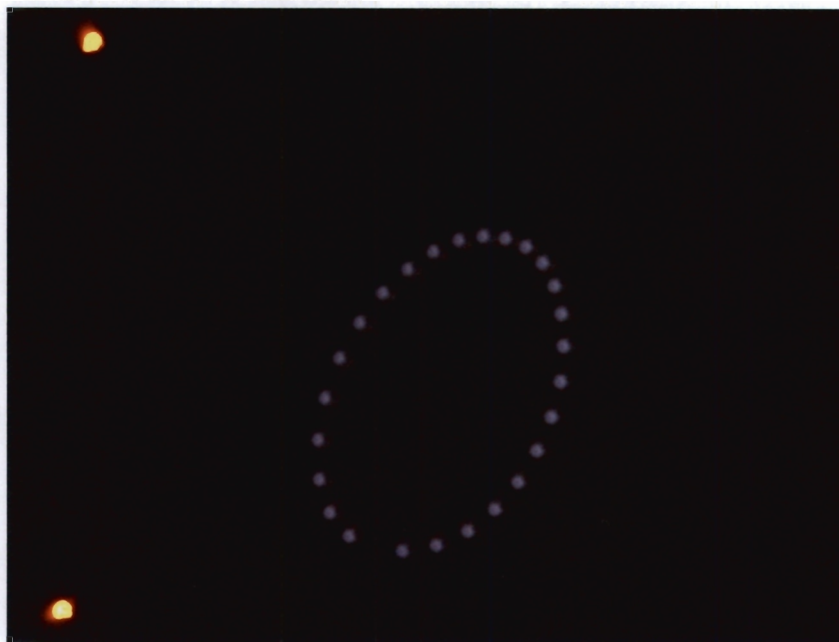


Figure 37 depicts the movement of a swift detaché stroke played at the wrist at four semi-quavers per second, with a beat of one crotchet per second. The movement of the wrist is circular, displaying the continuity of the movement, and the hand is moving in a balanced, continuous motion. This continuity of the stroke is created by the circular path followed by the hand. The first down and up-bow cycle is complete after half a second. The two yellow lights on the left of the picture are the stationary diodes, which are set 200 mm apart to give a scale. From this stable figure we are able to measure the distances between each dot within the circle. The distances between the dots within the circle are similar throughout. This shows that the speed of the hand is almost continuous throughout the circle.

Figure 38 depicts fast detaché using a straight-line movement. This movement is executed by the opening and closing of the forearm. The hand creates a straight-line pattern, showing the movement to be interrupted by a pause at each end of the stroke. The movement is played at four semi-quavers per second, with the first down- and up-bow cycle completed after half a second. This picture however captures only the down-bow stroke, as the up-bow stroke is identical. If both down- and up-bow strokes were captured on film then the dots would overlap, making the calculations unreliable. From this stable figure we are able to measure the distances between each dot within the line and hence determine the speed of the hand at the various positions.

Figure 38: Flashing cyclegraph of linear wrist movement – swift détaché



The spacing of the dots in Figure 38 shows how the arm accelerates rapidly at the start of the bow stroke and decelerates again towards the end of the stroke. The dots are closer together at the beginning and the end of the stroke and more widely spaced towards the centre of the line. This repeated acceleration, deceleration and stopping of the movement is inefficient, as the arm's musculature must provide the energy to accelerate and decelerate the bow repeatedly.

#### *Graphical analysis*

The graphs shown in Figures 39 to 41 were created from the data given in the Appendices. The method used is described in section 1.4 (Methodology).

The performance objectives were to determine the peak velocity and the rate of change of acceleration (jerk). They can be expressed in terms of minimising some measure of physical energy expenditure. The graph in Figure 40 depicts the velocity of the hand and of the bow in both linear and non-linear motion. The blue line indicates the velocity of both the hand and the bow in linear motion. The pink line depicts the velocity of the hand in non-linear motion. The yellow line shows the velocity of the bow in non-linear motion. Note that the hand and the bow have different velocities in non-linear motion, but are the same in linear motion.

The striking feature of the graph shown in Figure 39 is how the bow velocities (blue and yellow) are very similar in both cases, despite the fact that the hand velocities (blue and red) are very different. This shows that the more efficient non-linear hand action (red) results in

almost the same bowing action as that of the linear hand movement. The graph shows clearly that the hand moving in a non-linear motion maintains a relatively constant speed, especially when compared with the linear motion.

Figure 39: Graph of linear and non-linear hand and bow velocities



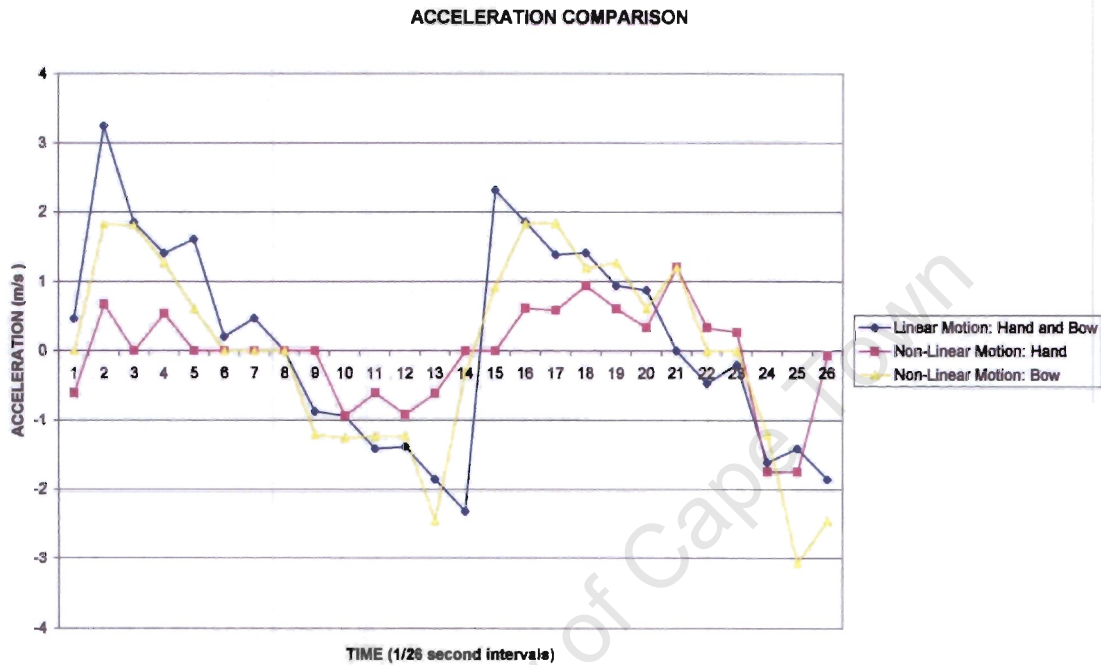
The graph in Figure 39 also shows how the hand has to slow to almost zero metres per second in linear styles and then accelerate again to achieve an effective bow speed. This energy-intensive action occurs with every up- or down-bow stroke. By contrast, in non-linear motion the hand maintains a relatively constant speed.

As discussed by WL Nelson, a graph of the velocity pattern with the minimum peak velocity would be rectangular. However, because acceleration cannot be instantaneous, the pattern has to be trapezoidal. The pattern depicted by the pink line shows the minimal impulse used in non-linear bow motion. The velocity does however increase slightly near the end of the down- and up-bow stroke (1983: 139–140).

The graph in Figure 40 compares the accelerations of the hand and bow in linear and non-linear motion. The blue line indicates the acceleration of both the hand and bow in linear motion. The pink line depicts the acceleration of the hand and the yellow line of the bow in non-linear motion. The blue line of linear motion shows how the hand reaches extremes of acceleration ( $-3$  and  $+3$   $\text{m/s}^2$ ). The pink line of non-linear motion shows how the hand seldom accelerates more than from  $-1$  to  $+1$   $\text{m/s}^2$ . This difference shows how the relatively

extreme acceleration and deceleration of the hand in linear motion requires large amounts of energy to start and stop each bow stroke – as has been previously explained. Again, the less extreme acceleration pattern of the non-linear hand requires less energy. The graph shows that the bow is performing similar motions in each case, despite the much gentler acceleration of the hand in non-linear bowing.

Figure 40: Graph of linear and non-linear hand and bow accelerations



As linear bowing requires repeated accelerations and decelerations, a high muscle force output is necessary to achieve this. The input power is proportional to the square of this force (Nelson, 1983: 138). These accelerations and decelerations can be seen in the angular movements of linear bowing. The repeated start and stop of each bow stroke is only possible by sudden accelerations and brakings. The impulse- and jerk-costs in linear movements are great, making these movements energy intensive. Non-linear bowing patterns tend to involve less extreme accelerations and therefore impulse- and jerk-costs are minimised.

## 2.6 CONCLUSIONS OF THE GRAPHICAL MOTION STUDY

The motion-tracking illustrations in this chapter depict the differences between linear and non-linear movement in the bow-arm. The paths described by the bow and the bow-arm are made visible by recording the movement and presenting it in the form of pictures and graphs which can be readily analysed.

In non-linear styles the movements of the bow-arm are inherently balanced and continuous, and originate mainly from the shoulder with its stable base and larger muscle groups. With both the upper arm and forearm describing elliptical paths in non-linear bowing there is conservation of momentum as they rotate around their respective axes. There is less demand on the elbow muscle groups to perform the repeated bow strokes. There is also a decreased tendency for the large muscle groups moving the shoulder to become fatigued. All these factors translate into efficient movement.

The shoulder is a multiaxial joint and movements of the shoulder have three degrees of freedom. It has flexion, extension, abduction, adduction, internal and external rotation (Trew & Everett, 2005: 91). As already mentioned, the principal muscles involved are the deltoid, *pectoralis major* and *minor*, *trapezius*, *supraspinatus*, *infraspinatus*, *subscapularis*, *teres major* and *minor*, and *latissimus dorsi*. These large muscle groups produce the main impetus for non-linear bowing by effecting rotatory movement in the upper arm. The deltoid flexes, extends, rotates and abducts the arm at the shoulder. The *pectoralis major* adducts, flexes and rotates the shoulder. The *supraspinatus* initiates abduction of the arm, and the *infraspinatus* laterally rotates the shoulder. Together with the deltoid, the *supraspinatus* and the *infraspinatus* also abduct the arm. The *subscapularis* rotates the arm medially (Faiz and Moffat, 2002: 163). The multitude of muscle groups acting on the shoulder explains the wide range and strength of the movements occurring in the upper arm. When doing rotatory movements it is desirable to use these large muscle groups whose use is physiologically less energy-intensive, rather than small muscle groups which make more energy intensive (linear) movements (ibid).

In linear bowing the work being done originates at the elbow joint, which has only two degrees of freedom. The forearm must thus repeatedly flex and extend to move the bow up and down the string. In comparison with the shoulder joint, the elbow has relatively small muscle groups acting on it and a smaller joint surface area. This results in increased strain on this joint and its associated tendons when subjected to repetitive actions.

The elbow is a hinge joint, capable only of flexion and extension under normal conditions (Tortora & Grabowski, 1993: 308). It is a biaxial joint (a joint with two degrees of freedom) with the flexion and extension around one axis and pronation and supination around the second axis (Trew & Everett, 2005:15, 90–91).

The principal muscles involved in moving the forearm are the *triceps*, *biceps*, *brachioradialis* and *brachialis*. The *biceps* flex and supinate the forearm; the *triceps* extend the elbow. The *brachioradialis* and *brachialis* assist flexion of the forearm (Faiz and Moffat, 2002: 163). These relatively small muscle groups are responsible for creating the majority of movement in linear bowing.

When a force arising from a muscle contraction is used to move an external load through a distance, for example moving the bow-arm and bow, mechanical work is done (Luttgens and Hamilton, 1997: 341). With regard to this muscle force, the strength generated by a fast contraction may be as much as three times greater than that generated at a slow speed (Trew & Everett, 2005: 15). When an object experiences rapid change in direction along a linear path, a sudden acceleration and deceleration is required. This is important to note as the hand performing linear bowing accelerates and decelerates far more rapidly than in the case of non-linear bowing. This is evident in Figure 40.

This chapter has illustrated the nature of the movements in linear and non-linear bowing and has clearly highlighted the differences between the two styles. The features of non-linear bowing that lead to efficiency of motion have been graphically illustrated and their relevance has been discussed.

# CHAPTER THREE

## POSTURE, BALANCE AND FLEXIBILITY

### *3.1 INTRODUCTION*

Posture, balance and flexibility complement each other to facilitate efficiency of movement. This chapter will focus on the importance of a good posture and sense of balance in achieving better efficiency of movement in violin playing. The need for flexibility in the right arm and shoulder is also outlined.

### *3.2 POSTURE*

One of the most important aspects of all forms of movement for the musician is posture. Movement is a result of balance, and good balance is a result of good posture (Hopkins, 2002 – website).

In order to execute efficient movement it is vital to have a posture that is balanced (Galley & Forster, 1987: 127). Balance in the lower limbs will ensure balance in the upper segments of the body. Trew and Everett state that the function of the kinetic chain, where the body segments are sequentially activated, relies on the optimum function of neurophysiological systems in the body. The posture of the trunk can thus determine the effectiveness of the function of the upper limbs (2005: 202).

Posture is seen as a gauge of mechanical efficiency, kinaesthetic sense, muscular balance, and neuromuscular coordination (Luttgens and Hamilton, 1997: 446). The importance of a good posture, sense of balance, and position and flexibility of the bow-arm is vital in the overall comfort of the musician. Rolland states that posture is the key to a relaxed body, freedom of movement and a better position and facility (1986: 4). Tubiana also states that the need for flexibility of the muscles in the trunk, shoulders and arms is a prerequisite for a well-balanced stance (Tubiana & Amadio, 2000: 178).

Rolland writes that 'Not only the shoulder area, but also the whole body should be kept in a natural, unlocked manner, permitting the small compensating motions used in throwing a stone or swinging a bat. Thus the small natural movements of the violin resulting from a

relaxed body attitude are not restricted, especially when sudden irregular bow movements are employed' (1979: 11).

'The function of the upper limb is primarily dependent on a stable base on which to work. The pelvis and more proximally the scapula can be viewed as the two interlinking platforms on which the upper limb functions. Function is also dependent on coordination between the scapular muscles and the muscles of the humerus, forearm, wrist and hand' (Trew & Everett, 2005: 202). Poor pelvic stability can lead to inefficient and uncoordinated activity of the upper limb because, according to Newton's law of reaction, the trunk must provide a force equal to the force driving the arm. Flesch, explaining that 'every emotion seeks to express itself in movement', states that the movements of the upper parts of the body are sometimes so violent that it is impossible for the lower segments to be unaffected by them. It is therefore not possible to play the violin with a stationary stance (Flesch, 1939: 14).

For the upper limb to function effectively there needs to be a transfer of forces from the proximal segments (the axial skeleton and scapula) to the upper limb (Trew & Everett, 2005: 202). It is also important to note that the postural muscles in the lower limb are actually activated before the arm moves. This adds to the stable base on which the arms can function. The balance from the pelvis and leg muscles which occurs before the arm moves is an important prerequisite for the production of coordinated action in the arms (ibid., 203). It is therefore important to note that, to have freedom of movement in the upper limbs, the body needs to have total balance. To acquire this balanced body position the postural muscles need to be well developed, and the body needs to be able to deliver adequate strength, power and endurance (Galley & Forster, 1987: 127).

A child's postural development follows a natural pattern of growth, from the infant who cannot hold up its body, to a child who can confidently and freely reach out to the world with both hands (Hansford, 2005 – interview). In this growth process the development of new skills can be impeded by a lack of freedom of movement and balance. This hindrance can also cause the body to feel pain. The mind will constantly be interrupted by somatosensory messages coming from the body for the need to find alternate ways to relieve any discomfort.

With a good posture one can avoid many of the pains that players may suffer from (Roos 2001: 2–3). The posture of many violinists is however often unnatural and therefore uncomfortable. It is therefore important to acquire a stable and flexible position for both the

bow-hold and the position of the violin. Mueller agrees, stating that excessive tension will have negative consequences on the player's immediate and long-term performance (Mueller, 1995 – website).

Holmwood and Porter state that repeated stress due to sustained postures and repetitive movements can cause an overload of the musculo-skeletal system, which can eventually result in injury (1991: 59). When standing while playing the violin, the legs provide the base on which the trunk and upper body are balanced. However, the individual who stands still in one place for a long period of time tends to tire more quickly than the individual who has subtle yet constant movement of the postural muscles within the body.

Galley and Forster state that standing is not a static position: 'The upright position is maintained by the alternating action of antagonistic muscle groups, which prevents overbalancing' (1987: 91). Hellebrandt (quoted in Rolland, 2000: 33<sup>8</sup>) says that standing is actually movement on a stationary base and postural movements are inseparable from standing. Hodgson (1958: 8), and Szende and Nemessuri (1971: 39) confirm Hellebrandt's statement that to stand upright the body uses a large number of muscles and righting reflexes, which constantly oppose and balance one another.

Flesch discusses body posture as being an important facet in the balance of the violinist (1939: 14–15). He states that an important aspect of posture is the position of the legs, indicating that tasks given to the arms cannot be executed properly if the legs are not correctly positioned. Flesch discusses three positions. The first position is called the 'joined together, rectangular leg' position, where the feet are close together and at right angles to each other. This deprives the violinist of a sufficient base to balance on. This may therefore cause the player to feel that their freedom of movement is greatly impeded when playing technically difficult passages. In Flesch's second position, the 'acutangular leg' position, the feet are parallel and one foot (either the left or the right) is advanced by four inches, encouraging the body to swing about 75° to the left or the right. This position is not ideal as the weight distribution on the feet will not be equal. In the third position, called the 'spread leg' or 'straddling leg' position, the legs are held further apart, giving the performer a broad

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8 Hellebrandt, FA & Bogen F. 1943. *Physiological Study of the Vertical Stance of Man*.

pedestal of stability (1939: 14–15). Rolland concurs that the optimal stance is with the toes turned out at 45° and the feet separated, thereby steadying the stance (2000: 69).

Hansford describes the body's optimum balance as achieved by standing 'feet apart'. In her physiotherapy studio she will show a child different options of how he or she can stand. The first is with the feet firmly set together. This is called the 'unstable' position. The feet will not be able to balance the body when large movements are made in the upper half of the body. The surface area of the feet together is not big enough to support such movements. Hansford's second stance, where the feet are set widely apart, she calls the 'static fixed' stance. Again the child will find it difficult to have freedom of movement within the upper body. Sideways movements from left to right are easier to balance but movements forward and backward are unstable. The third position is the 'stable' position. Here the feet are first set firmly with the heels together and the toes turned out at 45°. The heels are then lifted and replaced so that the feet are a space apart and parallel to each other. In this position the centre of balance runs from the hips to the knees to the arch of the foot. In violin playing the musician needs to take one step forward with the left foot in order to balance the asymmetrical upper body position. This position is comfortable as the violinist can better maintain balance in order to move freely in any direction whilst playing (Hansford, 2005 – interview).

In the writings of Szende and Nemessuri they too state that it is important to stand with the legs slightly apart, the knees slightly bent and the frontal plane of the body level with the legs. The upper body should be somewhere between relaxed and standing to attention, with the weight of the body resting equally on both feet (1971: 39).

Rolland teaches the importance of the stance at the very start of the violinist's training. He states that the feet should be placed a few inches apart, but adds that the left foot should be placed slightly in front of the right and should bear a little more of the weight (2000: 68). It is also important that the knees should not be locked into position but, as suggested by Szende and Nemessuri, should rather remain flexible. This flexibility helps to keep a relaxed posture and makes easy the transfer of weight from one leg to another while playing (2000: 68). Suzuki teaches the stance through a series of similar ideas. Firstly the child stands with his or her feet parallel, the feet are then moved into a 'V' shape with the heels slightly apart, and lastly the right foot is moved one step backward (Perkins 1995: 139).

Body balance also depends on the weight distribution on each foot (Galley & Forster, 1987: 88). Hodgson states that it is universally recognised that if the feet are placed apart it is easy to transfer weight from one foot to the other. This transfer of weight and stability in the stance is important for the correct foundation of free arm movements (Hodgson 1958: 8).

When playing the violin, balanced movements are essential. The body adapts its overall balance to suit the movement (Galley & Forster, 1987: 127). There are many different ideas on how and when the body should compensate, to balance the movements that are carried out in the upper body while playing. According to Flesch, the only movement should be the unconscious movement generated by an involuntary reflex (1939: 15). The balancing movements depend on the duration of the bow strokes. Flesch says that vigorous bowing elicits body movement in the opposite direction. Slow bow strokes however need to have movement that follows the direction of the bowing (1930: 95). In Szende and Nemessuri's book, Basler and Kawaletz<sup>9</sup> are quoted as saying that the trunk bending to the right compensates up-bow strokes. The function of these movements is to maintain the body's balance (Szende & Nemessuri, 1971: 30).

Galamian says that there is a certain amount of movement that is natural and helps coordination and the feeling for rhythm and accent (1985: 13). However, when teaching children, one must be aware of exaggerated bodily movements which will cause technical difficulties, as the child will have to keep on adjusting the bow to the violin. Suzuki says that, when comparing musical and unmusical movement, one will see that musical movement contains natural laws, whilst unmusical movement expresses disorder (Perkins, 1995: 167).

All of the above factors indicate that it is important to note that the overall posture and balance of the body is vital in maintaining freedom of movement and balance in the arms when playing the violin. A relaxed and balanced stance provides an adequately stable base for the arms to move freely, facilitating efficiency of movement.

The importance of correct posture and balance is the starting point to a successful, relaxed and natural method of playing the violin. In addition to the correct posture one needs to find a comfortable, relaxed and functional method of holding both the bow and the violin. The next

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<sup>9</sup> Basler, A & Kawaletz, K. 1943. Über den Einfluss des Konstitutionstypus auf die Technik des Geigenspiels. *Arbeitsphysiologie*, 12.

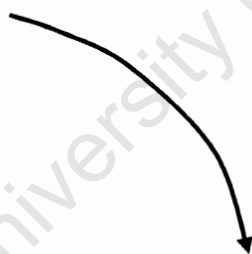
section will discuss physiologically-based positions for holding both the violin and bow to enhance efficiency of movement.

### **3.3 DRAWING THE FIRST BOW STROKE**

Hodgson states that Steinhausen maintained that there are ‘no straight lines’ in violin playing. The existing principle at that time (the early twentieth century) was that the bow had to move parallel to the bridge and therefore must move in straight lines. Steinhausen believed however that the bow moves only in curves (Hodgson, 1958: x). Hodgson decided to demonstrate this. He created graphs of actual performances that traced these curves.

Figure 41 is an example of the first long bow stroke described by Hodgson. He believed that the first bow stroke to be taught to a beginner are those that cross, slurred together, from the open G-string to the open D-string, the open D-string to the open A-string or the open A-string to the open E-string (Hodgson, 1958: 70). He writes that one should foster the natural movement the child makes when pulling the first bow stroke. This movement allows the bow to cross from the lower to upper adjacent string.

*Figure 41: The path of the hand playing the open D- to open A-string in one bow*



Hodgson teaches an extended bow stroke by asking the pupil to make figure of eight patterns in the air without the bow. The size of the pattern needs to be big enough to allow the elbow joint to open. This exercise helps the pupil to extend the bow to its full length and to maintain the parallel line of the bow to the bridge (1958: 70.).

Galamin also disproves the idea of drawing the straight bow stroke. He writes that the problems here lie in the fact that the action in the form of a straight line does not come naturally to the human body. The bending of the joint causes circular motion to take place. He writes that ‘A straight line can result only through the well-coordinated combination of circular motions’ (Galamin, 1985: 51).

Szende and Nemessuri speak of the 'square' position of the bow as being the most natural starting position. They say that the 'expedient arm position is one which maximally promotes the motor tasks, causes the least possible increase in muscle tone and relatively slight excess tension in the articular capsules and ligaments.' They continue, saying 'The position should be considered the "natural" starting position in which power expenditure is at a minimum. The starting positions of the elbow, wrist and fingers in playing the violin approximate the anatomical mid-position in which the aforementioned conditions of tension are the most favourable' (Szende & Nemessuri, 1971: 46).

Galamian writes that the square position is the ideal starting position for free play in all directions (1985: 52). Rolland also speaks of the square position of the bow. In this position the fingers are rounded and relaxed, as taught in the initial bow hold. Rolland emphasises that the middle third of the bow is the easiest part to control because the arm is most comfortable. This comfort is due to the fact that the elbow is in a mid-position (2000: 90), with the weight of the bow distributed equally between the hand and the string. From this point the beginner will draw the bow from the shoulder joint, using the whole arm as a unit. This is a natural movement that forms the basis of all further bowing movements (ibid.).

Rolland teaches that initial bow strokes should be short and at the point of balance (just below the middle of the bow). As the movements get longer than an inch<sup>10</sup>, the forearm starts to take part. The movement from the shoulder and the movement from the elbow will always be used together, but in different proportions (2000: 90). Suzuki, like Galamian and Rolland, teaches the first bow strokes from the square position. He agrees that this position is well-balanced and allows the arm to be free. Suzuki's first bow strokes too are very short, using only a few inches of the bow (Perkins, 1995: 160).

When extending the bow stroke, the arm has to traverse in circular movements, as described earlier by Galamian. These extended bow strokes can be created only by upper arm movements, in conjunction with forearm and finger movements. Hodgson describes the arm as a series of levers. To perform a whole bow stroke, the upper arm lifts the forearm. The upper arm hinge action and roll movements both occur naturally. These movements are transmitted into the smaller joints to create power on the string (Hodgson, 1958: 6). To get

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<sup>10</sup> About 2.5 centimetres.

power into the bow the player will have to focus on the stronger muscles in the back and upper arm (Perkins, 1995: 158).

Havas agrees with Hodgson that the bow should always move in natural arc-like patterns. She says that these movements originate from the back muscles and there should be a feeling of natural balance while playing (Perkins, 1995: 72). Suzuki also talks about bowing movements being initiated in the back and upper arm muscles. However he teaches the beginner pupil to play their first bow stroke leading with the elbow. He says that the elbow cannot move on its own, but is under the control of the muscles of the back and upper arm. It is much easier for a student to see and focus on the elbow rather than the upper arm and, with the elbow moving in the correct way, the bow will always draw semi-circular shapes (Perkins, 1995: 158).

When teaching beginners it is most useful to start the child at the middle of the bow, as does Galamian, Hodgson, Rolland and Suzuki. The child does not have to worry about the weight of the bow and the difficulties of balancing it. From this neutral position the child can learn the first movements of balance, suspension and weightlessness (Perkins, 1995: 72). The first strokes will be short and round and should lead from a relaxed swinging shoulder (Galamian, 1985: 72). The bow strokes can then be slowly extended.

### **3.4 THE RIGHT ARM**

Flesch states that the mechanical aspects of using the bow are more complex than those of the left hand. The reason for this is that the left hand comes into direct contact with the violin while the right arm comes into contact with the violin only through the bow and the bow hair. The fingers, hand, lower and upper arm all participate in the bowing action, with the fingers being the most important because they touch the bow, while the other parts of the arm simply transfer energy through the fingers (Flesch, 1939: 51). It is therefore essential to find the most natural and relaxed position for the fingers and hand, so that the hand is free to transfer energy from the arm to the strings.

#### *3.4.1 The bow hold*

For one to be able to play with the most efficient movement one has to have a secure and flexible bow hold. To create for a beginner an initial bow hold that has relaxed arm, hand and fingers is therefore fundamental.

If a violinist plays with a flexible and secure bow hold they will find it easier to execute all the different motions required in playing. The trend in the twentieth century has been towards a bow hold derived from natural finger positions; one that permits adjustment of the fingers during the bow stroke (Palac, 1992: 30–34). Roos emphasises the importance of a natural bow hold in achieving freedom of movement (2001: 3-3).

Leopold Auer believes that the bow hold is very individual. He suggests that the fingers should fall into position naturally when taking up the bow. When producing a tone the fingers and wrist are the predominant factors. By placing importance on the fingers and wrist to create the necessary tone, he stresses the need to avoid any pressure from the arm (Auer, 1980: 12–13).

Flesch supports Auer's ideas on holding the bow. He describes Auer's bow hold as the accepted Russian bow hold and suggests that this way of holding gives the best tonal results. The index finger touches the stick at the line that separates the second from the third finger joint. The first three fingers are the leading fingers in bowing and often the little finger only touches the bow when the lower half of the bow is in contact with the strings (1939: 51). Both Auer and Flesch suggest that the best tonal results are acquired through this particular bow grip and that the index finger is responsible for the guidance of the bow.

Galamian agrees with Auer that the player should hold the bow in a natural position. He confirms that the bow-hold must be comfortable with all the fingers curving in a natural relaxed way. No single joint must be stiff, resulting in a flexible grip that allows all the natural springs in the fingers and hand to function well (Galamian, 1985: 47). He writes that the bow forms an integral part of the right-hand mechanism. He suggests that the best way to find the natural position is to hold the hand absolutely relaxed, suspended from the wrist, and let the fingers hang loosely. The fingers should feel like 'loose flimsy springs'. The single adjustment when the hand is then placed onto the bow, is that the first finger will be set slightly away from the second and the little finger placed on top of the bow (ibid.). Here the difference between Galamian's bow hold and that of Flesch is clear. Flesch states that the little finger makes contact with the bow at the nut only when the lower half of the bow is in contact with the strings. In Galamian's bow grip, the little finger is in contact with the nut at all times. This grip, he says, ensures that 'the fingers control a larger part of the bow, and have a more secure hold on it' (Galamian, 1985: 47). Another difference between these two bow holds is that the first finger contacts the bow at different points on the finger itself.

Rolland also strives to find the most natural position for the fingers on the bow. He too suggests that the pupil should feel the natural fall of the fingers when the hand hangs loosely at the side. When on the bow, the fingers should have a similar feeling and position, resembling the natural resting position of the hand (1979: 8). Rolland suggests that the thumb, second, third and fourth fingers should support the bow, while the first finger rests passively on the top of the bow, and transmits pressure from the relaxed arm into the strings. Rolland thus disagrees with Flesch who stated that the tone production comes from pressure from the fingers or the wrist, and that the first finger will have to exert some form of pressure to create tonal strength (Flesch, 1939: 51). Rolland states that this action of finger pressure localises the pressure in the hand and short-circuits the forces of tone production (Rolland, 2000: 35). He suggests that the violinist should create pressure from the whole arm, which then transmits power through the fingers to the bow.

To create ease in learning, Rolland suggests practising the bow hold using a pencil. In this way a child can practise the bow hold without the difficulties created by the weight and size of the bow. They can then master the position of the fingers, thereafter returning to the bow with a more confident hand position.

Hodgson also discusses the method of teaching the preparation bow hold with the aid of a pencil. He says this enables the child to learn the bow hold with a relaxed hand. An important aspect for Hodgson is that the hold of the bow is a balance rather than a grip. He writes that 'when a correct method of holding the bow has been acquired the original suppleness of the arm will not have been interfered with appreciably'. The hand will still be able to move the bow from the wrist, forearm and upper-arm, thus showing that the thumb and fingers remain flexible (1958: 67–68).

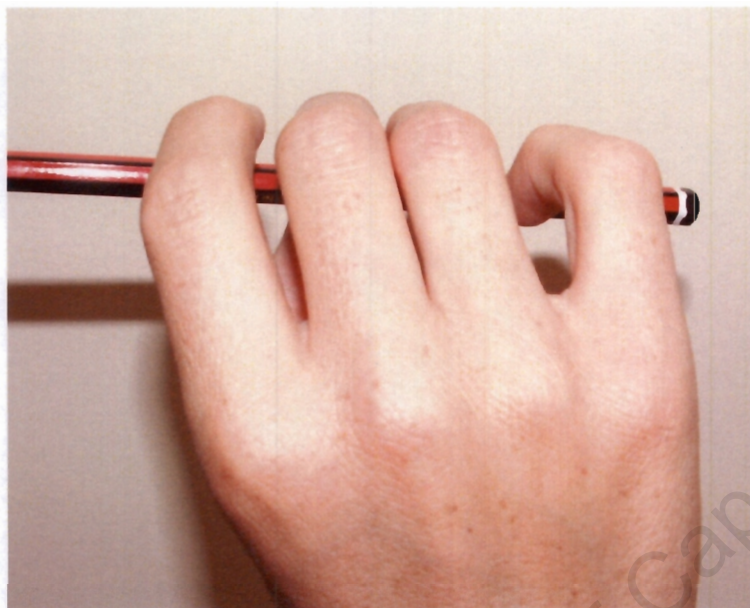
After the pupil has a secure position for the fingers on the bow, Rolland introduces a second step. That is to teach the early bow hold at the point of balance on the bow – the point where it has equal weight on either side. From the pencil to this bow hold is a easy transition for the pupil to make as the bow feels light and easy to control.

Hodgson and Rolland's use of practising the bow hold first on a pencil is invaluable as it facilitates a relaxed hand. The pencil is light and easy to move around when checking the bow hold from different angles. In my teaching experience the child is, however, impatient to

hold the bow. A solution is to teach using both pencil and bow, holding the pencil at times and the bow held at the point of balance at other times.

Figure 42 shows how the pupil can hold a pencil instead of the bow to acquire a natural balance and relaxed position on the bow.

*Figure 42: Bow hold practised on a pencil*



Galamian and Rolland both emphasise the necessity for the pupil to practise rotating the hand from the arm or shoulder at this early stage of development, to make sure that the hand can move freely in a relaxed fashion without letting the bow grip alter. This early introduction of forearm and upper arm rotation is important in the development of bowing technique. It ensures that the bow grip is flexible, and secure enough to develop well balanced bow-arm movements.

#### *3.4.2. Flexibility in the bow hold*

The need for flexibility is paramount in bowing. If the body is flexible it allows the individual parts to act in the most efficient way. If there is any stiffness in a particular movement the body will adapt the movement to one that may be less efficient.

The importance of flexibility in the right hand and fingers is that the violinist will be free to execute any number of actions with the bow. Through this flexibility the fingers will be able to adjust in accordance with the changing angles of the hand to the bow and the strings. In non-linear bowing it is important to have flexibility in the fingers, allowing the bow to

maintain its position parallel to the strings when changing bow direction. Roos emphasises the importance of elasticity and sensitivity in the right hand to ensure smooth bow changes as well as string crossings (2001: 4–10).

Flesch writes that in the change of direction in a bow stroke one should acknowledge Newton's first law of motion, the law of momentum and inertia (Rosenblith, 2000: 42). This law states that a body will continue in its state of motion or state of rest unless acted upon by an external force. In the change of direction in the bow stroke the arm cannot suddenly stop and change direction without the sound of a sudden jerk. This is important as it is not possible to change bow direction without a small continuing follow-through movement of the fingers and wrist. The arm must first change direction, followed then by the wrist and fingers, in order to achieve the most inaudible stroke-continuation in bow changes (Flesch, 1939: 60).

Galamian also emphasises the importance of flexibility in the bow grip. He writes that the fingers of a more advanced player will constantly be subconsciously adjusting. He states that the bow grip is not static, but is, rather, subject to constant modification as the bow moves from the tip to the nut (1985: 45). He calls these finger adjustments the 'horizontal motion' of the bow. At the end of a down-bow the bow is at the tip and the fingers and thumb are straightened.

*Figure 43: The position of the right hand playing at the tip of the bow*



At the end of an up-bow the bow is at the nut and the fingers resume their rounded shape (1985: 48). Szende and Nemessuri see these movements in the fingers as adjustments for a continuous balancing of the bow (1971: 73).

The photographs in Figures 43 to 45 show examples of the shape of the fingers on the bow at the point, the middle and the nut (Szende & Nemessuri, 1971: 73–75). It is clear that the positions of the fingers on the bow are constantly adjusting.

*Figure 44: The position of the right hand playing at the middle of the bow*



*Figure 45: The position of the right hand playing at the nut*



Rolland agrees that there is a need for flexibility in the fingers. He says the bow grip should be flexible so that adjustments will occur naturally in the fingers. The importance of this idea is that the fingers will adjust to keep the bow parallel to the bridge as a full bow stroke is executed (1992: 9). This idea is similar to that of Flesch, who emphasises the importance of both finger and wrist participation in the change of bow direction. Rolland writes that when one plays at the tip of the bow the hand reaches forward and the fingers become slightly straighter, and when playing at the nut the wrist is slightly arched and thumb and fingers are curved. In this statement Rolland agrees with Galamian (1992: 17), as well as with Szende and Nemessuri (1971: 73).

There are many exercises that can be taught to the pupil at this initial stage to ensure the flexibility of the fingers on the bow. Flesch teaches finger flexibility in preparation for the martelé stroke. A good exercise is for the pupil to hold the bow in a horizontal position with the hair facing upwards. The pupil must then bend and straighten his or her fingers pushing the bow up and then releasing down again. The pupil then does the same action in the fingers with the bow held vertically and lastly with the bow held horizontally with the hair facing downwards. In each different position of the bow the fingers will repeat the same finger positions of flexing and extending (Rosenblith, 2000: 41).

Galamian teaches finger flexibility in a similar way. He has an exercise where the pupil is taught to raise and lower the bow using only the fingers. The arm and wrist remain static (1985: 48). Figures 46 and 47 illustrate the two different positions of the fingers. Figure 46 is the flexed finger position and Figure 47 is the extended finger position.

*Figure 46: Flexion of the fingers on the bow*

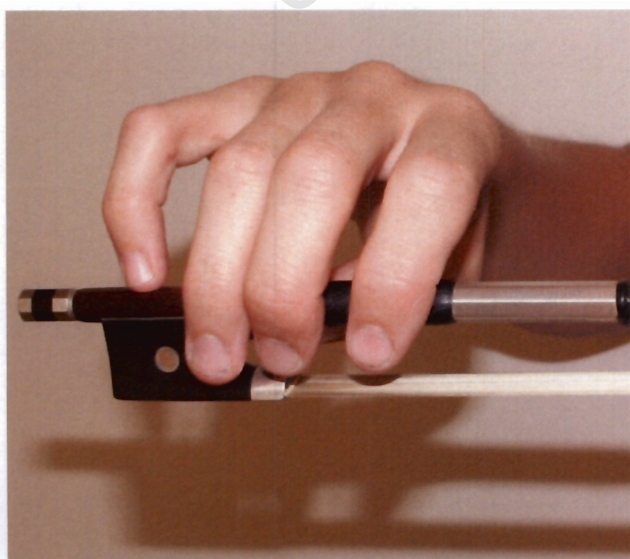
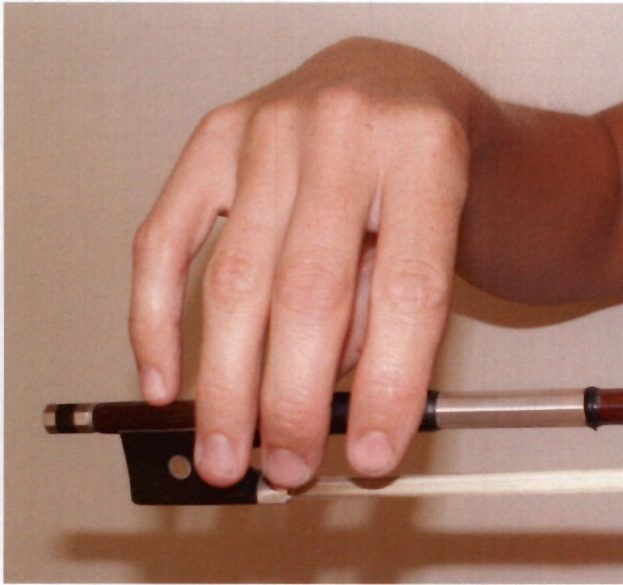


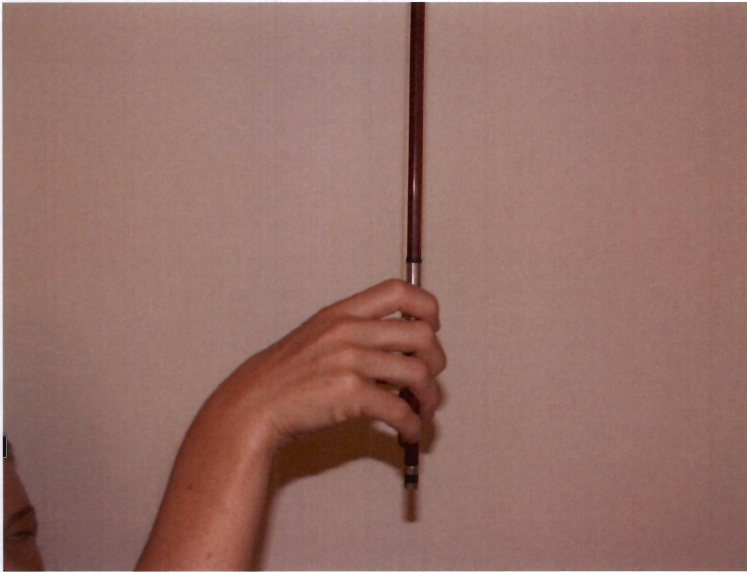
Figure 47: Extension of the fingers on the bow



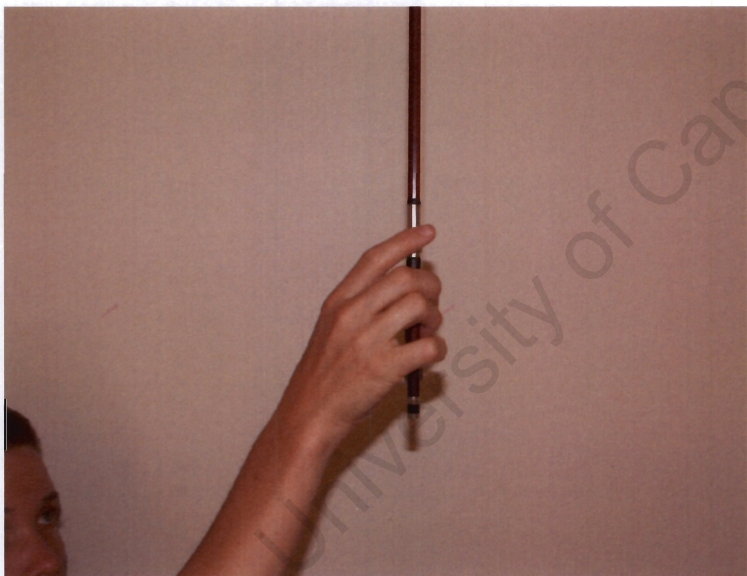
An exercise that Rolland uses to teach the fingers to be mobile is the 'elevator' or 'rocket' exercise. This exercise helps the pupil acquire flexibility in the fingers in order to achieve a smooth legato stroke through sequential motion. The motion starts in the shoulder and follows through to the arm, wrist and finally the fingers (2000: 145). The pupil holds the bow, pointing it to the ceiling. He or she then moves it up towards the ceiling leading with the upper arm. When the arm has reached its limit the hand, fingers and bow continue up, allowing the wrist to straighten and the fingers to follow through. The arm then leads the bow back down to the starting position (Rolland, 2000: 145). The movement of making the bow rise and fall vertically to the ground forces the fingers to move naturally along a specific path. The position of the fingers will change from a rounded bow grip when the rocket is high to a more straightened bow grip when the rocket is lower. This action replicates the movements of flexible fingers on the bow in a full bow stroke, changing from being round at the nut to being straight at the tip.

In Figure 48 the wrist is curved and the arm is at its limit. In Figure 49 the wrist is straightened, thus extending the bow slightly further upwards, and changing the position of the fingers on the bow. If the wrist remains straight the exercise will encourage the fingers to be flexible on the bow (Rolland, 1992: 9).

*Figure 48: Lifting the bow, before straightening the wrist*



*Figure 49: Lifting the bow, after straightening the wrist*



Another exercise is to push and pull the bow against resistance. The pupil must hold the bow with rounded fingers and pretend to play the down-bow as the teacher holds the bow in a stationary position. The next step is to pretend to play an up-bow by pushing the bow against the resistance of the teacher (Rolland, 2000: 150). He also teaches the 'teeter-totter' bow. Here the pupil holds the bow at 45° to the horizontal and moves it, using only the fingers, to a horizontal position and then back to the starting position. Repeating this exercise strengthens the fingers and encourages flexibility (Rolland, 2000: 148).

When teaching a beginner student to have flexibility in the fingers, I find it easier to show them movements that the bow should do rather than letting them focus on the fingers. This diversion in attention alleviates any tension that may occur in the fingers if the child is too worried about the finer movements of the fingers. Rolland speaks about this. He writes that in his teaching with a beginner student he focuses on the larger body parts. The less the child focuses on small movements, the less danger there is of fixation of the joints next to the moving part. He believes that the movements should be encouraged to occur without thinking about them (2000: 145). This is seen in his rocket exercise.

### *3.4.3 Flexibility of the shoulder*

It is important to have flexibility in the arm, from the shoulder. If the shoulder is not flexible it may hinder the movements of the bow. All of the non-linear movements discussed earlier need to be played with the use of a relaxed shoulder, enabling the violinist to execute the movements needed to play most efficiently. If there is any tension or disturbance in the shoulder girdle function, it can affect the function of the entire arm (Trew & Everett, 2005: 192).

Rolland teaches flexibility in the shoulder right from the start, as does his contemporary Kato Havas. Havas talks about releasing the shoulder socket hinges by lifting both arms in the air from the shoulders (Perkins, 1995: 72). Rolland has many different exercises to help prevent any tension or stiffness in the shoulder joint. One example is to teach the pupil to move the arm in circles from the shoulder with the bow in the hand (1992: 7). He or she then continues to practise, but with the added movement of plucking the string and letting the arm fall into a large circle and return to the string. This action allows the arm to move more freely because the bow does not get in the way. Another exercise is where the child places the bow on the strings at the point. The left hand is placed in the middle position and the point of the bow is hooked on the little finger. The child then lowers and lifts the right arm, hand and bow as a unit from the shoulder, with smooth relaxed movements. The next step is to continue the exercise with smaller movements with a relaxed arm. The movement should be natural, similar to that of shaking salt onto their foot with a saltshaker. The upper arm will rotate from the shoulder as the hand shakes up and down. The arm should be balanced and the elbow buoyant (Rolland, 2000: 87).

In teaching flexibility in the shoulder, the teacher creates a well-balanced and relaxed pupil. The teacher should utilise natural movements such as clapping or 'polishing pots'. When these are felt and understood by the child then they can be applied to violin technique.

### **3.3 THE LEFT ARM**

The aspects of the left arm which will now be discussed are holding the violin and elbow placement. The most important aspect of the use of the left arm is comfort and flexibility. The importance of holding the violin without raising or stiffening the left shoulder is discussed. If the player raises the shoulder or stiffens the neck, the overall posture will become unbalanced. The emphasis is on the natural balance of the arms, creating a smooth and relaxed left arm.

#### *3.3.1 Holding the violin*

It is vital to create a natural relaxed position where the violin is supported in such a way that the player is able to execute all the necessary arm movements. Roos states that the violin should be held in place by the use of weight and not tension (2001: 3-1). Rolland believes that in supporting the violin, it is important to emphasise total body involvement and left arm mobility. The total body involvement incorporates a good posture and a relaxed left arm. If the shoulder is raised to support the violin, the balanced stance would be affected and eventually pain and discomfort would interfere with the playing of the instrument. Left arm mobility helps the student to have freedom of movement, better position and facility (1992: 1).

Flesch discusses the position of the violin, saying that it should be balanced on the collar bone, held by the lower jaw, and supported by the left hand. He writes that the drawing up of the shoulder is to be avoided since any muscular contractions of the shoulder will affect the mobility of the entire left arm (1939: 15). Leopold Auer wrote that when holding the violin it is important to avoid resting it on the shoulder or drawing up the shoulder to meet the violin (1980: 10).

Galamin agrees with Flesch that the ideal and most relaxed position for the violin is to hold it balanced between the hand and the collarbone. Galamin states that the instrument has to have a relationship with the body, arms and hands that will allow a comfortable and efficient

execution of all playing movements (1985: 12–13). The actions of shifting and vibrato require a relaxed and mobile shoulder joint to help with the support of the instrument. If the shoulder is lifted or tensed up it will create unwanted tension in the joint, resulting in stiff movements of the upper arm. When a player elevates the left shoulder and pushes down with the side of the neck and jaw to support the violin, tension in the neck, left shoulder and upper back will appear. This in turn limits the ease of movement in the shoulder and left arm (Tubiana & Amadio, 2000: 183).

Rolland discusses the importance of a correct violin hold. He writes that without this correct hold, it is difficult to develop good bowing habits. He agrees with Flesch and Galamian that the violin should be held in a balanced position. Rolland writes that the violin should be placed on the right bump of the left collar bone. He suggests that the violin should not be held in a vice-like grip, but should rather be supported in a relaxed manner. He states that much of the weight is supported at the chin rest and that the left hand provides some support under the neck of the instrument, thereby alleviating much tension at the shoulder area. The chin will take an active part in certain situations, for example changing of positions (1986: 71). He also agrees with both Flesch and Galamian in that the violin should not be locked by the shoulder and chin, but that the left arm and shoulder should be kept as relaxed as possible (Rolland, 1979: 11).

Each person's body is a different shape and size. Therefore it is important that, when teaching the steps set out earlier, one should not have completely rigid rules. For example a violinist with a long neck will probably need a shoulder pad, and a violinist with a shorter neck could omit the use of a shoulder rest all together (Galamian, 1985: 13). For shorter people the violin should point further towards the front of the player, and for taller people with longer arms it should be pulled more to the left (Galamian, 1985: 14). Fischer agrees that the violin should be placed differently to suit different players. He writes that a violinist with long arms should point the scroll more to the left, and should place it lower on the shoulder. A violinist with short arms should point the scroll more to the front and place the violin so that the chin is closer to the tail piece, an idea which agrees with that of Galamian (Fischer, 1997: 20). To find the perfect placement one should hold the bow on the G-string at the point. The bow-arm should be almost straight and not over-stretched. If the bow is at right angles to the string, the position of the violin is correct. If the bow however cannot reach the tip at right angles to the

violin then the violin needs to be adjusted. The scroll should be pulled to the right (Galamian, 1985: 14).

The angle at which the violin is held is also important. Rolland uses the balancing of a ball on the strings to establish the correct height of the violin. A small ball is placed between the G- and D-strings. The strings should be parallel to the floor thus allowing the ball to balance against the bridge. If the ball falls towards the scroll the violin is too low. If it falls towards the child it is too high. If the violin is held too low the strings will be slanting towards the floor (1992: 5). This will create difficulties in producing a clean sound because the bow will have a tendency to slide towards the fingerboard, which will result in poor tone quality (Flesch, 1939: 15). The child will always be fighting gravity, trying to maintain the bow stroke moving parallel to the bridge (Rolland, 1992: 5). Similarly, if the violin is held too high, the bow will tend to slide towards the bridge, again creating poor tone quality (Flesch, 1939: 15).

Figure 50 shows a small ball balancing on the violin.

*Figure 50: Ball balancing on strings*



### 3.3.2 Placement of the elbow

Another important aspect discussed by Rolland is the placement of the elbow. To acquire this position Rolland teaches an exercise where the left fourth finger does pizzicato on the G-string. This exercise stretches the upper arm around to the right, allowing all four fingers to sit comfortably on the violin. This exercise strengthens the fingers and helps to create a correct position for the left arm and hand.

Figure 51 demonstrates the movement of left hand pizzicato on the G-string. Here the pupil's wrist is straight and the forearm is highly rotated. All four fingers will fall naturally onto the string from this position.

*Figure 51: Left hand pizzicato*



Having a good and natural posture in violin playing is of fundamental importance. This posture extends further than just the stance. It extends to the necessity for balance of the body, the violin and the bow. These aspects of violin playing enable the violinist to have economy of movement in the bow-arm, flexibility in the bow hold and the shoulder, and stability in their stance. Without these aspects there would be no efficiency of movement when playing the violin.

# CHAPTER FOUR

## SUMMARY AND CONCLUSIONS

*There is a best way to perform any task.* (Rolland, 2000: 207).

This dissertation attempts to prove that non-linear bowing is efficient. This efficiency is achieved primarily through minimising the extremes of velocity and acceleration, as well as through greater flexibility and arm balance. In the twentieth century an awareness of efficiency of movement and the need to acquire natural movements and postures in violin technique were documented by great violin pedagogues such as Auer, Flesch, Galamian, Hodgson and Rolland. These teachers were all influenced by the controversial writings of the scientist Steinhausen, who first described rotatory movements in violin technique.

In his works, Rolland is seen as a pioneer in the amalgamation of science and violin technique. Rolland was greatly influenced by scientific principles from the fields of physics and kinaesiology. He was also influenced by Hodgson's early motion analysis which confirmed Steinhausen's theories that the bow moves in curves. Rolland refined his teaching methods by applying the Newtonian principles of motion to the human body as a violin-playing machine. He summed up his teaching method in a single word 'naturalness'. The concept of naturalness embraces the use of habitual, physiological patterned movements, which include rotary components and circular motion.

The author made motion-track analyses of non-linear and linear styles showing the relative efficiency of movement of the former. The analyses revealed that non-linear arm and wrist movement patterns take place mainly in ellipses and curves, and that in non-linear motion the hand maintains a relatively constant speed although the path of the bow is similar to that of linear bow-strokes in which the speed is not constant. Non-linear movement originates mainly from the shoulder, with less forearm flexion and extension than in a linear motion, thus creating a balanced movement in the forearm around the mid-forearm axis. The shoulder's large muscle groups share the duty of energy provision for the movement. As the shoulder is the proximal lever for the rest of the arm, relatively small changes in shoulder angulation translate into much greater movement in the hand. Due to their efficiency, these two factors endorse the use shoulder-based bowing movements in non-linear bowing.

The application of Newton's laws of motion to the data acquired from motion-tracking pictures enabled the velocity and acceleration of the right hand to be calculated at various times in the bow strokes. Through Nelson's study of efficiency of skilled movement, the benefits of minimum peak-acceleration and near-uniform velocity in non-linear motion can be explained. The performance 'costs' incurred with the high peak-velocity, high acceleration and high rate of change of acceleration that are involved in linear bow movements render it more energy intensive.

The graphs resulting from the data analysis show that, in non-linear bowing, there is less extreme acceleration and peak velocity of the hand than in linear bowing. In addition, in non-linear styles the hand moves with a relatively constant velocity, representing conservation of kinetic energy.

This dissertation has drawn on scientific and mathematical principles to show that violin technique employing non-linear motion is efficient. This efficiency translates into creating sound with less effort, and reduced tendency for injury, both achieved through economy of movement.

It is hoped that this work will stimulate an awareness of efficiency of movement in contemporary violin pedagogues. It is hoped that the types of movement that achieve efficiency – as well as good posture and balance – will be included in violin didactics from an early age. Sound technique based on natural human movement which results in efficient motion will be of lifetime benefit to those to whom it is taught.

# Appendix A

## Linear motion: Hand and bow

Linear H&B	Time 1/26 sec	Velocity (v)	Delta v	Acceleration
0.002	0.038642	0.05	0.051757155	1.339401569
0.0051	0.038642	0.131980746	0.080223591	2.076072432
0.00831	0.038642	0.22	0.083070234	2.149739518
0.01	0.038642	0.258785777	0.043734796	1.131794326
0.0125	0.038642	0.323482221	0.064696444	1.674251961
0.0131	0.038642	0.339009368	0.015527147	0.401820471
0.0138	0.038642	0.357124372	0.018115004	0.468790549
0.0138	0.038642	0.357124372	0	0
0.0125	0.038642	0.323482221	-0.033642151	-0.87061102
0.0111	0.038642	0.287252213	-0.036230009	-0.937581098
0.0089	0.038642	0.230319342	-0.056932871	-1.473341726
0.007	0.038642	0.181150044	-0.049169298	-1.27243149
0.0042	0.038642	0.11	-0.07	-1.875162197
0.0042	0.038642	0.108690026	0.00	0
0.007	0.038642	0.181150044	0.072460018	1.875162197
0.0089	0.038642	0.230319342	0.049169298	1.27243149
0.0111	0.038642	0.287252213	0.056932871	1.473341726
0.0125	0.038642	0.323482221	0.036230009	0.937581098
0.0138	0.038642	0.357124372	0.033642151	0.87061102
0.0138	0.038642	0.36	0	0
0.0131	0.038642	0.339009368	-0.018115004	-0.468790549
0.0125	0.038642	0.32	-0.015527147	-0.401820471
0.01	0.038642	0.258785777	-0.064696444	-1.674251961
0.00831	0.038642	0.215050981	-0.043734796	-1.131794326
0.0051	0.038642	0.131980746	-0.083070234	-2.149739518

Equations used in graphical analyses for Figures 39-41:

Velocity = distance/time

Acceleration = change in velocity/time

# Appendix B

## Non-linear motion: Hand

Hand distance	Time 1/26 sec	Velocity (v)	Delta v	Acceleration
0.0105	0.038642	0.27	0.271725066	7.031858237
0.01233	0.038642	0.319082863	0.047357797	1.225552436
0.01233	0.038642	0.32	0	0
0.0128	0.038642	0.331245795	0.012162932	0.314759369
0.0128	0.038642	0.331245795	0	0
0.0128	0.038642	0.331245795	0	0
0.0128	0.038642	0.331245795	0	0
0.0128	0.038642	0.331245795	0	0
0.0128	0.038642	0.331245795	0	0
0.0114	0.038642	0.295015786	-0.036230009	-0.937581098
0.0105	0.038642	0.271725066	-0.02329072	-0.602730706
0.00913	0.038642	0.236271415	-0.035453651	-0.917490075
0.0082	0.038642	0.21	-0.024067077	-0.62282173
0.0082	0.038642	0.212204337	0	0
0.0078	0.038642	0.20	-0.010351431	-0.267880314
0.00913	0.038642	0.236271415	0.034418508	0.890702043
0.01	0.038642	0.258785777	0.022514363	0.582639682
0.0114	0.038642	0.295015786	0.036230009	0.937581098
0.0123	0.038642	0.318306506	0.02329072	0.602730706
0.0128	0.038642	0.331245795	0.012939289	0.334850392
0.0146	0.038642	0.377827235	0.04658144	1.205461412
0.0151	0.038642	0.39	0.012939289	0.334850392
0.0155	0.038642	0.401117955	0.010351431	0.267880314
0.0146	0.038642	0.38	-0.02	-1.540311804
0.0123	0.038642	0.318306506	-0.06	-1.540311804

# Appendix C

## Non-linear motion: Bow

Bow distance	Time 1/26 sec	Velocity (v)	Delta v	Acceleration
0.00457	0.038642	0.12	0.1182651	3.060532585
0.00822	0.038642	0.212721909	0.094456809	2.444407863
0.0128	0.038642	0.33	0.118523886	3.067229593
0.0146	0.038642	0.377827235	0.04658144	1.205461412
0.0146	0.038642	0.377827235	0	0
0.0146	0.038642	0.377827235	0	0
0.0128	0.038642	0.331245795	-0.04658144	-1.205461412
0.0119	0.038642	0.307955075	-0.02329072	-0.602730706
0.01004	0.038642	0.25982092	-0.048134155	-1.245643459
0.00822	0.038642	0.212721909	-0.047099011	-1.218855428
0.00578	0.038642	0.149578179	-0.06314373	-1.634069914
0.00274	0.038642	0.070907303	-0.078670876	-2.035890385
0.00182	0.038642	0.05	-0.102479168	-2.652015106
0.00548	0.038642	0.141814606	0.094715594	2.451104871
0.0073	0.038642	0.19	0.047099011	1.218855428
0.00913	0.038642	0.236271415	0.047357797	1.225552436
0.011	0.038642	0.284664355	0.04839294	1.252340467
0.0128	0.038642	0.331245795	0.04658144	1.205461412
0.0128	0.038642	0.331245795	0	0
0.0128	0.038642	0.331245795	0	0
0.0128	0.038642	0.331245795	0	0
0.012	0.038642	0.31	-0.020702862	-0.535760628
0.01	0.038642	0.258785777	-0.051757155	-1.339401569
0.0073	0.038642	0.19	-0.06987216	-1.808192118
0.00457	0.038642	0.1182651	-0.070648517	-1.828283142

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## **INTERVIEWS**

Greene, Prof John: 13<sup>th</sup> January 2006

Hansford, Dr Pam: 13<sup>th</sup> September 2005

Juritz, Prof John: 27<sup>th</sup> November 2005

Prim, Sebastian: 3<sup>rd</sup> November–1<sup>st</sup> December 2005

Van Rooyen, Michele: 2<sup>nd</sup> December 2005

University of Cape Town

HENRY HOLLOWAY'S PROGRAMME: 13<sup>TH</sup> OCTOBER 2001 1<sup>ST</sup> DRAFT:

MATERIAL SELECTED:

***OVER INTRO 'SOFTLY AS I LEAVE YOU' DORIS DAY [ 3:06 ] TRACK 7***

HENRY: with "Softly , as I leave you " playing in the background , I don't have to tell you that my guest today is my old friend Hal Shaper ..

HENRY TO ADD HIS COMMENTS over the song.....

1 . its his birthday etc.....

and at the end of it..

" HAPPY BIRTHDAY HAL"...

HAL : Thank you Henry...

HENRY: NOW... DORIS DAY.. THAT WONDERFUL HOLLYWOOD FILM STAR AND SINGER.. SHE'S AN OLD FRIEND OF YOURS ISN'T SHE ? DIDN'T YOU WORK WITH HER EARLY IN YOUR CAREER ?

HAL: Soon after I arrived in London , I got a job with a small publishing company .and I met Doris at the reception her Record Company threw for her .She was visiting with her husband Marty Melcher...and her young son Terry ...Doris and I got along very well. No idea why...I visited her at her Hotel to show her a song if I would liase between her and her British Fan Club I said fine..and it was great ; she started to send me tapes to play to her Fan Club ; and my first real break came with her and Marty suggesting that we all form a publishing company together...and almost the first song. success we had together was " Que Sera Sera".. it won the Academy Award..and went Number 1 worldwide. So , in a way , I was part of owning the number One song throughout the world...it was fantastic..

Anyway... couple of years on I wrote " Softly ,as I leave you" and the song became a major hit in America...and after Matt Monro , Doris went straight into the studio and cut it...and it was a lovely version .. She was the first person to cover..the song...after Matt and that , led on eventually to Sinatra and Presley....

HENRY: AND ANOTHER FIVE HUNDRED RECORDINGS ?

HAL : It must be close to that by now. I must tell you that when I explained to that great songwriter Sammy Cahn , that Doris Day and I were friends , Sammy .who had actually discovered her.... and got her her first job in pictures.." Romance on the High Seas" ...Sammy said very sniffily.." What the hell Hal , I knew her before she became a virgin !"

HENRY: THAT'S A VERY FUNNY REMARK.. NOW THIS YEAR IN THE WORDS OF THE SINATRA CLASSIC HAS BEEN A " VERY GOOD YEAR " FOR YOU....SO LET'S TAKE IT BIT BY BIT..



Anyway..Pia started singing the songs at school and her teacher asked about them . So she took the CD to school... When her Drama Teacher heard it., she came to see me to ask if she could produce it for this coming December...and that's just wonderful .

HENRY: WHAT'S IT ABOUT ?

HAL: Mel had written a story about a Sultan who wanted to go on Safari...and his monkey Chango , saved all the animals from being killed...Mel was staying with me in London at the time..Cyil Ornel and I had just completed.." Treasure Island" and were about to start on " Great Expectations" . Mel read it to us..and said ." come on guys., write the story into a Musical , for kids " and that's exactly what we did... Cyril and I we set to work and wrote the entire thing...the ten songs ..during the one free week we had between the two Productions ..We called it " Chango on Safari " and it won the BBC Special Award for Childrens's Album of the Year ".

HENRY: WHICH OF THE SONGS WOULD YOU LIKE TO PLAY ?

Hal: Oh the one where the Sultan sits down in the Jungle , and fans himself with his fine old China Fan ..The Music is by Cyril Ornel , and the Voice ..of course ..is Mel Ferrer....

*" I LOVE MY FAN" [ 2: 23 ]*

**TRACK 4**

**HENRY: " I LOVE MY FAN" FROM THIS YEARS NEW SCHOOL MUSICAL..' CHANGO ON SAFARI"...**

NOW WE MUST TALK ABOUT YOUR NEW BOOK.." THE GREAT SONMGS AND SONGWRITERS OF THE 20<sup>TH</sup> CENTURY" ..I'VE SEEN IT , AND I CAN HONESTLY SAY ..

[ and then say whatever you like ]

I UNDERSTAND THAT AS A WEBSITE BOOK IT IS GETTING AROUND TEN THOUSAND VISITS TO THE SITE , PER DAY ! FROM ALL OVER THE WORLD..

UP TO NOW IT RUNS TO EIGHT HUNDRED PAGES..COVERING OVER FIVE HUNDRED WRITERS AND OVER TWO THOUSAND IMAGES ,PHOTOGRAPHS AND SIGNED PIECES OF MEMORABILIA.

Hal: That's just " so far" it's a work I can never hope really to finish..but I am renewing my friendships with writers from all over the world...and perhaps we can talk about some of them..

HENRY: THAT WOULD BE TERRIFIC..WHO.FOR STARTERS ..GIVE ME SOMEONE ENTIRELY UNUSUAL...AS A WRITER...

Hal: Okay..Here's a piece by Bet Midler...I first met Bet in New York just after she had become an underground hit at the New York Baths,,,Her piano player was Barry Manilow...Anyway the song will surprise you...It's a craftily written piece telling

.the story of the inventor of the over the well..call it the maiden-form bra..if you like... whose name was .Otto Titzling....and don't forget to ask me afterwards if the story is true !

**' OTTO TITZLING" BET MIDLER ..[ 3:09 ] .                      TRACK 1**

HENRY: OH THAT IS HILARIOUS..YOU HAVE TO TELL ME..IS THAT STORY TRUE..WAS THERE REALLY AN OTTO TITZLING..AND A PHILLIPE DE BRASSIERE..? OR DO I HAVE TO READ YOUR BOOK TO FIND OUT ...

Hal : The story..and isn't it wonderful.... is entirely..... [ long pause ] nonsense..

Both characters and the entire story were invented by a madly funny Englishman Wallace Reyburn who died this year on July the 14<sup>th</sup>..aged 87..He was a war correspondent at the Dieppe Raid in 1942..He wrote that marvellous book about Thomas Crapper ..the alleged inventor of the loo..entitled " Flushed with pride" with such dead pan..humour.....in fact bedpan humour....that no one was ever sure if it was true..and partially ..it was...But in 1971 he wrote a killer legpull with " Bust-up" .. the story of Otto Titzling's invention of the titzling..until that despicable French patent thief Phillipe de Brassier ran off with it...It was pure fantasy..and even " Trivial Pursuit" believed it all..and named de Brassiere as the official inventor of the bra .

HENRY: AND IS THAT STORY IN YOUR BOOK ?

Hal: Oh yes..and many more of course.. You'll remember , as we all do, " Somewhere over the rainbow" .. written by Harold Arlen and Yip Harburg Now..when it came to writing songs for the Marx Brothers...it was a very different chore...and when this one came out no-one believed it was from the "Oscar" winners of the year before...Here's Chico introducing his best friend "Loophole the Lawyer" played typically by Groucho Marx.in the Marx Brothers film " A Day at the Circus"..This is lyric writing and rhyming at its very best

**GROUCHO ; " LYDIA THE TATTOOED LADY" [ 3:19 ]      TRACK 21**

HENRY : " LYDIA THE TATTOOED LADY" GROUCHO MARX ....

Hal: The song was originally banned as being too rude...They got around it by having the Admiral marry Lydia !

HENRY : NOW FROM THE AMUSING TO THE SUBLIME. YOUR MASTERPIECE OPERA.." LA BOHEME: NOIR" ..? IT'S PRESENTLY BEEN PUT UP FOR A GRAMMY AWARD IN AMERICA...WHERE THE RECORDING HAS BEEN HIGHLY PUBLICISED AND IS IN GREAT DEMAND...AGAIN..I HAVE TO SAY , IT RECEIVED THE BEST REVIEWS I HAVE EVER SEEN FOR ANY OPERA....

Hal We have to wait for the Grammy Nominations...but it's certainly been entered I'd love to choose one of my favourite tracks from this great South African recording...which I'd like to dedicate to the memory of Donald Graham...Donald

recorded live all the versions of the show and lovingly stitched the best of everything together after two years of tenacious work . Donald was a true friend of South African Opera...and but for Donald Graham many of our most historic Opera's might never have been recorded . If I thank Louis Heyneman , Oude Meester ...and Mr Brian Williams , it is because .without their support..we might well have lost this Opera too

***“ ALL THROUGH MY LIFE “ [ MUSETTA’S WALTZ ]***  
***[ time it to : 2:12 and then fade ]***

**TRACK 13**

Hal: That was sung by the incomparable Thokozane Mkize..and add in Marcus Desando ..Sibongile Ngomo and Fikile Mvinjelwa..each of them quite brilliant... Thokozane Mkhize...Isn't she superb ... I love that track...

HENRY: WE MUST ALL HOPE THAT THE OPERA RETURNS CENTRESTAGE TO SOUTH AFRICA IN THE VERY NEAR FUTURE...NOW , ANOTHER OF YOUR LONGSTANDING FRIENDSHIPS IS WITH ROLF HARRIS ... YOU TWO HAVE BEEN FRIENDS FOR...HOW LONG ?

Hal: It must be a round thirty five years ..I think...

HENRY : I'M SITTING HERE AND LOOKING AT THE FIRST COPY , OFF THE PRESS OF ROLF'S NEW WORLDWIDE XMAS BOOK AND RECORD... AND OF COURSE , THERE YOUR NAME IS STARING UP FROM THE CD.. I KNOW IT'S THE FIRST COPY BECAUSE HE HAS SIGNED THE BOOK TO YOU SAYING.." HERE'S THE FIRST COPY !" THE NEW XMAS SINGLE IS ENTITLED " CHRISTMAS IN THE SUN" AND THIS IS A NEW SONG . WHICH YOU HAVE WRITTEN WITH ROLF ? IS THAT RIGHT ?

Hal: Rolf was here two summers ago , to appear at Spier..and we got into a conversation about the sizzling African and Australian Christmasses we both loved , compared to the freeze-your-butt-off Christmasses we endured in Europe,,and the song started from that....This will be the songs very first play..

***‘ CHRISTMAS IN THE SUN” [ 3:02 to fade ]***

**TRACK 1**

HENRY : “ CHRISTMAS IN THE SUN” Hal Shaper and Rolf Harris... A FIRST SPIN FOR ROLF HARRIS LATEST SINGLE....AND THE BOOK CALLED “ SIX WHITE BOOMERS” CONTAINING THE CD RECORDING .

NOW , EVERYONE IN EUROPE KNOWS THE BAND ‘ PULP ‘ ...IT IS A MAJOR ‘ TODAY ‘ TOUGH GUY BAND WHOSE RECORDINGS SELL MILLIONS AND WHOSE SINGLES ARE GUARANTEED HITS ..[ ALTHO THEIR SOUND IS OFTEN INCOMPREHENSIBLE TO AN ADULT EAR LIKE MINE.] .YET YOU SEEM TO HAVE ACHIEVED THE NEAR IMPOSSIBLE BY WRITING THEIR NEW SINGLE RELEASED [ IN FACT ] THIS WEEK IN THE UK AND AMERICA.. HOW DID THIS ONE COME ABOUT ?

Hal : Some years ago I wrote a song for Sinatra called “ Tell her you love her”. The song was featured , on a major film soundtrack....Jarvis Cocker , the popwriting genius behind Pulp heard it only recently .....he wrote to me asking for permission to add his own thoughts..to the song ... and of course I said yes...and here it is...

**‘ TREES ‘ by PULP [ 4:13 ]**

**TRACK 2**

HENRY : “ TREES ” by the London-based band PULP...

HAL : Henry , As I know we’re running out of time...you mentioned Sinatra and you mentioned..that for me , this has been “ a very good year . and that’s what I’d like to sign off with,,the Sinatra song “ It was a very good year” . This painfully beautiful song was written at a single sitting..words and music...by Ervin Drake....a genius songwriter... an alltime classic by a great , great man ...It is the “ September Song” .of our Generation...and no-one has looked back at a life through a song with more youthful joy and mature reflection ..with more , wisdom perception and acceptance , than Mr Drake ; whose 82<sup>nd</sup> birthday has just passed.. So may I say ..on all our behalf’s ...Happy Birthday Ervin ....This message comes with love and respect and admiration from us all...

**HENRY : AND SO SAY ALL OF US...**

**“ IT WAS A VERY GOOD YEAR” [ Sinatra ] [ 4:25 ]... ..HENRY’S CD**

HENRY : HAL... THERE MAY BE TIME FOR JUST ONE MORE SONG..SO WHAT’LL IT BE..ONE OF YOURS..OR ONE FROM THE BOOK.

Hal: I think one from the book...Bing Crosby and his wife Katherine lived in my house in London for two weeks while recording a a TV Show.. Bing had already cut a couple of my songs so we weren’t strangers ... I remember Bing with great affection...He and his fellow jester Louis Satchel-Mouth Armstrong had more command of spontaneous wit and charm than almost anyone in the entire industry...Nick and Charles Kenny a couple of very smart journalists-interviewers and New York-smart scribblers..picked up a remark of Bing’s..and as smart as paint , they wrote the following laid back..ain’t-life-a-breeze...song ..I love this one.. s.....

**GONE FISHIN”” Crosby and Louis Armstrong [ 2:20 ] TRACK 10**

Hal: Isn’t that fun..Now Henry ..ask me...how do you get THAT spontaneous...? Hmm

HENRY : OKAY ..HOW DO YOU GET THAT SPONTANEOUS ? hmmm ?

Hal: Henry..the same way you get to Carnegie Hall...you practise....

HENRY ; CLOSING COMMENTS: AND FINALLY.....  
“ HAPPY BIRTHDAY HAL ”;

**PLAYOUT “ SOFTLY AS I LEAVE YOU” DORIS DAY TO FADE....[3 : 06 ]**

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RESERVE RECORD IF WE ARE SHORT , IS  
WEEPING” by THE SOWETO STRING QUARTET..AND WE CAN BUSK THE  
INTRO..

It is Dan Heymann;s ...

I consider it the most important song in our troubled South Africn history..and it incorporates “ Nkosi I’ Sikelel I”It s a song written at the height of apartheid by a white Jewish South African youngster...with a depth of poetic hearbreak which in my experience has never been matched..It remains brave and beautiful and I feel privileged to playit today..If a Streisand or a Ray Charles or Springsteen cuts it..it will finally become one of the world’s greatest songs standards.... **TRACK 4**

University of Cape Town