AN INVESTIGATION INTO THE FORCE-EMG RELATIONSHIP FOR STATIC AND DYNAMIC EXERTIONS

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ABSTRACT

The force-EMG relationship has multiple applications in varying fields of study and practice. One such application is the development of safety guidelines and regulations. Current guidelines are based on static muscle actions even though the majority of tasks encountered in industry are dynamic in nature. This may have negative implications for the health, safety, and productivity of workers as regulations based on static muscle actions may place higher force demands on manual labourers compared to what would be expected if regulations were based on dynamic muscle actions. Regulations based on dynamic muscle actions may be more effective in worker safety as the nature of the regulation matches that of the demand. Few studies have investigated the force-EMG relationship during dynamic muscle actions and the few that do exist have reported contradictory / mixed results. Therefore, the purpose of this study was to: 1) gain an understanding of EMG responses at different load levels, and 2) show how the relationship differs between static and dynamic muscle actions.

A two-factorial repeated-measures experiment was developed for this study. Eighteen experimental conditions, utilizing six load levels (0%, 20%, 40%, 60%, 80%, and 100% of maximum voluntary force) for each of the three muscle actions (isometric, concentric and eccentric). Surface EMG responses were obtained under these conditions by repeatedly dorsiflexing and plantarflexing the foot, thus activating the soleus muscle. A maximum voluntary exertion on an isokinetic dynamometer determined the maximum force level, based on which the sub-maximal loads were calculated and added to a pulley system. 31 student participants were recruited for this experiment which was conducted over two sessions – one information and habituation session, and one experimental session.

The EMG data recorded were processed and checked for normality and outliers. The data was then analysed via a General Linear Model analysis to determine the effect of exertion type and of load level on the muscle activity. Significant differences were identified at $p<0.05$ and followed by a Tukey post-hoc test. Correlation analyses were also conducted to determine the relationship between the force and EMG at all three exertion types.

All dependent measures showed that as the load level increased so did the sEMG amplitude for all muscle actions. Muscle actions differed significantly between majority of six force levels. Correlations between the load levels and sEMG amplitude for each muscle action indicated a significant correlation with a moderate strength. The conclusion draws from this study that there is a positive correlation between force and sEMG amplitude, at all load levels, with a moderate strength. However, the muscle actions differed significantly from each other.

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TABLE OF CONTENTS

CHAPTER 1: INTRODUCTION 1

1.1 Background to the Study 1

1.2 Statement of the Problem and Purpose of the Study 3

CHAPTER 2: REVIEW OF LITERATURE 5

2.1 Muscular Force Production 5

2.2 Motor Control 7

2.2.1 Rate coding 9

2.2.2 Motor unit recruitment 10

2.3 Muscle Actions/ Exertions 12

2.3.1 Isometric muscle action 12

2.3.2 Isotonic muscle action 13

2.4 Electromyography (EMG) 13

2.5 Force-EMG Relationship 16

CHAPTER 3: METHODS 20

3.1 Purpose and Value 20

3.2 Experimental Design 20

3.2.1 Statistical Hypotheses 21

3.3 Selection of Independent Variables 22

3.3.1 Force levels 22

3.3.2 Exertion type 23
3.4 Selection of Dependent Variables 24
3.4.1 Electromyography (EMG) activity 24
3.4.2 Peak Torque 24
3.4.3 Demographic and Anthropometric Data 25
3.5 Variables of No Interest 25
3.5.1 Muscle 25
3.5.2 Range of motion (ROM) 26
3.5.3 Movement Velocity 26
3.5.4 Knee flexion angle 27
3.6 Equipment 27
3.6.1 Isokinetic Dynamometer 27
3.6.2 Pulley system 28
3.6.3 Surface Electromyography (sEMG) 30
3.6.4 Computer for Instructions 31
3.6.5 Electrogoniometer 31
3.7 Participants 32
3.8 Ethical Considerations 33
3.9. Experimental Procedures 33
3.9.1 Session 1: Information and Habituation session 36

3.9.2 Session 2: Experimental Session 37

3.10 Data Analysis 39

3.10.1. Data reduction and processing 39

3.10.2 Basic descriptive statistics 40

3.10.3 Inferential statistics 40

CHAPTER 4: RESULTS 41

4.1 Outliers and Normality Testing 41

4.2 Participant Characteristics 43

4.2.1 Basic Anthropometric and Demographic Data 44

4.2.2 Strength Expression 44

4.3 Inferential Statistics 46

4.3.1 Interaction Effect of Muscle Action and Load 48

CHAPTER 5: DISCUSSION 50

5.1 Strength expression 50

5.1.1 Effect of sex on torque 52

5.1.2 Effect of time-of-day on torque 53

5.2 Surface Electromyography (sEMG) 54

5.2.1 Effect of muscle action on sEMG 55

5.2.2 Effect of force levels on sEMG 58

5.2.3 Interaction effect of muscle action & force levels on sEMG 59

6 CONCLUSIONS & RECOMMENDATIONS 62

6.1 Purpose of the Study 62

6.2 Summary of Procedures 62

6.3 Summary of Results 63

6.4 Responses to Hypotheses 64

6.5 Delimitations 64

6.6 Limitations and Recommendations for Future Studies 65

6.7 Significance of Findings 67

7 REFERENCES 69

8 APPENDICES 90

8.1 Appendix A – Permutation Matrix & Raw sEMG Data 90

8.3 Appendix B – Ethical Considerations 95

8.4 Appendix C – Information and Consent Letters 97

8.5 Appendix D – Statistical Tables 102

D.1. Outliers and Normality Testing 102

D.2. Descriptive Statistics 153

D.3 Inferential Statistics 157

LIST OF FIGURES

Figure 1: The effects of motor neuron recruitment (a) and rate coding (b) on the force-EMG relationship. Taken from De Luca (1997, p.21). 14

Figure 2: Linear (a) and non-linear (b) force-EMG relationships. Figure taken from (Chasey, 2015). 17

Figure 3: Illustration of the range of motion of the ankle joint used in this study. (Image adapted from (Germanotta et al., 2017). 26

Figure 4: Set-up of the isokinetic dynamometer (a) and the set-up of foot-pedal-pulley system (b). 29

Figure 5: Placement of the sEMG electrodes. 31

Figure 6: Protocol timeline and permutated testing order of participant 1. 35

Figure 7: Graph showing the interaction effect of force levels and exertion types on maximum EMG responses. 48

Figure 10: A schematic force-EMG relationship during ramping (increasing force output) muscle exertions. The figure shows the EMG activity during various conditions affecting the force production. Taken from Konrad (2006, p. 44). 56

Figure 11: The force production of eccentric and concentric muscle actions vs the energy cost. 57

Figure 12: Raw sEMG data of P02 at 0% force level isometric exertion. 92

Figure 13: Raw sEMG data of P02 at 20% force level isometric exertion. 92

Figure 14: Raw sEMG data of P02 at 40% force level isometric exertion. 93

Figure 15: Raw sEMG data of P02 at 60% force level isometric exertion. 93

Figure 16: Raw sEMG data of P02 at 80% force level isometric exertion. 94

Figure 17: Raw sEMG data of P02 at 100% force level isometric exertion. 94

Figure 18: Shapiro-Wilks test and Box & whisker plots for age. 102

Figure 19: Shapiro-Wilks test and Box & whisker plots for sex. 103

Figure 20: Shapiro-Wilks test and Box & whisker plots for mass. 104

Figure 21: Shapiro-Wilks test and Box & whisker plots for stature. 105

Figure 22: Shapiro-Wilks test and Box & whisker plots for peak torque concentric exertion. 106

Figure 23: Shapiro-Wilks test and Box & whisker plots for peak torque eccentric exertion. 107

Figure 24: Shapiro-Wilks test and Box & whisker plots for peak torque isometric exertion. 108

Figure 25: Shapiro-Wilks testand Box & whisker plots for peak torque concentric exertion. 109

Figure 26: Shapiro-Wilks test and Box & whisker plots for peak torque eccentric exertion. 110

Figure 27: Shapiro-Wilks tests and Box & whisker plots for peak torque isometric exertion. 111

Figure 28: Shapiro-Wilks test and Box & whisker plots for peak torque concentric exertion. 112

Figure 29: Shapiro-Wilks test and Box & whisker plots for peak torque eccentric exertion. 113

Figure 30: Shapiro-Wilks test and Box & whisker plots for peak torque isometric. 114

Figure 31: Shapiro-Wilks test and Box & whisker plots for Maximal EMG during concentric 0% of MVE 115

Figure 32: Shapiro-Wilks test and Box & whisker plots for Maximal EMG during concentric 20% of MVE. 116

Figure 33: Shapiro-Wilks test and Box & whisker plots for Maximal EMG during concentric 40% of MVE. 117

Figure 34: Shapiro-Wilks test and Box & whisker plots for Maximal EMG during concentric 60% of MVE. 118

Figure 35: Shapiro-Wilks test and Box & whisker plots for Maximal EMG during concentric 80% of MVE. 119

Figure 36: Shapiro-Wilks test and Box & whisker plots for Maximal EMG during concentric 100% of MVE. 120

Figure 37: Shapiro-Wilks test and Box & whisker plots for Maximal EMG during eccentric 0% of MVE. 121

Figure 38: Shapiro-Wilks test and Box & whisker plots for Maximal EMG during eccentric 20% of MVE. 122

Figure 39: Shapiro-Wilks test and Box & whisker plots for Maximal EMG during eccentric 40% of MVE. 123

Figure 40: Shapiro-Wilks test and Box & whisker plots for Maximal EMG during eccentric 60% of MVE. 124

Figure 41: Shapiro-Wilks test and Box & whisker plots for Maximal EMG during eccentric 80% of MVE. 125

Figure 42: Shapiro-Wilks test and Box & whisker plots for Maximal EMG during concentric 100% of MVE. 126

Figure 43: Shapiro-Wilks test and Box & whisker plots for Maximal EMG during isometric 0% of MVE. 127

Figure 44: Shapiro-Wilks test and Box & whisker plots for Maximal EMG during isometric 20% of MVE. 128

Figure 45: Shapiro-Wilks test and Box & whisker plots for Maximal EMG during isometric 40% of MVE. 129

Figure 46: Shapiro-Wilks test and Box & whisker plots for Maximal EMG during isometric 60% of MVE. 130

Figure 47: Shapiro-Wilks test and Box & whisker plots for Maximal EMG during isometric 80% of MVE. 131

Figure 48: Shapiro-Wilks test and Box & whisker plots for Maximal EMG during isometric 100% of MVE. 132

Figure 49: Shapiro-Wilks test and Box & whisker plots for average EMG amplitude during concentric 0% of MVE. 133

Figure 50: Shapiro-Wilks test and Box & whisker plots for average EMG amplitude during concentric 20% of MVE. 134

Figure 51: Shapiro-Wilks test and Box & whisker plots for average EMG amplitude during concentric 40% of MVE. 135

Figure 52: Shapiro-Wilks test and Box & whisker plots for average EMG amplitude during concentric 60% of MVE. 136

Figure 53: Shapiro-Wilks test and Box & whisker plots for average EMG amplitude during concentric 80% of MVE. 137

Figure 54: Shapiro-Wilks test and Box & whisker plots for average EMG amplitude during concentric 100% of MVE. 138

Figure 55: Shapiro-Wilks test and Box & whisker plots for average EMG amplitude during eccentric 0% of MVE. 139

Figure 56: Shapiro-Wilks test and Box & whisker plots for average EMG amplitude during eccentric 20% of MVE. 140

Figure 57: Shapiro-Wilks test and Box & whisker plots for average EMG amplitude during eccentric 40% of MVE. 141

Figure 58: Shapiro-Wilks test and Box & whisker plots for average EMG amplitude during eccentric 60% of MVE. 142

Figure 59: Shapiro-Wilks test and Box & whisker plots for average EMG amplitude during eccentric 80% of MVE. 143

Figure 60: Shapiro-Wilks test and Box & whisker plots for average EMG amplitude during concentric 100% of MVE. 144

Figure 61: Shapiro-Wilks test and Box & whisker plots for average EMG amplitude during isometric 0% of MVE. 145

Figure 62: Shapiro-Wilks test and Box & whisker plots for average EMG amplitude during isometric 20% of MVE. 146

Figure 63: Shapiro-Wilks test and Box & whisker plots for average EMG amplitude during isometric 40% of MVE. 147

Figure 64: Shapiro-Wilks test and Box & whisker plots for average EMG amplitude during isometric 60% of MVE. 148

Figure 65: Shapiro-Wilks test and Box & whisker plots for average EMG amplitude during isometric 80% of MVE. 149

Figure 66: Shapiro-Wilks test and Box & whisker plots for average EMG amplitude during isometric 100% of MVE. 150

Figure 67: Shapiro-Wilks test and Box & whisker plots for self-selected testing sessions.. 151

Figure 68: Shapiro-Wilks test and Box & whisker plots for grouped testing sessions. 152

LIST OF TABLES

Table i: The experimental design matrix used in the study. 20

Table ii: Summary results of the Shapiro-Wilks test for normality for the torque data. 41

Table iii: Summary of the Shapiro-Wilks tests for normality for maximum sEMG data. 42

Table iv: Summary of the Shapiro-Wilks tests for normality for average sEMG data. 43

Table v: Participants' basic anthropometric and demographic data (means, ± standard deviations (SD), with coefficients of variation (CV) in brackets. 44

Table vi: Means, standard deviations, and coefficients of variation (in brackets) for peak torque, average torque and peak torque to body-weight for each muscle action. 45

Table vii: Time of day effects on torque variations. 46

Table viii: Effect of repetition on EMG(RMS) responses (p-values). 47

Table ix: The effects of exertion type and force level on maximum and average EMG amplitude, as well as the interaction effect between exertion type and force levels. 47

Table xi: Permutation of exertion types. 90

Table xii: Permutated order of force levels. 90

Table xiii: Combination of table xi and table xii showing the order of participants. 91

Table xiv: Descriptive stats for age, sex and stature of all participants. 153

Table xv: Descriptive stats for age, sex and stature of females. 153

Table xvi: Descriptive stats for age, sex and stature of males. 153

Table xvii: Descriptive stats for torque of all participants. 154

Table xviii: Descriptive stats for torque of female participants.............................. 154

Table xix: Descriptive stats for torque of male participants. 154

Table xx: Descriptive stats for EMG responses for all experimental conditions. 155

Table xxi: Descriptive stats for EMG responses of female participants.............. 155

Table xxii: Descriptive stats for EMG responses of male participants................. 156

Table xxiii: Post-Hoc Tukey test for differences between concentric, eccentric, and isometric muscle actions. 157

Table xxiv: Post-Hoc Tukey test for differences between all load levels. 157

Table xxv: Post-Hoc Tukey test for differences between muscle actions at each load level.. 158

Table xxvi:Maximum sEMG in (mV) recorded during muscle actions at various loads. 159

Table xxvii: Post-Hoc Tukey test for differences between time of day and peak torque. 160

Table xxviii: Post-Hoc Tukey test for differences between time of day and average torque. 160

Table xxix: Post-Hoc Tukey test for differences between time of day and average torque. 161

Table xxx: Post-Hoc Tukey test for differences between time of day and load levels. 162

Table xxxi: Post-Hoc Tukey test for differences between time of day and muscle actions. 163

CHAPTER 1: INTRODUCTION

1.1 Background to the Study

Human movement is complex as it can take place in multiple planes and around multiple axes at the same time (Hall, 2012). For these movements to occur, a force or torque must be generated within the muscles, also known as a muscle action or exertion, which results in a range of motion (ROM) about a joint. The production of this muscle force is regulated by means of two main neuromuscular mechanisms, namely motor neuron recruitment and rate coding (Vinet & Zhedanov, 2011).

When a muscle action takes place, motor neurons are activated, stimulating the muscle fibres connected to that motor neuron, resulting in the production of force, known as 'motor unit recruitment' (Bubbico & Kravitz, 2010; Herzog et al., 2008; Pasquet et al., 2000; Vinet & Zhedanov, 2011) . Once the motor neurons have been activated, the frequency at which each individual motor neuron fires is adapted to meet the force demands of the task (Herzog et al., 2008; Pasquet et al., 2000) . The control of these firing rates is referred to as 'rate coding' (Enoka & Duchateau, 2017). Generally, as muscular effort increases, so does the rate coding. As rate coding increases in one motor unit, additional motor neurons are recruited and their rate coding in turn increases until the desired force is achieved (Devanandan et al., 1965; Heckman & Enoka, 2004; Henneman et al., 1964; Linnamo, 2002; Mottram, 2004; Vinet & Zhedanov, 2011). Rate coding and recruitment of motor neurons thus occur in parallel (De Luca et al., 1996; De Luca & Erim, 2002; Lawrence & De Luca, 1983). Furthermore, as additional motor neurons are recruited, the change in force increments may be drastic; hence the rate coding is adjusted to allow for a smoother and more controlled transition. This adjustment of the rate coding fills the 'gaps' between these increments, thus making the transitions in force less noticeable.

Electromyography (EMG) is a measurement technique used to monitor electrical impulses in the muscle during a muscle action (Ball & Scurr, 2013). These impulses appear as vertical wave-like signals (or spikes) when observed on the electromyogram

(De Luca, 1997; Guo et al., 2012; Heckman & Enoka, 2004; Kamen & Gabriel, 2010; Silverthorn, 2013). Surface EMG (sEMG) is the most commonly used method for EMG studies as it is less invasive than other EMG techniques. The signal amplitude of sEMG is dependent on both the number of activated motor units (motor neuron recruitment) and the firing rates (rate coding) of the activated motor units (Farina et al., 2010; Vinet & Zhedanov, 2011).

Since force production and EMG activity both increase as a result of the same physiological mechanisms (motor unit recruitment and rate coding), one could argue that muscle force can be predicted from sEMG analysis, or vice versa (Vinet & Zhedanov, 2011). The possibility of predicting EMG signal from a force would be useful as it allows for the assessment of a single muscle's contribution towards the net force produced by a larger muscle group (Kuriki et al., 2012; Miller et al., 2017; Vinet & Zhedanov, 2011). Understanding the link between force and EMG may be particularly useful in the industrial sector when creating manual labour guidelines and safety regulations, as it provides crucial information on the upper limits of human performance, force-producing capabilities and fatigue. Such knowledge could be used to create a safer and more productive working environment (Balogh et al., 2009; Village et al., 2005). However, the accuracy and success of such guidelines is dependent on the predictability or shape of the force-EMG relationship; a relationship that currently polarises the literature into two camps (Ashnagar, 2013; Vinet & Zhedanov, 2011). The two main camps include those who argue for a linear or near-linear relationship (Carrascal et al., 2011; Lippold, 1952; Madeleine et al., 2001; Uliam et al., 2012), versus those who consider the relationship to be non-linear (Konrad, 2006; Vredenbregt & Rau, 1973; Zuniga & Simons, 1969). Both groups become more polarised when focusing on the force-EMG relationship during dynamic exertions, as these exertions present unique EMG recording challenges compared to static EMG recordings (Christensen et al., 1995; De Luca, 1997; Konrad, 2006). The main concern of research during dynamic muscle actions is the placement of the electrodes with respect to the active muscle fibres being recorded (De Luca, 1985, 1997). For example, EMG amplitude depends on the distance between the muscle fibers and the electrode, as well as the properties of the surrounding tissues. Furthermore, the changes in length of the muscle belly during an exertion and the force-length relationship of the fibres could potentially change recruitment patterns of the active fibres, consequently altering EMG amplitudes (Konrad, 2006). Madeleine et al., (2001) found that a non-linear relationship depended mainly on the type of muscle action on the force level measured in conjunction with angular velocity. For this reason, De Luca (1997) stated, “If a quantitative relationship between the EMG signal and force is required, then the contraction must be isometric”. However, later in the paper he added that it is generally accepted that when EMG data is sufficiently smoothed, the relationship between force and EMG is monotonic (i.e., it moves in the same relative direction but not necessarily at a constant rate). Various authors (Ball & Scurr, 2013; Hunter et al., 2002; Rouffet & Hautier, 2008) picked up on this and added that if the EMG data is relativised to a dynamic maximal voluntary exertion (MVE) then there is a greater chance of linearity.

1.2 Statement of the Problem and Purpose of the Study

It is evident from the literature that the relationship between force production and EMG activity is not yet well understood due to several factors influencing the dynamic component resulting in testing variability. Additionally, humans very rarely perform prolonged static (isometric) exertions but are designed to perform large ranges of motions along all planes of movement. Yet, most studies have used isometric normalisation procedures in dynamic activities. If the force-EMG relationship under dynamic exertions is assumed to be the same as under static conditions, any guidelines and predictions based on the relationship found in static exertions may be flawed as they could overestimate human capability (during the concentric muscle action) or underestimate (during the eccentric muscle actions) over an eight-hour work shift. This has the potential to compromise safety and productivity within the workplace if a healthy balance is not found (Dimitrova et al., 2009; Rantalainen et al., 2012; Village et al., 2005).

The aim of this study was therefore to: 1) gain a better understanding of the relationship between force and EMG at different force levels, and 2) show how this force-EMG relationship differs between static and dynamic (concentric and eccentric) muscle actions.

CHAPTER 2: REVIEW OF LITERATURE

The review of literature has three foci, namely relevant theory on muscle physiology (sections 2.1-2.3), electromyography (EMG) (section 2.4), and the force-EMG relationship (section 2.5). The sections on muscle physiology will explain how force is produced within a muscle; the different types of muscle actions and how they differ from one another; the mechanisms that control the force output and how the task demands influence the force output. The section on EMG will explain briefly what EMG is, the types of EMG, their application and some of the challenges surrounding the applications and processing of EMG. Finally, understanding how a muscle action occurs and how the force generation is controlled and measured using EMG will provide the background information to understanding the force-EMG relationship and some of the complexities of the relationship.

2.1 Muscular Force Production

Of the three types of muscle tissue found in the human body, skeletal muscles are responsible for skeletal movements as they attach muscles to bones, thereby creating lever systems for movement. Skeletal muscles differ from other muscle types as they are controlled by the peripheral portion of the central nervous system (CNS), thus allowing these muscle actions to be consciously and voluntarily controlled (Betts et al., 2013).

Movement is created by the force produced in all skeletal muscles and occurs due to what is known as the "sliding filament model". Herzog et al., (2008); Silverthorn, (2013); and Tortora & Derrickson, (2011) summarise the sliding filament process as follows: a muscle action starts with an action potential originating from the CNS. This action potential is directed to somatic motor neurons, which in turn refer the action potential to the relevant neuromuscular junction(s). At the neuromuscular junction, the electrical impulses are converted to a chemical reaction within the muscle, ultimately resulting in force production and thus movement. The model stems from two groundbreaking papers in 1954 by Huxley & Hanson and by Huxley & Niedergerke, who, using high-resolution microscopy, observed the changes in sarcomeres and the position of the actin and myosin filaments during various stages of muscle exertions (Heckman & Enoka, 2004). From these observations, the sliding filament model was proposed, which states that it is the sliding action of actin past myosin that generates a muscle exertion. Any changes of the actin filament length would result in a change in the sarcomere length, the muscle fibres' length, and thus the muscle as a whole (Heckman & Enoka, 2004).

Muscle fibres change length when the motor unit they are a part of is activated by the CNS via the motor neuron axon terminals (Kandel et al., 2013). A single somatic motor neuron extends via an axon from the CNS to a group of muscle fibres and is known as a motor unit (Buchthal & Schmalbruch, 1980; Kandel et al., 2013). Motor units may differ in size and the number of fibres innervated by a single somatic motor neuron (Buchthal & Schmalbruch, 1980). At the neuromuscular junction, the action potential triggers the release of acetylcholine (ACh) into the synaptic cleft at the synapses (Tortora & Derrickson, 2011). This release of the neurotransmitters allows chemical communication between the motor neuron and muscle fibre. As the released ACh binds to the receptors of the motor endplate, which forms part of the sarcolemma, ion channels open, allowing sodium (Na^+) to flow across the membrane (Heckman & Enoka, 2004; Knierim, 1997; Tortora & Derrickson, 2011). The influx of Na^+ positively charges the muscle, triggering the next action potential. This new action potential within the muscle moves along the sarcolemma and into the transverse tubule (T-tubule), resulting in the release of calcium ions (Ca^{2+}) from the sarcoplasmic reticulum (Heckman & Enoka, 2004; Knierim, 1997; Tortora & Derrickson, 2011). Calcium binds to troponin, which then moves tropomyosin away from the myosin-binding sites on actin, allowing myosin to bind to actin (cross-bridge formation) in the presence of sufficient adenosine triphosphate (ATP). This is also called 'excitation-contraction coupling' (Heckman & Enoka, 2004; Knierim, 1997; Tortora & Derrickson, 2011). Once a cross-bridge has been formed, the attached myosin filaments pull on the actin filaments during what is known as the 'power stroke' (Tortora & Derrickson, 2011). After the myosin head has used its energy by converting ATP into Adenosine diphosphate (ADP) and a free phosphate (P), it unbinds from the actin and moves back to a stretched position until another ATP molecule is present, and a new cross-bridge can be formed (Herzog et al., 2008). Force is generated because of the filaments sliding past each other, resulting in the shortening of a muscle on a macro level (Nigg & Herzog, 1999). This occurs at the beginning of a muscle action, and, provided there is sufficient ATP and Ca^{2+} present, the cross-bridge cycling will continue, thus resulting in the continuous twitching of the muscle (Buchthal & Schmalbruch, 1980; Nigg & Herzog, 1999; Tortora & Derrickson, 2011).

The number of motor units and the frequencies at which they are twitching (electrophysiological discharges) can be measured by means of electromyography. This in turn provides an indication of muscle activity as represented by a percentage of that muscle’s maximum capability (Ashnagar, 2013; Day, 2002; De Luca, 1997; Kuriki et al., 2012; Mottram, 2004). Motor neurons are the main efferent neurons relaying control commands from the CNS. When motor units are stimulated concurrently, the result is a greater motor unit action potential (Enoka & Duchateau, 2017). This increase in the number of active motor units leads to increased internal muscle tension, thus resulting in external force production (Enoka & Duchateau, 2017; Kuriki et al., 2012). Relaxation occurs when the motor neurons stop stimulating the muscle fibres. When this happens, Ca^{2+} is pumped back into the sarcoplasmic reticulum, away from the actin and myosin, thus the tropomyosin shifts back into place, blocking the myosin-binding sites on actin (Tortora & Derrickson, 2011). As the actin and myosin can no longer bind, they return to their natural state, which is ultimately a relaxed muscle (Bigland & Lippold, 1954; Tortora & Derrickson, 2011).

2.2 Motor Control

A muscle action occurs in response to information gathered by sensory receptors from the environment or task. This information is essential as it ensures the motor output is adequate to meet the task demand in a manner that is energy efficient, controlled and coordinated (Knierim, 1997). This relationship between sensory input and motor output may be simple and direct, as in the case of a reflex. However, during conscious actions, there is the added component of cognitive processing that occurs and allows one to choose/adapt the action appropriately for that situation.

In both reflex and conscious actions, the final output results in a set of commands to specific muscles in the body that result in a force-generating muscle action (Knierim, 1997). Larger muscles typically have larger motor neurons and motor units that are responsible for larger, less delicate movements that require greater amounts of force (gross motor control) (Buchthal & Schmalbruch, 1980; Knierim, 1997). Smaller muscles, such as those found in the eyes and fingers, have fewer muscle fibres attached to smaller motor neurons, thus forming small motor units. These smaller motor units are responsible for precise, delicate movements known as fine motor control (Kandel et al., 2013; Knierim, 1997). When a motor unit responds to a single action potential, the innervated fibres contract and result in what is called a ‘twitch’ (Kandel et al., 2013). Even though each muscle action consists of many steps, the transition between movements is smooth and controlled. This is due to the muscles’ ability to produce varying force outputs known as a ‘graded muscle response’. Individuals' past experiences and repetition of similar movements allow for faster and smoother neural pathways and patterns to be created (Knierim, 1997). This is known as ‘motor learning’ (Buchthal & Schmalbruch, 1980; Kandel et al., 2013).

If motor control is the process of purposefully initiating, directing, and controlling the force output of a voluntary muscle movement through a set of motor patterns (Kitago & Krakauer, 2013; Roller et al., 2013), then motor learning is the neurological process that accrues when selecting the best motor patterns to meet the task (Krakauer & Mazzoni, 2011). A motor pattern refers to the sequence of directed muscle movements in accomplishing an external purpose and is achieved through the interaction between neuron recruitment and rate coding (Kenyon & Blackinton, 2011). Motor patterns may alter the speed and force of a movement based on past experiences of similar movements (Kenyon & Blackinton, 2011; Schmidt, 1975). Motor patterns are also dependent on the muscle fibre architecture and composition (Scott et al., 2001). Therefore, motor patterns may differ between individuals based on the previous experiences of similar movements using that specific muscle or muscle group when completing a given task. Inter-individual and intra-individual variability add to the complexities of research during dynamic muscle actions as each individual has different muscle fibre architecture and composition, but also different firing patterns and neuron recruitment patterns based on past experiences (Kenyon & Blackinton, 2011; Scott et al., 2001). However, Kallio et al., (2013) found that by using muscles that are predominantly comprised of the same fibre composition, particularly stabilising muscles such as the soleus, the activation patterns remained constant between individuals and muscle actions.

The ability to control one's force output is essential in all activities of work, sport and daily living. It allows one to use the same muscles to, for example, hold an egg without crushing it, even when one is more than capable of doing so. There are two ways that the force produced in a muscle is regulated, namely 'rate coding' and 'motor unit recruitment'. 'Rate coding' refers to the frequency with which the muscle fibres are stimulated by their innervating axon, while 'motor unit recruitment' refers to the number of motor units activated by increasing the intensity of the action potential.

2.2.1 Rate coding

Also known as 'motor unit firing rate', rate coding is the rate at which nerve impulses arrive at the motor endplate. This firing rate may range from frequencies low enough to produce a series of single twitch contractions to frequencies high enough to produce a fused tetanic twitch (Beltman et al., 2004; Enoka & Duchateau, 2017). Force produced by a single muscle fibre is directly proportional to how many myosin heads are attached to actin in each sarcomere and that pull against one another during the power stroke. A greater frequency of stimuli releases more Ca^{2+}, thus opening more available binding sites on the actin and allowing for a 2-fold to 4-fold increase in force (De Luca, 1985). The increase in force gain is dependent on stimulus frequency and the size of the motor neuron receiving it (see Henneman's size principle in section 2.2.2 Motor unit recruitment) (Henneman et al., 1964, 1965).

The individual motor unit firing rates increase with increasing demands for muscular effort until a maximum rate is reached and all available myosin-binding sites have been opened (De Luca, 1985; Enoka & Duchateau, 2017). It is at this point that force output will plateau, and the muscle fibre enters a state of tetanus as maximum tension has been reached. The muscle will stay in tetanus state until the finite supply of ATP has been expended, and the muscle fibre enters a state of fatigue, characterised by a decrease in force output (De Luca, 1985; Enoka & Duchateau, 2008, 2017; Lawrence & De Luca, 1983).

2.2.2 Motor unit recruitment

When a motor neuron is activated, all muscle fibres that are innervated by that motor neuron are stimulated and contract as a result (Enoka & Duchateau, 2017; Fauth et al., 2010; Hodson-Tole & Wakeling, 2008). The activation of only one motor neuron will result in a weak but distributed muscle contraction across fibres, whilst the activation of multiple motor neurons will result in more muscle fibres being activated, and therefore result in greater force output (Enoka & Duchateau, 2017; Gordon et al., 2004; Milner-Brown & Stein, 1975). Motor unit recruitment, or motor unit summation, is therefore a measure of how many motor neurons are activated in a muscle, which is a measure of how many muscle fibres of that muscle are activated (De Luca, 1985; Knierim, 1997). A greater intensity of action potentials leads to more fibres being recruited and thus greater force production (De Luca, 1985; Knierim, 1997). Motor unit recruitment is not random, as motor units are generally recruited in order of smallest to largest as the task demand increases (Bawa et al., 2014; Gordon et al., 2004; Henneman et al., 1964, 1965; Milner-Brown & Stein, 1975). This order of recruitment is known as ‘Henneman's size principle’ (Henneman et al., 1964, 1965; Milner-Brown & Stein, 1975).

Henneman's size principle states that, under load, motor units are recruited from smallest (type I muscle fibres) to largest (type II muscle fibres) (Henneman et al., 1964, 1965). This also means that slow-twitch, low-force, fatigue-resistant (type I) muscle fibres are activated before fast-twitch, high-force, less fatigue-resistant (type II) muscle fibres (Henneman et al., 1965; Hodson-Tole & Wakeling, 2008; Senn et al., 1995).

This principle exhibits a task-appropriate recruitment pattern and has two important physiological benefits. The first benefit is that fatigue development is minimised as the fatigue-resistant muscle fibres are recruited first, whilst the fatigable fibres are only recruited when a high force is needed, thus conserving energy (Enoka & Duchateau, 2017; June et al., 2009). The second benefit is that Henneman's principle allows for fine control of force at all levels of force output (Enoka & Duchateau, 2017).

To date, Henneman's principle remains the leading theory in understanding recruitment patterns, with more recent research (Bawa et al., 2014; Carrascal et al., 2011; Gordon et al., 2004; Kiehn & Churchland, 2015; McLean & Dougherty, 2015; Mendell, 2005) building upon it. However, research by (Kanda et al., (1977) and (Garnett & Stephens, (1980) pointed out that under some circumstances, the normal order of motor unit recruitment may be altered, and larger motor units may be recruited sooner. This altered recruitment order is thought to be due to the interactions between rate coding and motor unit recruitment as the muscle responds to meet the task demands (De Luca, 1985; Knierim, 1997). This interaction allows for seamless force changes, which would otherwise occur incrementally as each additional motor unit is recruited (De Luca, 1985; Knierim, 1997). The process of controlling a muscle’s force output may further be improved through motor learning (Kitago & Krakauer, 2013; Krakauer, 2006; Krakauer & Mazzoni, 2011; Wolpert et al., 2011).

Burke and colleagues disputed the size principle in two published papers (Burke et al., 1976, 1979). In the first paper, they demonstrated that there was a graded decrease in the excitatory amplitudes from small to larger motor neurons (Burke et al., 1976). Although this seemed to agree with Henneman's research, Burke et al., (1976) argued that larger motor neurons have a larger surface area and therefore have space for more synapses. In a second paper, Burke et al., (1979) showed that smaller motor neurons have a greater number of synaptic inputs from a single source. However, it is important to note that these findings were based on a very small sample of cat neurons and therefore is regarded as controversial.

2.3 Muscle Actions/ Exertions

For this section on muscle actions, it is important to note that the terms 'muscle action' and 'muscle exertion' will be used interchangeably. The terms ‘exertion’ and ‘action’ are currently preferred over ‘contraction’ as ‘contraction’ refers to the muscle shortening as opposed to lengthening (eccentric) or remaining static (isometric), even though at a micro level it is still true that the filaments are contracting (Siff, 2000). Muscle actions can be separated into isometric and isotonic muscle actions (Tortora & Derrickson, 2011), with all muscle actions being a series of exertions and relaxations. During the exertion phase, force is dependent on the rate of neural input and the number of innovated motor neurons (Enoka & Duchateau, 2017). The shortening of a muscle takes place due to the binding of the contractile element (actin and myosin), while the return to that muscle's resting position is achieved via the release of stored energy in the parallel filaments and the series of elastic components (Kumar, 2010). Due to the stretch component within muscle fibres, little to no energy is needed whilst relaxing (Kumar, 2010).

2.3.1 Isometric muscle action

An isometric exertion can be described as a muscle action during which the muscle does not change its overall size or length (Chaffin et al., 1999; Kuriki et al., 2012; Tortora & Derrickson, 2011). It is, however, important to note that even when the muscle is not changing length, a movement still takes place within the muscle as contractile elements (actin and myosin filaments) slide along each other. This movement within the muscle causes elastic strain to rise and results in micro-movements that are not noticeable from an observer's view (Doheny et al., 2008). This means that muscle work is performed, although there is no movement observed externally (Enoka, 2015; Kuriki et al., 2012). The elastic strain is stored predominately by the tendons and is dependent on the tensile strength (ability to resist stretch) of that specific tendon as it may vary based on the tendon's morphology (Kumar, 2010; Lai et al., 2014). The elastic strain energy stored in the tendons is used to reduce muscle fibre work and optimise contractile conditions, thus minimising mechanical energy expenditure during the force-length-velocity relationship (Lai et al., 2014).

2.3.2 Isotonic muscle action

An isotonic muscle action is a muscle action where the length of the muscle changes, either through concentric (shortening) or eccentric (lengthening) actions (Nigg & Herzog, 1999; Silverthorn, 2013; Tortora & Derrickson, 2011). A concentric muscle action occurs when cross-bridges are formed between the actin and myosin, drawing the Z-lines of the sarcomere towards one another, thus resulting in the muscle length shortening. The opposite is true for an eccentric exertion as the muscle length will increase (Nigg & Herzog, 1999; Silverthorn, 2013; Tortora & Derrickson, 2011). The lengthening or stretching of the muscle is due to the opposing force (e.g., an external load) being greater than the force production inside the muscle. Although the myofilaments of the muscle fibre are stretched while contracting, Herzog et al., (2008) state there is a decrease in the rate of cross-bridge detachment. The percentage of cross-bridges remaining attached is thus increased, leading to greater force production capabilities in eccentric muscle actions compared to concentric and isometric actions.

2.4 Electromyography (EMG)

Electromyography measures and records the electrical potential difference (voltage difference) produced by skeletal muscle activity between two or more electrodes during a task (Ashnagar, 2013; De Luca, 1997; Konrad, 2006). Of the two techniques to measure EMG, surface EMG (sEMG) is the most commonly used technique during biomechanical and sport studies as it is less invasive than intramuscular EMG (needle EMG) which is more commonly used in medical diagnoses (Milner-Brown & Stein, 1975). The EMG data recorded during both techniques are directly affected by the rate coding and motor neuron recruitment of the measured muscle. Therefore, it is essential that when selecting a muscle for testing, one understands the basic functioning of the selected muscle (i.e. movement of the muscle) and the architecture of the muscle (i.e. fibre type distribution and fibre orientation) as these will alter the muscle fibre rate coding and recruitment patterns (De Luca, 1985, 1997). These relationships can be seen in

Figure 1 below.

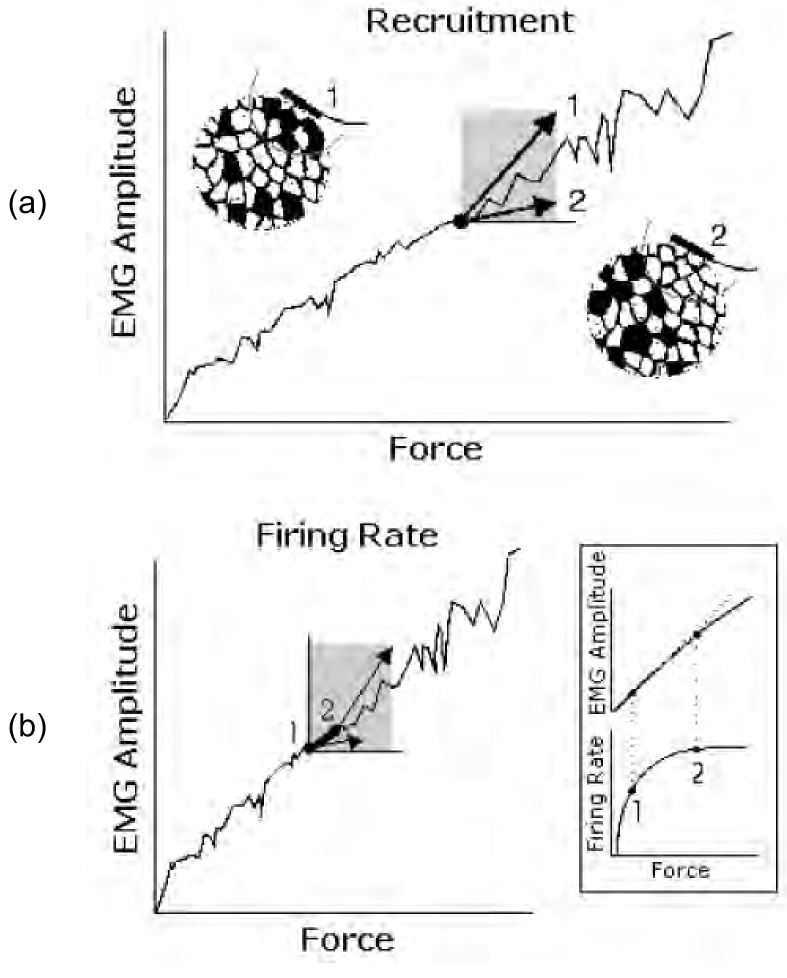


Figure 1: The effects of motor neuron recruitment (a) and rate coding (b) on the force-EMG relationship. Taken from De Luca (1997, p.21).

Figure 1a shows that when motor units are recruited, they contribute to the force of the contraction. However, the EMG signal amplitude is dependent on the proximity of the electrodes to the active muscle fibres; Figure 1a depicts that; fibres closer to the electrodes will have a greater effect on the EMG amplitude compared to those further away, thus either increasing or decreasing the slope of the force-EMG relationship respectively.

Figure 1a, the slope of the force-EMG relationship will either increase or decrease depending on the firing rate value and the upper frequency limit of that motor unit.

Figure 1b indicates how a motor unit will increase its firing rate, as greater force requirements are needed to meet task demands. The increase in firing rate will cause a rapid increase in force but a slower increase in EMG amplitude. As in the case of

Factors affecting EMG amplitude can be grouped into extrinsic and intrinsic sub-factors (De Luca, 1997). The extrinsic factors are those that can be controlled by the researcher (e.g., electrode configuration and placement, muscle selection and motor point used), while the intrinsic factors include the physiological, anatomical, and biochemical characteristics of each muscle and individual (e.g. fibre type architecture, fibre diameter, subcutaneous tissue, blood flow, water intake and so on) (De Luca, 1997; Halaki & Ginn, 2012). Given the many factors that influence EMG, the interpretation of raw EMG is problematic without first normalising the EMG data (Ball & Scurr, 2013; Burden, 2010; De Luca, 1997; Halaki & Ginn, 2012; Konrad, 2006). Normalisation refers to the process of relativizing EMG amplitude to a value that is both known and repeatable. (Halaki & Ginn, 2012) state that there currently is no "best" method of EMG normalisation; however, the most common methods include:

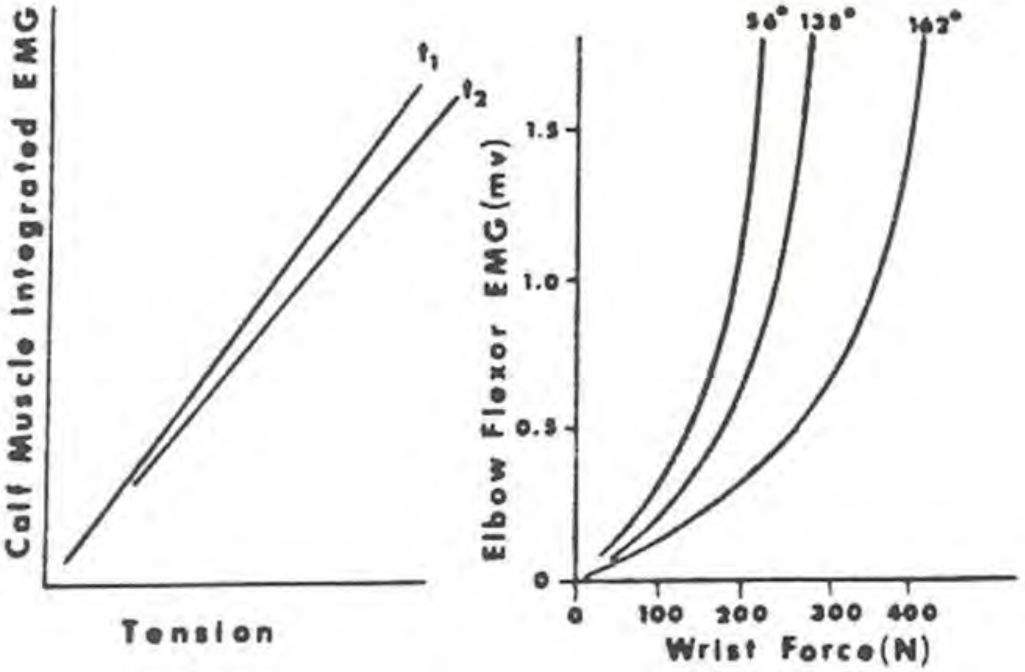
- Maximum voluntary exertions (MVE)
- Peak or mean activation levels recorded during a given task
- Submaximal isometric exertions
- Peak to peak amplitudes, also known as maximum M-wave (M-max)

The most common of the above-mentioned methods is the MVE, more specifically, maximum voluntary isometric exertions (MVIE) (Ball & Scurr, 2013; Halaki & Ginn, 2012; Prentice, 2016). The benefit of this method is that it allows the researcher to exert greater control over the extrinsic factors affecting the EMG amplitude (De Luca, 1997). However, despite the common use of MVIE as a normalisation method, the use of this method for dynamic muscle actions is debatable. Many studies have reported EMG amplitudes, particularly during forceful exertions (Perry, 1992) or eccentric exertions (Kumar & Mital, 1996), to be greater than 100% of the MVIE. For example, (Jobe et al., (1984) reported amplitudes of 226% and 212% during a throwing task. When performing a dynamic movement, there is a change in the joint angles as the muscle moves through a ROM (Farina, 2006), which influences the muscle's length-tension relationship. This, in turn, affects the muscle’s force-production capacity, which ultimately influences motor unit recruitment (De Luca, 1997; Enoka & Duchateau, 2017; Konrad, 2006). To address this problem, (Halaki & Ginn, 2012) recommended that maximum dynamic (usually isokinetic) exertions are used to obtain reference EMG levels to normalise the EMG data obtained during dynamic exertions rather than the MVIE. Their method proposes that a participant needs to perform a maximum isokinetic contraction at a speed that is similar to the dynamic task that is being measured, and to process the EMG data by either using a high-pass filter, rectifying and smoothing, or by calculating the root mean square of the EMG signal (Halaki & Ginn, 2012).

2.5 Force-EMG Relationship

The association between muscle force and EMG amplitude is directly proportional such that a increase /decrease in one will result in a increase /decrease in the other (De Luca, 1997; Konrad, 2006). The force-EMG relationship brings together the disciplines of biomechanics and electromyography in such a manner that the importance of the force-EMG relationship is unquestionable. However, the shape of this relationship sparks some debate amongst researchers. Some argue that the force-EMG relationship is linear (Bigland & Lippold, 1954; de Jong & Freund, 1967; DeVries, 1968; Körner et al., 1984; Lippold, 1952; Milner-Brown & Stein, 1975), while others advocate for a non-linear relationship (Alkner et al., 2000; Komi & Buskirk, 1970; Potvin & Norman, 1996; Solomonow et al., 1986; Vredenbregt & Rau, 1973; Zuniga & Simons, 1969). (b)

Figure 2 shows an example of a linear relationship (a) and a non-linear force-EMG relationship (b) from (Lippold, 1952; Vredenbregt & Rau, 1973), respectively. Lippold, (1952) demonstrated that provided the electrodes are placed over the muscle belly or its tendons the force-EMG relationship would remain linear. This can be seen in figure 2(a) where a linear relationship can be seen in the same subject during two experiment conditions. In contrast Vredenbregt & Rau, (1973) demonstrated a non-linear force-EMG relationship, figure 2(b), as the muscle length changed. Muscle length in figure 2(b) was represented by elbow inclination angle.



(a) (b)

Figure 2: Linear (a) and non-linear (b) force-EMG relationships. Figure taken from (Chasey, 2015).

Staudenmann et al., (2010) state that the relationship between muscle activity and force output may not necessarily be linear, as the interactions between rate coding and force are different to the relationship between rate coding and EMG amplitude. In addition, Criswell, (2011) argued that the force-EMG relationship is dependent on the recruitment range (different sizes and number of activated motor neurons) and hence the composition of the muscle fibres. Muscles that consist of predominantly one fibre type display a more linear force-EMG relationship (Beltman et al., 2004; Hodson-Tole & Wakeling, 2008; Simpson et al., 2019). This relationship in muscles with a mixture of fibre types appears to be curvilinear until approximately 50% of maximum voluntary exertion (MVE), after which the curve will flatten out as predominantly larger, same-type motor neurons are firing. There are also non-linearities between both force and EMG amplitudes when related to the neural drive (Vinet & Zhedanov, 2011). Neural drive is the sum of the motor neuron spiking activities of the muscle that are generated by the transformation of synaptic input into spike/ wave output (Farina et al., 2014;

Heckman & Enoka, 2004). However, the non-linearities between force and neural drive and the non-linearities between EMG and neural drive seem to 'balance' the relationship between force and EMG signal, leading to a linear force-EMG relationship, or at least one that is close to linear (Vinet & Zhedanov, 2011). Other factors influencing this relationship include the limitations of sEMG, the placement of electrodes and how the force-EMG relationship changes over different muscle actions (Mesin et al., 2009; Rainoldi et al., 2004; Sacco et al., 2009; Zipp, 1982).

Added to the complexities that govern the shape of the force-EMG relationship, the majority of research has been conducted on static muscle actions, as dynamic muscle actions incur various mechanical, physiological, anatomical and electrical changes that alter the EMG amplitude and the force produced by the muscle (De Luca, 1997). Changes in the muscle which occur during dynamic exertions include those relating to the force-length, length-tension, and force-velocity relationships, as well as the movement of the muscle belly under the skin resulting in the electrodes possibly changing position (De Luca, 1997). The force-length relationship states that muscular force generation is dependent on the lengthening and shortening velocity of the muscle ("Force of Muscle Contraction," 2020; Gordon et al., 1966; Herzog, 2018). The length-tension relationship on the other hand refers to the tension generated at a specific joint angle (Sandercock, 2009; Sandercock & Heckman, 2001). Due to the fact that the formation of cross-bridge cycles is not instantaneous, the force-velocity relationship shows that as the velocity increases the force of a muscle will decrease as fewer muscle fibers are able to contract (Cress et al., 1992; Gordon et al., 1966; Kuriki et al., 2012).

These challenges of dynamic muscle testing are the reason why most EMG studies tend to normalise data by means of a maximum voluntary isometric muscle exertion (MVIE) (Ball & Scurr, 2013). Normalisation of EMG data involves rescaling the data to a percentage of the reference value (Ball & Scurr, 2013) and is of particular importance in EMG studies that express the relative neuromuscular capacity of a muscle during a given task (Ball & Scurr, 2013; Burden, 2010). The process also allows for comparisons between different muscles, studies and participants (Allison et al., 1993;

Ball & Scurr, 2013; Burden, 2010) by calculating submaximal forces and workloads in the form of a percentage of maximum voluntary exertions (%MVE) (Allison et al., 1993, 1998). Despite the preference of MVIE for EMG normalisation, Ball & Scurr, (2013; Hunter et al., (2002) and Rouffet & Hautier, (2008) advocate for the use of the dynamic normalisation method over isometric normalisation for EMG studies involving dynamic activities. Ball & Scurr, (2013) add that this is particularly true when the muscle action is similar to that of the given task.

The literature agrees that there is great value in understanding the force-EMG relationship for a multitude of applications. However, the complexities of the relationship, particularly during dynamic exertions has led to debate amongst researchers due to contradicting / mixed research results. It is evident that to understand the force-EMG relationship, one needs to understand the regulation of force by means of rate coding and recruitment patterns. While it is undisputed that this relationship is a positive one, it is uncertain whether it is linear or curvilinear, and whether the same relationship holds for different exertion types. An understanding of variables affecting force production during different muscle actions, such as sex and time-of-day, is thus also of importance.

CHAPTER 3: METHODS

3.1 Purpose and Value

The value of this study is to contribute to the limited knowledge of EMG during different muscle actions, thus aiding the development of better work guidelines and towards a safer and more efficient work environment. It aimed to achieve this by investigating the relationship between EMG and the force produced during static exertions (muscle actions maintaining a stable position) and dynamic exertions (muscle actions that result in movement).

3.2 Experimental Design

The study made use of a two-factorial repeated-measures experimental design, which entailed participants activating the muscle under investigation, namely the soleus muscle, by repeatedly dorsiflexing and plantarflexing the foot at different force levels and exertion types. The two factors under investigation were three muscle actions and six force levels. This resulted in a total of eighteen test conditions (Table i). The order of the 18 conditions was permutated as seen in 8.1 Appendix A – Permutation Matrix & Raw sEMG Data.

Table i: The experimental design matrix used in the study.

		Force (% Max) *					
		0%	**20%**	**40%**	**60%**	**80%**	**100%**
Exertion Type	Isometric						
	Eccentric						
	Concentric						

** The percentage force for each condition was calculated based on the maximum force generated for that exertion type.*

3.2.1 Statistical Hypotheses

Hypothesis 1: Effect of Load Level on Surface Electromyography (sEMG)

The first null hypothesis (H_O) stated that surface electromyography responses (EMG amplitude) are not dependent on force level variations, while the alternative hypothesis (H_A) stated that sEMG amplitude is dependent on the force load level.

H_O: μ0% = μ20% = μ40% = μ60% = μ80% = μ100%

H_A: μ0% ≠ μ20% ≠ μ40% ≠ μ60% ≠ μ80% ≠ μ100%

Where: 0% refers to no added external load.
20% refers 20% of the calculated maximum voluntary exertion (MVE).
40% refers 40% of MVE.
60% refers 60% of MVE.
80% refers 80% of MVE.
100% refers 100% of MVE.

Hypothesis 2: Effect of Muscle Action on Surface Electromyography (sEMG)

The second null hypothesis (H_O) stated that EMG amplitude is not dependent on the type of muscle action, while the alternative hypothesis (H_A) does infer different sEMG responses due to the type of muscle action.

H_O: μCon = μEcc = μIso

H_A: μCon ≠ μEcc ≠ μIso

Where: Con refers to concentric muscle action.
Ecc refers to eccentric muscle action.
Iso refers to isometric muscle action.

Hypothesis 3: Interaction Effect of Muscle Action and Force Level combinations on Surface Electromyography (sEMG)

The final null hypothesis stated that sEMG amplitude are not dependent on the interaction of the independent measures. The alternative hypothesis therefore stated that the sEMG activity is dependent on such an interaction.

H_O: μCon(0%) = μEcc(0%) = μIso(0%) = μCon(20%) = μEcc(20%) = μIso(20%) = μCon(40%) = μEcc(40%) = μIso(40%) = μCon(60%) = μEcc(60%) = μIso(60%) = μCon(80%) = μEcc(80%) = μIso(80%) = μCon(100%) = μEcc(100%) = μIso(100%).

H_A: μCon(0%) ≠ μEcc(0%) ≠ μIso(0%) ≠ μCon(20%) ≠ μEcc(20%) ≠ μIso(20%) ≠ μCon(40%) ≠ μEcc(40%) ≠ μIso(40%) ≠ μCon(60%) ≠ μEcc(60%) ≠ μIso(60%) ≠ μCon(80%) ≠ μEcc(80%) ≠ μIso(80%) ≠ μCon(100%) ≠ μEcc(100%) ≠ μIso(100%).

3.3 Selection of Independent Variables

3.3.1 Force levels

Load levels were defined as the external loads applied during a movement. It is acknowledged that the moving limb itself has a mass and should therefore be considered when calculating the force needing to be exerted. However, for the purpose of this study, the mass of the foot (which is moved by the soleus muscle selected for this study) was considered negligible as it only accounts for 1.33% of an individual's body weight (de Leva, 1996; Plagenhoef et al., 1983) and remained constant throughout the study. Furthermore, the isokinetic dynamometer takes this weight into consideration during calibration before testing. Six load levels were tested: 0%, 20%, 40%, 60%, 80% and 100% of maximum voluntary exertion (MVE) as these intervals allowed for evenly spaced increments from 0% to 100%, and they were similar to those used by (Dimitrova et al., 2009; Kuriki et al., 2012). This means that for the 0% conditions, no external weight was added to the experimental set-up, while for the remaining force levels, the external load was relativised as a percentage of the maximum voluntary force produced. This allowed the external loads to be normalised to each participant's maximum strength-producing capacity.

Furthermore, in calculating the load levels, the current study deviated from the conventional procedure of using a maximal voluntary **isometric** exertion to relativise sub-maximal force exertions. As recommended by Halaki & Ginn, (2012), this study relativised the sub-maximal loads for each exertion type to their own MVE; in other words, the submaximal forces for the concentric exertions were determined by using the forces obtained from the maximal concentric protocol, the submaximal eccentric loads were calculated from the eccentric maximal force exertions, and sub-maximal loads for the isometric MVEs from the maximum isometric exertions. The isokinetic dynamometer was used to measure the peak torque during the maximum voluntary exertions for each muscle action. Peak torque was then converted to the submaximal force (in kilograms) to provide the sub-maximal load.

3.3.2 Exertion type

The study differentiated between three different muscle action types, namely isometric and dynamic actions, of which the latter was separated into concentric and eccentric muscle actions. These muscle actions are defined below:

- Isometric muscle action - a muscle action where the muscle does not change size or length (Kuriki et al., 2012; Tortora & Derrickson, 2011) and no overt movement can be seen.
- Dynamic muscle action - a muscle action where the length of the muscle changes by moving through a range of motion, either through:
    a. concentric (muscle shortening), or
    b. eccentric (muscle lengthening) actions (Silverthorn, 2013; Tortora & Derrickson, 2011).

Humans make use of all three types of muscle actions in activities of daily living (ADL), sport and work, and often in conjunction with each other (Maton, 1981; Tortora & Derrickson, 2011; Village et al., 2005), hence the importance of investigating the force-EMG relationship for all exertion types. Since many tasks use combinations of muscle exertions, understanding the relationship between the muscle activity and the force produced for each of the exertion types will allow better-informed decisions on workplace guidelines or training regimes (Kenyon & Blackinton, 2011; Suzuki et al., 2014).

3.4 Selection of Dependent Variables

3.4.1 Electromyography (EMG) activity

EMG is the most commonly used measurement to record muscle activity (Ashnagar, 2013; De Luca, 1997; Farina et al., 2010; Kuriki et al., 2012). Researchers such as (Christensen et al., (1995); Farina, (2006); Potvin, (1997); Potvin & Bent, (1997) and Søgaard et al., (1996) argued that provided the maximal reference EMG measurement used for normalisation is obtained at a constant velocity and nature to the measured task, EMG data collected during dynamic exertions are reliable. This then means that EMG can be used in this study to compare the force-EMG relationship of the different muscle actions over varying load levels. A sample of raw sEMG from a participant's isometric exertions at various loads can be seen in Appendix A Figure 10 - Figure 15.

3.4.2 Peak Torque

While not a response variable per se, determining maximum strength was necessary to calculate the loads to be moved during the experimental conditions. Simpson et al., (2019) defined muscle strength as the maximal force produced against resistance during a single muscle action. Joint torque is the force produced by the muscles acting upon a joint (Simpson et al., 2019). Therefore, peak torque is the single highest torque output of the joint, produced by muscle actions as the limb moves through the range of motion (Morrissey, 1987). If a muscle is isolated the vast majority of the joint torque would therefore be created by that muscle. Both (Morrissey, 1987; Simpson et al., 2019) agree that peak torque is the universal standard parameter used to measure muscle strength during isokinetic testing. In this study, the peak torque for each muscle action (isometric, eccentric, concentric) represented the 100% MVE load and was used to calculate the respective submaximal loads for each muscle action. The formula used to calculate force from the peak torque was F = d/t where "F" refers to the force acting on the direction of movement, "d" refers to the length of the lever arm and "t" refers to the torque.

3.4.3 Demographic and Anthropometric Data

In addition to the above variables, age, sex, stature, and body mass were recorded as well as the time of the time of the participants selected testing session. These measurements were needed to set up each participant's profile on the isokinetic dynamometer. Age and sex were obtained verbally, while stature was measured using a stadiometer (*Holtain (Ltd)* stadiometer) and body mass was measured with a scale (Model: Toledo Scale corp. type no. 8142). Health status was also assessed by means of a PAR-Q questionnaire (Appendix C – Information and Consent Letters.3). The PAR-Q was needed to confirm each participant was free of injury or any underlying conditions that could further injure them or skew the results. Participants were allowed to self-select the time of the testing session based on the hour. This was to allow the participant to select a time where they felt they could perform optimally.

3.5 Variables of No Interest

3.5.1 Muscle

The soleus was selected as the muscle under investigation since it is a stabilising muscle of the lower extremities and consists predominantly of type 1 muscle fibres. The dominance of type 1 muscle fibres is crucial as they have the same recruitment pattern (Gollnick et al., 1974). It is also easily isolated by manipulating the hip and knee angles, and its superficial location posteriorly makes it suitable for surface EMG recordings (Hatfield, n.d.; King, 2015; Rantalainen et al., 2012; Tortora & Derrickson, 2011). The choice of the soleus muscle is similar to those used by (Kallio et al., 2013; Vandervoort & McComas, 1983). The soleus muscle on the dominant side was selected for the experimental procedures.

3.5.2 Range of motion (ROM)

The ankle's ROM during the dynamic exertions was set at 20° of dorsiflexion and 40° of plantarflexion (see Figure 3) as these are the recommended norms for ankle ROM (Germanotta et al., 2017; Roaas & Andersson, 1982). The total ROM tested would therefore be 60° and coincided with the recommended speed of the isokinetic dynamometer (see section 3.5.3 for more details). The ankle position during isometric testing was neutral (0°) as seen in Figure 3.

Although joint angles were set, ROM was still recorded to confirm that participants did move through the entire ROM, particularly during the dynamic exertions.

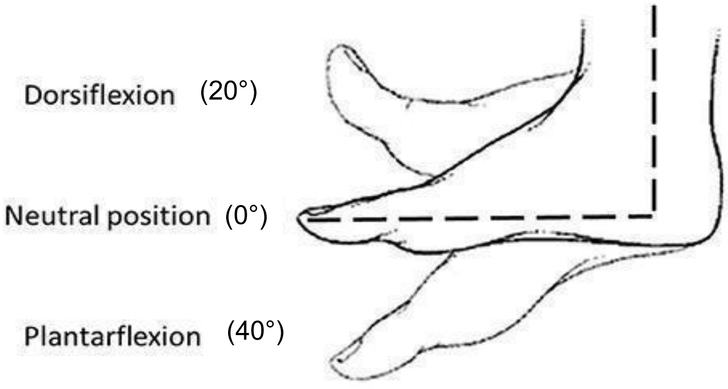


Figure 3: Illustration of the range of motion of the ankle joint used in this study. (Image adapted from (Germanotta et al., 2017).

3.5.3 Movement Velocity

The ankle's movement velocity during the dynamic MVE, as well as the experimental conditions, was set at 60° per second. This speed is recommended for ankle joint motion by the isokinetic dynamometer's user manual but was also chosen specifically as the total ROM of the ankle was 60°.

During the dynamic protocol, participants performed one ankle dorsiflexion-plantarflexion cycle in two seconds (i.e. 1 second for the concentric and 1 second for the eccentric exertion), thus mimicking the 60° per second speed of the maximal isokinetic exertions. As the isokinetic dynamometer is designed to measure maximum force at a constant velocity, sub-maximal testing becomes a potential source of error. The isokinetic dynamometer can only control speed and range of motion while measuring the force produced. The isokinetic dynamometer cannot control force and therefore producing a certain (sub-maximal force) cannot be controlled. Therefore, a pulley system (see section 3.6.2) was used for all sub-maximal conditions. In order for the maximal conditions conducted on the isokinetic dynamometer to match the sub-maximal condition conducted on the pulley system, participants' timing (velocity) had to match that during the maximal exertions. A metronome display on a Microsoft PowerPoint slideshow was used to guide participants with the timing of the movement, thus controlling movement velocity.

3.5.4 Knee flexion angle

Knee flexion was set at an angle of 45° as this angle allowed the soleus to be isolated from the gastrocnemius muscle during plantarflexion. Gastrocnemius is a bi-articular muscle and plays a role in knee flexion. Therefore, flexing the knee beyond 30^{o} renders it less effective due to a sub-optimal length-tension relationship, and soleus takes up the role as the main plantar flexor (Kallio et al., 2013; Suzuki et al., 2014). The specific knee angle was selected after participant feedback during pilot testing showed 45° of flexion to be the most comfortable.

3.6 Equipment

3.6.1 Isokinetic Dynamometer

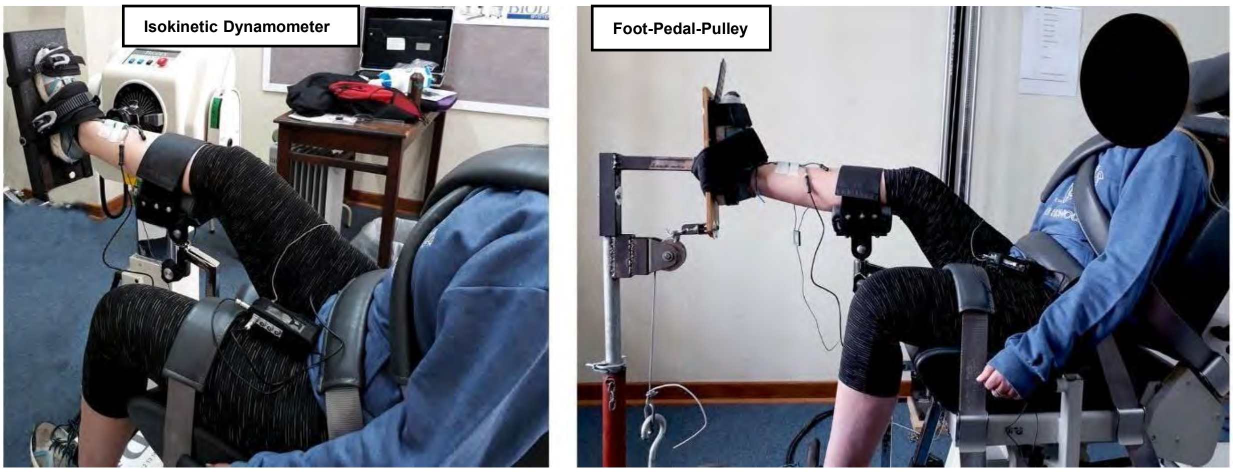
The Biodex4 (*Model: Biodex System 4 Pro. Biodex Medical Systems, Inc. New York; 11967-4704*) was used to measure peak torque (PT) during the maximal effort of the three types of muscle exertions (isometric, eccentric, concentric). This maximal effort represented the 100% force loads (MVEs) of each muscle action and was used to calculate the submaximal force loads used in the sub-maximal experimental conditions. The Biodex4 is an isokinetic dynamometer, making use of an isolated joint isokinetic system (Feiring et al., 1990; Valovich-mcLeod et al., 2004). This means that the Biodex4 measures the torque production of a selected joint through its ROM at a constant predetermined velocity. Once the limb reaches the pre-set velocity, the dynamometer produces an equal counterforce to ensure a constant velocity throughout the ROM. The Biodex4 has built-in stoppers that allow one to preselect the desired ROM for testing. This allowed this study to pre-set each participant’s ROM to 60º.

The Biodex4 chair set-up was standardised as follows: the back angle of the isokinetic dynamometer was set at 120º with the orientation of the chair set to 90º with a tilt of 0º, as per manufacturer's instructions. Depending on the participant's dominant leg, the dynamometer was moved to the correct side of the chair, with the dorsi/plantarflexion ankle attachment in place (Figure 4a). Due to anthropometric variability between participants, finer adjustments to the chair set-up were performed once participants were seated and securely strapped into the Biodex seat. The length of the ankle attachment lever arm was noted for calculation purposes as it is needed when converting torque into kilograms.

3.6.2 Pulley system

To test sub-maximal force levels, a foot-pedal-pulley system was developed in-house (depicted in Figure 4b). This pulley system allowed for sub-maximal loads to be added. These loads corresponding to either 0%, 20%, 40%, 60% or 80% of MVE of the maximal peak torque of each exertion type (isometric, eccentric & concentric), whilst keeping the postural set-up identical to that of the isokinetic dynamometer. The pulley system was designed in a manner that external weights could be adjusted and created a resistance. Participants had to push the foot against a footplate (i.e. attempt to dorsiflex the ankle), thus activating the soleus muscle. For the isometric condition, the footplate was immovable, thus creating an isometric exertion. For the dynamic exertions, the footplate could move; concentric activation of the soleus muscle involved pressing against the footplate and thus plantarflex the ankle to activate the soleus muscle, while releasing the footplate in a controlled manner by dorsiflexing the foot would activate the soleus muscle eccentrically. In order to control ROM during testing, the cable length of the pully was adjusted in a manner that acted as a stopper to control the desired movement ROM.

The pulley system was located next to the isokinetic dynamometer, which meant that changing between the maximum condition (MVE) and the sub-maximal conditions only necessitated the dynamometer's chair to be rotated by 180°, but no further adjustments to the set-up were necessary. The participants' posture thus remained the same, as did the EMG electrode placement and all testing procedures for maximal and sub-maximal force exertions. For larger loads, standard weight plates were attached to the pulley system, whilst a *Prochef™* electronic kitchen scale was used to make smaller adjustments by adding lead weights to a pouch.



(a) (b)

Figure 4: Set-up of the isokinetic dynamometer (a) and the set-up of foot-pedal-pulley system (b).

3.6.3 Surface Electromyography (sEMG)

The soleus muscle activity was recorded for the full duration of the experimental protocol using the EMG component of the Biometrics data logger system (*Model: Biometrics Ltd. Type no. SX230)*. To ensure the best electrode-to-skin contact, the participants' hairs on the skin overlying the soleus muscle were shaved, and the area cleaned with alcohol to remove any residue before the electrodes were attached (Day, 2002). The placement of the electrodes was two-thirds of the longitudinal distance from the medial condyle of the femur and the medial malleolus, starting from the medial condyle (see Figure 5). This electrode placement, coupled with knee flexion, is where soleus is most superficial (Rainoldi et al., 2004; Sacco et al., 2009; Zipp, 1982). The electrodes used were two Kendall™ 200 foam silver-silver bipolar surface electrodes (*Medtronic, Canada*) with built-in amplifiers (*Model: Meditrace ™ Ground electrode 32 strips, Type no. SX230FW*). The amplifier had two flying leads with a 4 mm snap-on each and an amplification range of 20Hz-450Hz. Maximum inter-electrode distance was 200mm, with the minimum being dependent on electrode size used. The reference electrode (*Model: Killstat ® high quality grounding product. Type no. CA4AADB*) was placed on an uninvolved limb, which in this case was midway on the medial side of the forearm on the opposite side to the leg being tested. EMG data were sampled with a sampling frequency of 1000Hz and were bandpass filtered (10–500 Hz).

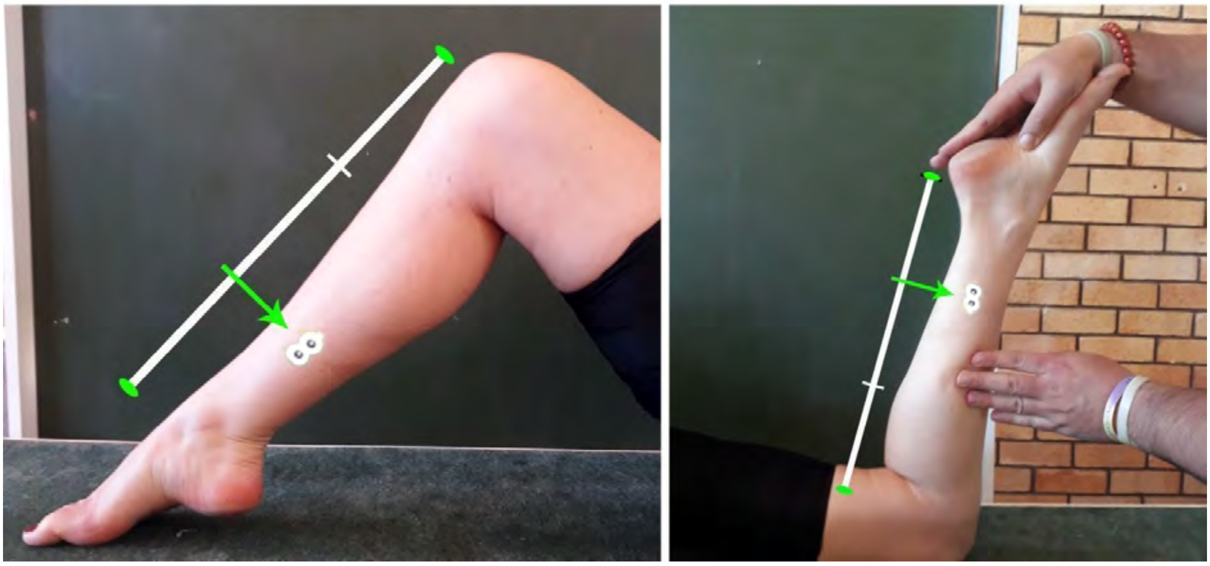


Figure 5: Placement of the sEMG electrodes.

3.6.4 Computer for Instructions

Instructions to guide the participants' movement velocity and rest periods were displayed on a computer screen with the use of a Microsoft PowerPoint (*Model: Microsoft Office 360®. version no. 18.2008.12711.0*) slideshow for visual feedback and a pre-recorded voice-over for audio feedback.

3.6.5 Electrogoniometer

To verify that participants did indeed move within the stipulated ROM, an electrogoniometer was fitted. Fitting the electrogoniometer entailed aligning the immovable arm of the goniometer with the lateral side lower limb and the movable arm of the goniometer with the 5th metatarsal, while the centre of the goniometer was aligned with the lateral malleolus of the dominant leg. This method of measurement is the standard approach to measuring ankle range of motion (Prentice, 2016). The electrogoniometer, which formed part of the Biometrics data logger system (*Model: Biometrics Ltd. Type no. SX230)* was secured to the anterior-superior portion of the ankle aligned with the participants' middle toe and halfway between the lateral and medial malleolus of the ankle (the top of the foot, extending up the middle of the lower limb). This allowed ankle ROM to be recorded throughout each experimental condition and was also used during the analysis phase to separate the EMG data for each exertion type into its relevant ROM.

3.7 Participants

A sample of 32 participants (11 males & 21 females), aged 18 – 28 years, were recruited for this study from the Rhodes University student population via convenience sampling. Thirty participants were the number of participants needed to complete one full permutation as seen in 8.1 Appendix A – Permutation Matrix. Two additional male participants were tested to increase the ratio of male to female participants. One male participant had to be removed from the study as he experienced cramping during testing and was unable to complete the testing protocol. This resulted in the final number of participants tested at 31 (10 males & 21 females). The age range of 18-25 years for this study was selected on the grounds that individuals past the age of 25 years may experience reduced muscle function due to motor unit remodelling that gradually deteriorates with age. This denervation leads to degeneration of muscle fibres (irreversible muscle atrophy) and a decrease in strength, increasing injury risk (Dumitru et al., 2018; Kwan, 2013). Younger populations are generally the healthiest and 'fittest', and thus the risk of any adverse effects is the lowest in this group (McArdle et al., 2015). Participants were not required to engage in regular physical activity or moderate weight training to partake in the study. This study did not control participant physical activity due to the soleus muscle being a stabilising muscle and therefore should already be trained even in sedentary individuals who engage in minimal walking (Gollnick et al., 1974; Vandervoort & McComas, 1983). However, researcher notes were taken of physical activity levels and exercise habits.

It may also be noted that there is always a slight risk of muscular strain during any maximum test; however, as these exertions were voluntary in nature, the risk of overexertion during a voluntary maximum test is rare, and the risk was therefore considered minimal (Gail & Künzell, 2014; Potvin, 2012). This is due to the fact that voluntary exertions are limited to the force/effort an individual perceives they can produce without injury. A muscle is therefore never exposed to anything they believe is harmful (Potvin, 2012). Additional measures put in place to minimise this risk included a warm-up activity for soleus before the testing procedure began, as also performed by (Gail & Künzell, 2014; Inez et al., 2003). In addition to this, the Biodex will only apply as much force as is necessary to match the participant's strength, thus decreasing the risk of the participant overexerting themselves.

Participants were also required to be in good general health and absent from all symptoms of musculoskeletal disorders, sprains or strains in the lower limbs at the time of the testing and the preceding 6 months to avoid aggravating the condition or re-injuring the participant (Rantalainen et al., 2012). For these reasons, the participants were drawn from the Rhodes University student population as this population possessed the necessary characteristics for this study. A PAR-Q questionnaire (Appendix C – Information and Consent Letters.3.) was completed to ensure this. Inter-individual differences were accounted for by normalising results.

3.8 Ethical Considerations

The study was approved by the Ethics Committee of the Human Kinetics and Ergonomics Department of Rhodes University (reference number HKE-2018-15) as seen in Appendix B – Ethical Considerations, and gatekeeper permission to recruit university students was provided by the University Registrar (Appendix B – Ethical Considerations). Ethical considerations took into account full disclosure to participants of the study's purpose and its procedures, voluntary participation, issues of privacy, anonymity and confidentiality, risks and benefits, and feedback to participants.

3.9. Experimental Procedures

Each participant was required to participate in two sessions, comprising of an information and habituation session (Session 1) and an experimental session consisting of all eighteen experimental conditions (Session 2). Participants were given at least two days of recovery time between both sessions in case they experienced delayed onset of muscle soreness (DOMS). If a participant experienced DOMS the day before the testing session (Session 2), they were provided with more recovery time. Session 1 and Session 2 are explained in more detail below with an overview of the procedures provided in Figure 6.

Potential participants were contacted both verbally and in writing via emails. Interested individuals that fit the required participant characteristics were provided with a letter of information and pre-testing instructions, which they were asked to adhere to. These included abstaining from consuming tobacco, alcohol, or caffeine-rich drinks 12 hours before testing, as well as avoiding any strenuous exercise two days prior to testing. These instructions were given to reduce injury risk and avoid results being affected either by improving or decreasing the muscle's natural ability to produce force (Piitulainen et al., 2009; Rantalainen et al., 2012). Honesty was emphasised to the participants, and thus it was assumed that participants were truthful when asked about their level of health, physical activity, and certain demographic information.

Protocol Timeline

<table>
<tr>
<td rowspan="1"><i>Session 1 (45 min)</i></td>
<td>Habituation Session</td>
<td>• Information to participants
• Addressing questions
• Signing of consent form
• <i>Physical Activity Readiness Questionnaire (PAR-Q</i>)
• Basic demographic and anthropometric data
• Isokinetic dynamometer
- Setup & Timing practice</td>
</tr>
<tr>
<td colspan="3">Rest: 48 Hours</td>
</tr>
<tr>
<td rowspan="8"><i>Session 2 – Testing Session (2 hours)</i></td>
<td>Part A: Maximal Exertions</td>
<td>• Session Briefing
• Preparation
- Skin preparation
- Attach equipment
- Warm-up
• Testing of maximum voluntary exertions (<i>3 maximal efforts of each exertion type (isometric, eccentric & concentric) through the ankle ROM).</i>
<i><u>Measures:</u></i>
<i>• Peak Torque (Nm)</i>
<i>• sEMG</i></td>
</tr>
<tr>
<td colspan="2">Rest: 10 min</td>
</tr>
<tr>
<td rowspan="6"><i>Part B: Submaximal Exertions</i></td>
<td><i>3 submaximal repetitions using the foot-pedal-pulley system with 2 min rest breaks between load levels.</i>
<i><u>Measures:</u></i>
<i>• sEMG</i>
<u>Concentric</u>
EMG - 0% <i>(2 min)</i>, 20% <i>(2 min)</i>, 40% <i>(2 min)</i>, 60% <i>(2 min)</i>, 80% <i>(2 min)</i></td>
</tr>
<tr>
<td>Rest: 10 min</td>
</tr>
<tr>
<td><u>Eccentric</u>
EMG - 0% <i>(2 min)</i>, 20% <i>(2 min)</i>, 40% <i>(2 min)</i>, 60% <i>(2 min)</i>, 80% <i>(2 min)</i></td>
</tr>
<tr>
<td>Rest: 10 min</td>
</tr>
<tr>
<td><u>Isometric</u>
EMG - 0% <i>(2 min)</i>, 20% <i>(2 min)</i>, 40% <i>(2 min)</i>, 60% <i>(2 min)</i>, 80% <i>(2 min)</i></td>
</tr>
</table>

** Note: the order of the submaximal testing is an example of participant 1. Permutations (detailed in* 8.1 Appendix A – Permutation Matrix*) differed for all participants.*

Figure 6: Protocol timeline and permutated testing order of participant 1.

3.9.1 Session 1: Information and Habituation session

Information

Prior to the Information and Habituation session, participants were given a letter of information (Appendix C – Information and Consent Letters) containing necessary information about this study. During the first session, which lasted approximately 45 minutes, the information presented in the letter of information was repeated verbally. Once participants had been given a chance to ask questions about the study and its procedures and had these answered to their satisfaction, they signed the consent form (Appendix C – Information and Consent Letters). To ensure each participant was healthy at the time of testing, they each completed the *Physical Activity Readiness Questionnaire (PAR-Q)* (Appendix C – Information and Consent Letters).

Anthropometric and Demographic Data

Basic anthropometric and demographic data such as age, sex, and exercise status were determined verbally. To measure stature, participants stood barefoot against the stadiometer and looked straight ahead of them. Stature was recorded as the distance from the stadiometer's baseplate to the apex of the skull. Body mass measurements were obtained by the participant standing on an electronic scale. The participants were asked to remove shoes, excess clothing (e.g., thick jackets, caps, etc.) and have their pockets emptied of any heavy items (e.g., keys, mobile phone, etc.). Leg dominance was determined by asking the participant to kick a ball. This method has been shown to have a 100% accuracy when compared to other methods and questionnaires (van Melick et al., 2017).

Isokinetic Dynamometer Set-up

The set-up of the isokinetic dynamometer ensured that participants were comfortable with the machine during both the habituation and testing sessions. The isokinetic dynamometer positions and lever arm length were recorded for each participant (refer to detailed set-up description in the equipment section), followed by an opportunity to practice the different experimental conditions. The particular focus during the habituation was to achieve the correct timing and motion (as dictated by a pre-recorded slideshow) of the maximal concentric and eccentric exertions. As most participants were unfamiliar with the Biodex4 system, the correct timing of the exertions, particularly during the dynamic conditions, was crucial to this experiment. Participants were also exposed to the set-up and timing for the sub-maximal conditions. A second habituation session was available to participants if deemed necessary to ensure that they were comfortable with the equipment and capable of achieving the correct timing.

3.9.2 Session 2: Experimental Session

The experimental session lasted approximately 2 hours and involved performing all 18 experimental conditions. It was decided to perform all experimental conditions in one testing session, since even slight variations in EMG electrode placements, which may occur from sessions over multiple days, are known to influence the EMG signal (Konrad, 2006; Mesin et al., 2009; Sacco et al., 2009; Vinet & Zhedanov, 2011). To minimise the influence of muscle fatigue accumulation on the data, the conditions were permutated.

Information to Participants

At the start of the second session, participants were reminded of their rights and responsibilities in participating in this study. They were also reminded of what was expected of them during the testing session, with an emphasis placed on the timing of the dynamic exertions.

Set-up and Warm-up

The leg of the participant was then prepared and fitted with the EMG electrodes and electrogoniometer. Thereafter, participants performed a warm-up protocol similar to that used by Suzuki et al., (2014) by pedalling for 5 minutes on an exercise bike set to the lowest resistance. Once the warm-up was complete, participants were strapped into the chair of the isokinetic dynamometer to stabilise shoulders and trunk. The foot was secured in the ankle attachment of the Biodex4, and the leg secured with the limb pad.

Data Collection

The data collection portion of the study can be separated into two parts. Part A involved performing maximal exertions for all three exertion types on the isokinetic dynamometer and obtaining peak torque, and Part B entailed performing the experimental conditions. Peak torque was used to calculate the sub-maximal loads to be used on the pulley system.

Part A: Maximal Exertions

For the first part of the testing session, participants were strapped into the Biodex seat using the shoulder and waist straps to stabilise the torso. The participant's dominant leg was then placed onto the stabilising limb pad at a 45° angle of knee flexion. Three repetitions of maximal isometric exertions, as well as three repetitions of maximal dynamic (concentric and eccentric) exertions at 60^o per second were then performed, with a rest break of 10 minutes provided between each MVE. Of the maximal exertions, both static and dynamic actions, the highest torque for each exertion type was used to calculate the sub-maximal loads. The rest breaks were necessary to prevent the accumulation of muscle fatigue. EMG data, peak torque and joint angles were recorded throughout these maximal exertions. The MVEs not only provided the necessary torque values to calculate the loads for the submaximal exertions (Part B) but also served as the 100% load level for the experimental conditions.

Part B: Submaximal Exertions

During the 10-minute rest that followed the last maximal exertion, the researcher turned the Biodex chair by 180° to align it with the foot-pedal-pulley system and firmly secure the participant's foot into the footplate of the pulley system. Furthermore, the appropriate sub-maximal weights were added for each experimental condition.

Testing of the submaximal experimental conditions entailed recording EMG data and joint angles. All experimental conditions were permutated to minimise any learning or cumulative fatigue effects that may have occurred. The exertions performed during the sub-maximal protocol mimicked those of the maximal exertion on the Biodex. In other words, participants were either required to maintain the position of the foot pedal resisting the weight (isometric) or move the pedal through the set range of motion, thus inducing concentric and eccentric muscle actions. The ankle was fitted with an electrogoniometer to measure the joint angle and allowed for the EMG data of concentric and eccentric movement phases to be identified during the data analysis phase. Each muscle action (isometric & isotonic) was separated by a 10-minute rest break, while each condition within these (0%, 20%, 40%, 60% & 80%) were separated by 2-minute rest periods. All participants performed three exertions of each condition.

After all conditions had been completed, participants were thanked for their participation and given the opportunity to ask any questions.

3.10 Data Analysis

All data were captured and reduced in Microsoft Excel and then transferred to the Statistica Software, *Model: Statistica 13©, TIBCO Software Inc. Version no. 13.5.0.17. USA (1984-2018)* for analysis.

3.10.1. Data reduction and processing

The data first underwent a reduction process before it was analysed. This reduction process included separating the EMG dynamic data into concentric and eccentric muscle actions with the assistance of the electrogoniometer data. Thereafter the data were inspected for obvious errors or outliers. EMG data recorded during the maximal test conditions were full-wave rectified, smoothed, and thereafter the root mean square (RMS) of the data normalised, before extracting the highest 1-second peak period from each of the three repetitions. The EMG data recorded during the sub-maximal protocol was also reduced and processed in the same manner. The data was then tested for normality by means of a Shapiro-Wilks test. Box and Whisker plots were constructed for all experimental conditions. This was done to inspect the data's distribution and to detect outliers in each data set.

3.10.2 Basic descriptive statistics

All biomechanical, physiological, demographic, and anthropometric data were summarised using the mean, standard deviation and coefficient of variance. Of the three repetitions performed for each condition, the repetition with the highest mean EMG data were identified and is referred to as “Maximum EMG” from here on. Furthermore, the average EMG RMS amplitude of all three repetitions was calculated (referred to as “Average EMG amplitude” from here on.

3.10.3 Inferential statistics

Comparisons between experimental conditions were conducted by use of the General Linear Models (GLM) option in Statistica. This was to determine; 1) the effect of load, 2) the effect of exertion type, and 3) the interaction between these two factors on EMG responses. The confidence level was set at 95%, meaning significant differences were identified at a p-value of less than 0.05. Any significant differences identified underwent the Tukey post-hoc test to determine where the differences lay. GLM was used as it encompasses T-tests, ANOVA, regression and Analysis of Covariance (ANCOVA) within its statistical analysis; fitting both categorical effects and continuous effects (Brown & Prescott, 2014). GLM thus allows for the use of a linear model even when data sets are not normally distributed (Brown & Prescott, 2014; Phillips, 2017).

Correlation analyses were then conducted to determine the relationship between the external load moved and the corresponding sEMG. Research generally considers correlations above 0.75 to be relatively strong; correlations between 0.45 and 0.75 are moderate, and those below 0.45 are considered weak (Shortell, 2001). The p-value was again set at 0.05 identifying significant correlations.

CHAPTER 4: RESULTS

Chapter 4 displays and compares the biomechanical and physiological responses measured during each muscle action across all load levels. This chapter analyses each variable in terms of (1) the effect of muscle action on sEMG responses, (2) the effects of relativized load levels on sEMG responses, and 3) the interaction effects of the two independent variables. Furthermore, correlation analyses were conducted to determine the relationship between force and EMG for all exertion types. All statistical tables and additional graphs for this section can be found in Appendix D – Statistical Tables.

4.1 Outliers and Normality Testing

Once the raw data had been processed, outliers were identified by means of box-and-whisker graphs, and Shapiro-Wilks tests were conducted to test for normality (See Appendix D.1. Outliers and Normality Testing). It is important to note that the tables for demographic data do not appear in the appendix section. The demographic data, however, showed that age, mass, stature and time of day were normally distributed (p = 0.07, 0.71, 0.48 and 0.45 respectively), but sex was not (p<0.001). Tables ii to iv provide an overview of the overall normality of the data set and aided in the identification of outliers.

Table ii: Summary results of the Shapiro-Wilks test for normality for the torque data.

	Muscle Action		
	Concentric	**Eccentric**	**Isometric**
Peak Torque	p=0,25 *	p=0,75 *	p<0,001
Average Torque	p=0,06 *	p=0,19 *	p<0,001
Peak Torque/ Body Weight	p=0,81 *	p=0,04	p<0,001

** Indicates normality at p>0,05*

Normality was found for all torque data except for isometric muscle actions and the percentage of peak torque to body weight. Participant 26 was found to be the outlier in the isometric muscle action and participant 31 in the eccentric condition. However, it was decided that neither of these participants would be removed as their data results could be attributed to their training status as both participants took part in sport at a high level. Furthermore, the outliers varied from condition to condition, and removing all outliers from the data set would have dramatically decreased the sample size.

Table iii: Summary of the Shapiro-Wilks tests for normality for maximum sEMG data.

Load levels in % of MVE	**Muscle Actions**		
	Concentric	**Eccentric**	**Isometric**
0%	p<0,001	p<0,001	p<0,001
20%	p<0,001	p<0,001	p<0,001
40%	p=0,541 *	p<0,001	p<0,001
60%	p=0,569 *	p<0,001	p<0,001
80%	p=0,452 *	p<0,001	p<0,001
100%	p=0,038	p<0,001	p=0,01

** Indicates normality at p>0,05*

When considering the EMG responses of the highest repetition per exertion (referred to as ‘maximum sEMG’), normality was only found for the concentric muscle actions at load levels of 40%, 60% and 80% (Table iii). The box-and-whisker plots showed several outliers. These included the following: P02 $^{(6)}$, P03 $^{(1)}$, P06 $^{(1)}$, P08 $^{(1)}$, P09 $^{(1)}$, P10 $^{(2)}$, P20 $^{(1)}$, P21 $^{(1)}$, P28 $^{(6)}$ and P30 $^{(1)}$. The number in superscript shows the frequency of individual participants appearing as an outlier in the data set. Participant P02 and participant P28 both appear six times. Despite participant P02 and P28 appearing as outliers multiple times, it was decided not to remove them from the data set either. As with P26 and P31, the outliers varied from condition to condition and removing all outliers from the data set would have dramatically decreased the sample size.

Table iv: Summary of the Shapiro-Wilks tests for normality for average sEMG data.

Load levels in % of MVE	**Muscle actions**		
	Concentric	**Eccentric**	**Isometric**
0%	p<0,001	p<0,001	p<0,001
20%	p<0,001	p=0,002	p<0,001
40%	p=0,40 *	p<0,001	p<0,001
60%	p=0,27 *	p<0,001	p=0,001
80%	p=0,28 *	p<0,001	p=0,001
100%	p=0,14 *	p<0,001	p=0,004

** Indicates normality at p>0,05*

Using the average EMG amplitude results of all three repetitions per condition, normality was only found for the concentric muscle actions at load levels 40%, 60%, 80% and 100% (Table iv). The box-and-whisker plots mostly showed the same outliers as found for the maximum EMG results; namely participant P02 and participant P28 appearing as outliers with a frequency of 6 and 11 respectively. The remainder of the outliers were: P03 (1), P06 (1), P08 (1), P10 (2), P13 (1), P14 (1), P21 (1) and P26 (1). Again, the decision was made to not exclude these data. Overall, the average EMG amplitude data had fewer outliers than the maximum data.

4.2 Participant Characteristics

31 young and healthy students (21 females, 10 males) gave their written informed consent to participate in this study. Table v provides an overview of the basic anthropometric and demographic data, while Table vi depicts the results for the participants' strength.

4.2.1 Basic Anthropometric and Demographic Data

Table v: Participants' basic anthropometric and demographic data (means, ± standard deviations (SD), with coefficients of variation (CV) in brackets.

	All (n=31)	Female (n=21)	Male (n=10)	p-value
Age (yrs)	22,00 ± 1,77 (8,05%)	21,90 ± 1,48 (6,76%)	22,20 ± 2,35 (10,57%)	p=0,99
Mass (kg)	68,57 ± 13,33 (19,44%)	62,05 ± 9,29 (14,98%)	82,26 ± 9,64 (11,71%)	p<0,001*
Stature (m)	1,67 ± 0,09 (5,35%)	1,63 ± 0,07 (4,12%)	1,75 ± 0,07 (3,98%)	p=1,00

** Indicates significant difference (p<0.05) between male and female participants.*

A significant difference between the sexes was found only for body mass (p<0,001). Males had, on average, a greater mass than females (82,26 ± 9,64kg and 62.05 ± 9,29kg respectively). Age and stature were not significantly different between males and females.

4.2.2 Strength Expression

The isokinetic dynamometer was used to collect the torque values from the three repetitions performed. Of these three repetitions, the greatest recorded torque (peak torque) for the three repetitions and for each muscle action was used to calculate the submaximal load levels to be moved during the experimental conditions. The peak torque was selected by this study as it has been shown to have greater reliability when measuring EMG (Larsson et al., 2003; Oliveira et al., 2012). Table vi provides an overview of the torque values collected (peak torque, average torque, and peak torque to body-weight percentage) for each muscle action.

Table vi: Means, standard deviations, and coefficients of variation (in brackets) for peak torque, average torque and peak torque to bodyweight for each muscle action.

Torque (T) variation	Muscle Action	All (n=31)	Female (n=21)	Male (n=10)	p-value
Peak Torque (Nm)	Concentric	42,33 ± 22,74 (53,73%)	34,03 ± 17,70 (52,00%)	59,77 ± 23,01 (38,50%)	p=0,001*

	Eccentric	21,84 ± 6,31 (28,90%)	18,73 ± 4,38 (23,39%)	28,38 ± 4,48 (15,78%)	p=0,602
	Isometric	32,22 ± 21,56 (66,92%)	24,29 ± 10,27 (42,27%)	48,87 ± 29,33 60,02%)	p=0,002*
Average Torque (Nm)	Concentric	32,76 ± 19,13 (58,39%)	26,37 ± 15,18 (57,57%)	46,17 ± 20,30 (43,98%)	p=0,176
	Eccentric	19,57 ± 6,51 (33,24%)	16,30 ± 4,23 (25,92%)	26,43 ± 4,92 (18,63%)	p=0,993
	Isometric	28,44 ± 19,51 (68,62%)	21,02 ± 8,92 (42,44%)	44,01 ± 26,35 (59,87%)	p=0,588
Peak Torque / Body Weight (%)	Concentric	61,01 ± 30,98 (50,78%)	54,29 ± 28,44 (52,39%)	75,11 ± 32,79 (43,65%)	p=0,006*
	Eccentric	29,08 ± 8,40 (28,87%)	27,50 ± 9,37 (34,08%)	32,39 ± 4,67 (14,41%)	p=0,412
	Isometric	38,05 ± 24,70 (64,91%)	33,49 16,44 (49,10%)	47,63 ± 35,81 (75,19%)	p=0,001*

** indicates significant difference (p<0.05) between male and female participants.*

When comparing the muscle actions with one another, it is evident that the concentric exertions yielded the highest torques, irrespective of the format in which torque was analysed, followed by isometric exertions and finally, the eccentric exertions. Inter-individual variability followed the same trend, with concentric exertions showing the greatest variability and the eccentric exertions the lowest.

The effects of sex on strength expression were varied. For average torque, no significant differences were found between the sexes for any of the muscle actions. Significant sex differences were however found for peak torque for the concentric (p=0.001) and isometric muscle actions (p=0,002), and for the percentage of peak torque to bodyweight during the concentric (p=0,006) and isometric actions (p=001). Neither peak torque, nor percentage of peak torque to bodyweight showed significant differences between the sexes for the eccentric muscle actions (p=0,602 and p=0,412 respectively).

Table vii: Time of day effects on torque variations.

	p-value

Torque	Peak Torque (Nm)	p=0,333
	Average Torque (Nm)	p=0,292
	Peak Torque / Body weight (%)	p=0,389

A comparison of the time-of-day of testing (morning, midday and afternoon) was found to have had no significant effect on all three of the torque variations (peak torque, average peak torque and peak torque to body weight %).

4.3 Inferential Statistics

The purpose of the following analyses was to determine whether any significant differences existed in sEMG amplitude between the different muscle actions, force levels, and whether an interaction effect existed between exertion type and force levels. Maximum sEMG data (mV) and average sEMG data (mV) were used for these comparisons. For the purpose of this study, "maximum EMG" (maxEMG) was defined as the highest EMG activity of the three repetitions, while "average EMG amplitude" (AveEMG) was the average of all three repetitions. Maximum EMG is generally used during EMG studies; however, some studies have made use of average EMG amplitude (Hibbs et al., 2011). All EMG data displayed are the outcome of the root mean square (RMS) calculation. Table viii shows an overview of the p-values when comparing the three repetitions for each condition with one another.

Table viii: Effect of repetition on EMG (RMS) responses (p-values).

Load Level	**Concentric**	**Eccentric**	**Isometric**
0%	0.109	0.656	0.034 *
20%	0.028 *	0.113	0.817
40%	0.035 *	0.473	0.339
60%	< 0.001 *	0.712	0.035 *
80%	0.026 *	0.238	0.003

100%	0.101	0.283	0.382

When comparing the EMG amplitude results for the three repetitions with one another for each experimental condition, the results were varied, with the eccentric exertions showing no significant difference between trials, while the concentric and isometric exertions provided mixed results. A closer assessment of the three repetitions showed that in most cases the first repetition yielded the lowest sEMG amplitude activity, while the second and third repetitions showed similar results to one another. It is for this reason that the highest of the three EMG readings was used for subsequent analyses. Furthermore, Table ix shows that the overall effects of exertion type, force level and their interaction effects were similar between maximum EMG and average EMG amplitude.

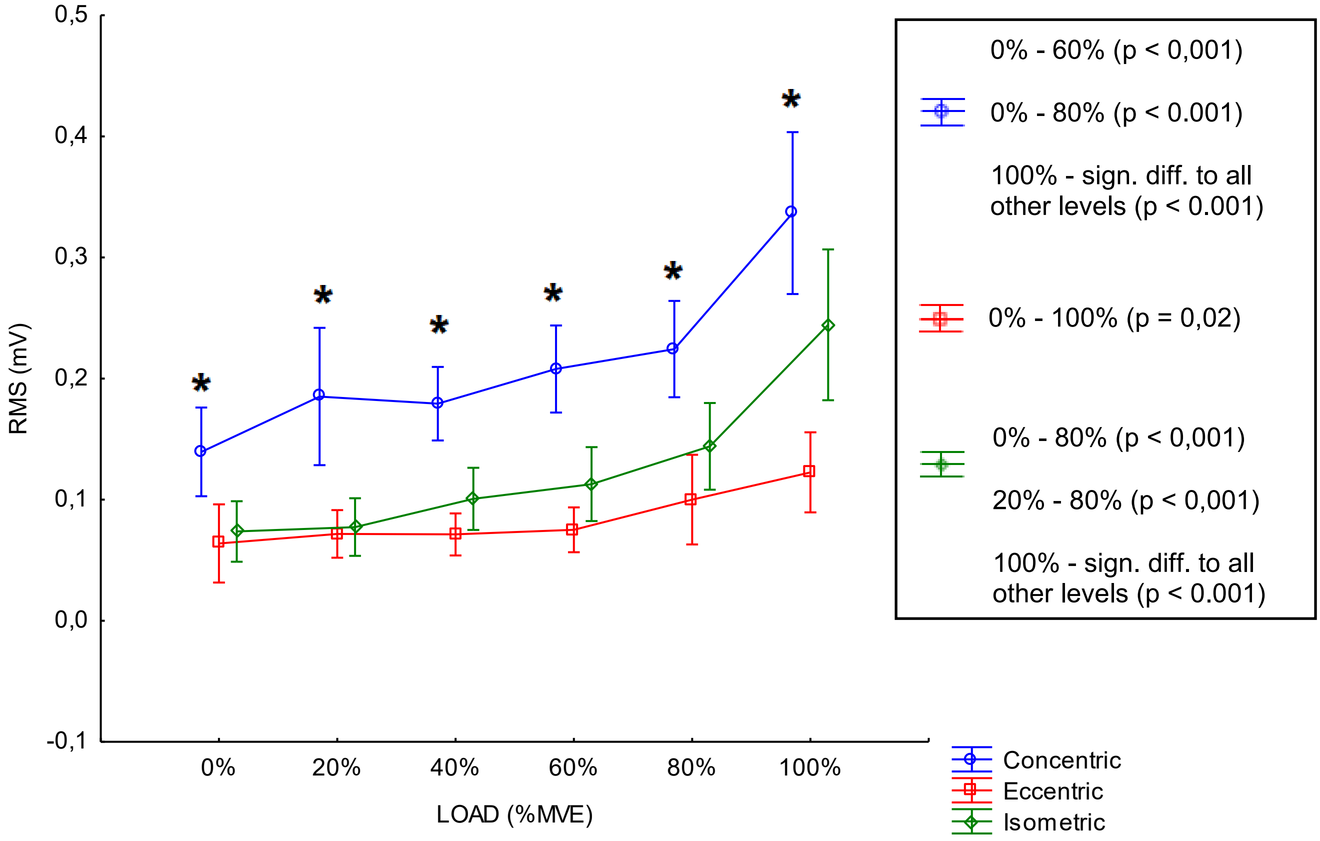
Table ix: The effects of exertion type and force level on maximum and average EMG amplitude, as well as the interaction effect between exertion type and force levels.

	Maximum EMG	**Average EMG amplitude**
Exertion Type	p < 0,001*	p < 0,001*
Force Level	p < 0,001*	p < 0,001*
Exertion Type x Force Level	p < 0,001*	p < 0,001*

The General Linear Model Analyses (as seen in Table ix) indicated that both factors, namely exertion type and force level, had significant effects on the EMG responses. Furthermore, a significant interaction effect was also identified indicating a difference in the trend between factors.

The following sections address the focus of this study and are directly relevant in addressing the hypotheses. This section first looks at the effect of load levels on sEMG, secondly how sEMG is affected by different muscle action type and lastly the interaction of both load levels and muscle action on the sEMG signal produced.

4.3.1 Interaction Effect of Muscle Action and Load



* *Indicates significant differences between the concentric and other exertion types (isometric and eccentric)*

The box on the right shows significant differences between force levels for each muscle exertion when compared within that muscle exertion.

Figure 7: Graph showing the interaction effect of force levels and exertion types on maximum EMG responses.

Figure 7 shows that as the load level increased so did the sEMG activity for all types of muscle exertions, indicating a rise in muscle activity. The sEMG increased significantly for all exertion types between the 0% condition and the 100% condition, as indicated by p<0,001. Additionally, the concentric exertion showed a significant difference between the 0% and 60% conditions (p>0,001), as well as the 0% and 80% conditions (p.0,001). Similarly, the isometric exertion type showed a significant increase in EMG between the 0% and 80%, and the 20% and 80% force levels.

Furthermore, as the load levels increased, so did the inter-individual variability, with the 100% load level having the greatest variability overall.

When comparing exertion types, significantly higher sEMG responses were recorded for the concentric condition compared to the eccentric and isometric conditions at all load levels. No significant differences existed between the RMS recorded for the eccentric and isometric exertions. All exertion types were shown (Table xxiv) to be significantly different from one another at all load level (p<0,001). Concentric exertions had the highest levels of variability (SD = 0,086mV) followed by the isometric and eccentric exertion types (SD = 0,069mV and SD = 0,052 mV respectively). However, inter-individual variability shows higher variability in the eccentric exertion compared to the isometric one at load levels 0% and 80% (Figure 7).

CHAPTER 5: DISCUSSION

This study aimed to contribute to the scientific understanding of the force-EMG relationship by recording muscle activation at different force levels, as well as to determine how this relationship differs between various muscle actions (concentric, eccentric, and isometric). This study differed from most other studies on the force-EMG relationship in that it utilized force levels that were relativized to each muscle action's maximum voluntary exertion (MVE). The outcomes from this study could be beneficial in the workplace to improve work design guidelines, as it contributes to the knowledge of relativizing loads and individual strength capacity, thus resulting in a safer and more productive work environment (Dimitrova et al., 2009; Rantalainen et al., 2012; Village et al., 2005).

To interpret the findings of this study in the clearest manner possible the discussion will read as follows: torque (the importance of torque; the factors affecting torque production), surface electromyography (the effects of muscle action; force levels and their interaction effect on sEMG). Finally, the discussion on the correlations will consider each muscle action separately.

5.1 Strength expression

Torque was the key variable to calculating the force / load levels for each of the sub-maximal experimental conditions. This study considered three variations of torque, namely peak torque, average torque, and peak torque to body weight percentage. The peak torque is the highest torque recorded during the MVE of each muscle action (100% force level) while the average peak torque is the average torque recorded throughout the joints' ROM (Feiring et al., 1990; Simpson et al., 2019; Valovich-mcLeod et al., 2004). Peak and average torque differ from the peak torque to body weight percentage (PT/BW%) as PT/BW% is the only torque variable that is relativized to a demographic variable (Simpson et al., 2019). Of the three torques mentioned, this study made use of peak torque (the highest value obtained from the three repetitions). Peak torque was used with the reasoning that a muscle cannot voluntarily produce more force than what it is capable of, thus making peak torque a true reflection of a muscle’s force producing capabilities (MVE) (Oliveira et al., 2012; Rouffet & Hautier, 2008).

It is well-established that eccentric muscle actions can produce significantly more force, require less energy and have lower sEMG activity than both concentric and isometric muscle actions (Herzog, 2018; Hody et al., 2019; Li, 1996; Padron, 2018; Vasković, 2020). Cress et al., (1992) explains that this may be due to muscle physiology consisting of two parts, the contractile and elastic components. Active lengthening of a muscle makes use of both components whereas shortening and isometric make sole use of the contractile component to generate muscular force (Cress et al., 1992; Herzog, 2018; Hody et al., 2019; Oliveira et al., 2012). The force of an eccentric muscle action is sustained throughout the muscle’s ROM, whereas an isometric muscle action only produces force at the point in its range of motion it is tested at. A concentric action produces the greatest force in the middle of the range of motion (ROM) and tappers off at the ends (Padron, 2018). As each muscle action modulates force differently though the ROM, making use of the average torque would balance the muscle action’s strong and weak points in the ROM due to a sub-maximal maximal load having to be moved. However, as this study practical value was to guide the design of safety regulations, the use of peak toque would represent the upper limit of worker strength expression. Furthermore, peak torque is commonly used for research involving EMG data (De Luca, 1997; Konrad, 2006; Rouffet & Hautier, 2008). Majority of EMG studies make use of the single highest isometric peak torque value to relativize EMG data. As with a one rep maximal test, these peak efforts may not be consistently reproducible unlike the average torque values. The average, perhaps, may have been a better measure to relativize EMG signal during the dynamic exertions as by definition it is more consistent than a maximal value (Lund & Lund, 2018).

Lastly, considering the use of peak torque-to-bodyweight to relativize the loads, this measure of torque is represented as a percentage normalized to participant bodyweight and compared to an estimated goal. This value is more relative and pertinent to functional activity (Biodex Medical Systems Inc., 2012; Simpson et al., 2019). Hody et al., (2019) and Hoppeler & Herzog, (2014) add that untrained individuals are usually unable to fully activate the muscle during maximal eccentric actions when compared to concentric and isometric exertions. This would also mean that for this study training status would have potentially yielded lower torques for the eccentric exertions than for concentric and isometric.

As torque is so important in this study it is beneficial to look at the variables that may affect torque, as ultimately changes in torque will affect the sEMG at the effected force level. The peak torque in this study differed from what was expected based on literature as the eccentric condition produced the least amount of torque whereas the concentric condition had recorded the greatest torque (32,22 Nm and 42,33 Nm respectively). This was also true for both other torque variations in this study. As mentioned above, various studies (Herzog, 2018; Hody et al., 2019; Li, 1996; Padron, 2018; Vasković, 2020) have indicated that the torque should have been the greatest for the eccentric condition and least for the concentric condition. The main reason that eccentric exertions produce more force is due to the protein titin (Hoppeler & Herzog, 2014). Titin acts as a spring during eccentric exertions increasing the lengthening force of the muscle significantly thus increasing the capacity to store stretch-energy (Hoppeler, 2016; Hoppeler & Herzog, 2014). It is the passive stretch energy not present during concentric exertions that allows for greater force and lower EMG activity during eccentric exertions (Hoppeler & Herzog, 2014). A possible explanation of this is the type of eccentric action used (explained in detail below in 5.2.3 as a “maximal eccentric” muscle action would have produced more torque compared to the “submaximal eccentric” action used in this study (Abbott et al., 1952; Herzog, 2018; Hody et al., 2019; Konrad, 2006; Lindstedt et al., 2001). Other extraneous variables that may have affected the peak torque were sex and time-of-day discussed below.

5.1.1 Effect of sex on torque

The difference between males and females in this study become more apparent when comparing muscle actions for each of the torque variations. As a general trend males had the highest torque for all exertion types and all torque parameters in this study; a result that is not unexpected as it supports the findings of many studies such as (Brent et al., 2013; Hill et al., 2016; Minnich, 1987; Pradhan et al., 2020). Brent et al., (2013) found that due to males having greater muscle mass and therefore a higher body mass to females of the same age, they also produced a greater peak torque relative to body mass than females. The results of this study concur with those of (Minnich, 1987) who found that at the isokinetic testing speeds of 3, 30, and 60 degrees per second, males generated significantly greater peak torques than females.

This study found that there were significant differences between males and females in peak torque and the percentage of peak torque to body weight ratio during both the concentric and isometric muscle actions. However, no significant differences were found during average torque for all three exertion types (p=0.176, p=0.993 and p=0.588), or during the eccentric actions of peak torque and peak torque to body weight percentage. For this reason, average peak torque should possibly be considered as a more appropriate means to calculate load levels when the sample group contains mixed sexes.

5.1.2 Effect of time-of-day on torque

The effect of time-of-day on torque production is also a debated topic in the literature. Some studies found differences in peak torque during different times of the day (Gauthier et al., 2001; Grgic et al., 2019), while others found no difference (Küüsmaa-Schildt et al., 2017; Nicolas et al., 2005; Sedliak et al., 2008). According to Mirizio et al., (2020), there are many factors that may cause such diverse results, including hormone levels, body temperature, circadian rhythm, mood state and motivation, to name but a few. However, in the majority of the studies mentioned, participants were not given a choice of time for testing, and in some cases, and testing occurred over multiple sessions. This may have had an impact on factors such as the mood, motivation and so on of the participant and thus a possible explanation for the differences found (Mirizio et al., 2020). The current study attempted to negate these by allowing participants self-selected testing times and testing all experimental conditions within a single session. When considering Table xxvi, one can see that time of day not only had no significant difference on all torque variations, and nether on maximum sEMG and average sEMG at all force levels of each muscle action.

Despite there being no significant differences between the sexes and time-of-day in average torque, this study still made use of peak torque for two reasons. Firstly, as mentioned by Morrissey, (1987) and Simpson et al., (2019), peak torque is the universal standard during isokinetic testing, making this study more comparable to others. Secondly, by relativizing each muscle action to its own maximum exertion, the sEMG should be unaffected by any effects of sex on torque (Hill et al., 2016). Similar to Hill et al., (2016), the results in Table xxv indicate no significant differences between sexes and sEMG recorded across all force levels and muscle actions.

In conclusion, the torque data from this study contradicted the literature as the concentric, not eccentric, condition showed the highest torque for all torque variations. It is generally accepted that the order of torque producing muscle actions are, eccentric, isometric and lastly concentric muscle actions (Clancy & Hogan, 1997; Li, 1996; Oliveira et al., 2012; Simpson et al., 2019). In this study the order was reversed. Possible reasons for this discrepancy are the use of “submaximal eccentric” vs. “maximal eccentric” and the use of peak torque over average torque when using a mixed sex sample group. Possible implications on sEMG are that lower amplitudes may have been recorded with the use of “submaximal eccentric” muscle action and sEMG variability due to the significant sex differences in peak torque.

5.2 Surface Electromyography (sEMG)

This study, as far as possible, has made every attempt to rule out any influence on the force-EMG relationship other than the muscle actions and force levels themselves. The results of the torque values show that sex and time-of-day had no significant effect on the torque levels, and therefore it was therefore concluded that these factors had no effect on the force-EMG relationship in the current study. This section of the discussion will consider the effects of muscle action on sEMG; the effects of force levels on sEMG and the interaction effect of muscle actions and load levels on sEMG.

5.2.1 Effect of muscle action on sEMG

Concentric muscle actions were shown to have the highest sEMG activity followed by isometric exertions, and then eccentric actions, which had the lowest sEMG activity. This was expected as the concentric condition had the greatest maximum torque and therefore greater sub-maximal load levels when compared to other exertion types (De Luca, 1997; Konrad, 2006). Due to the greater load levels, a greater EMG amplitude was expected to move the heavier load. All muscle exertions were significantly different from one another, as indicated by p<0,001. This was true for both the maximum and average testing conditions in this study.

Muscle actions make use of the sliding filament mechanism to produce the necessary force/torque to meet a given task demand (Herzog, 2018; Hody et al., 2019; Li, 1996; Padron, 2018; Vasković, 2020). However, this does not mean that muscle actions are the same when it comes to generating peak torque. This study found that the eccentric muscle action produced the least force followed by the isometric condition and with the concentric conditions producing the largest force. The sEMG amplitudes followed a similar order as force production where the eccentric condition had the lowest sEMG activity followed by the isometric and concentric having the greatest sEMG activity. This was contradictory to literature as it would be expected that the eccentric condition would have produced the greatest force with the least sEMG activity, as this would be in line with current literature (Douglas et al., 2017; Fauth et al., 2010; Grabiner & Owings, 2002; Westing et al., 1991). Figure 8 shows the order that would be expected when considering the force-EMG relationship, as described by Konrad (2006). According to this author, the concentric action produces the greatest EMG amplitude for the least amount of force when compared to other muscle actions, followed closely by the isometric exertion, while the eccentric exertion produces the least EMG activity but highest force.

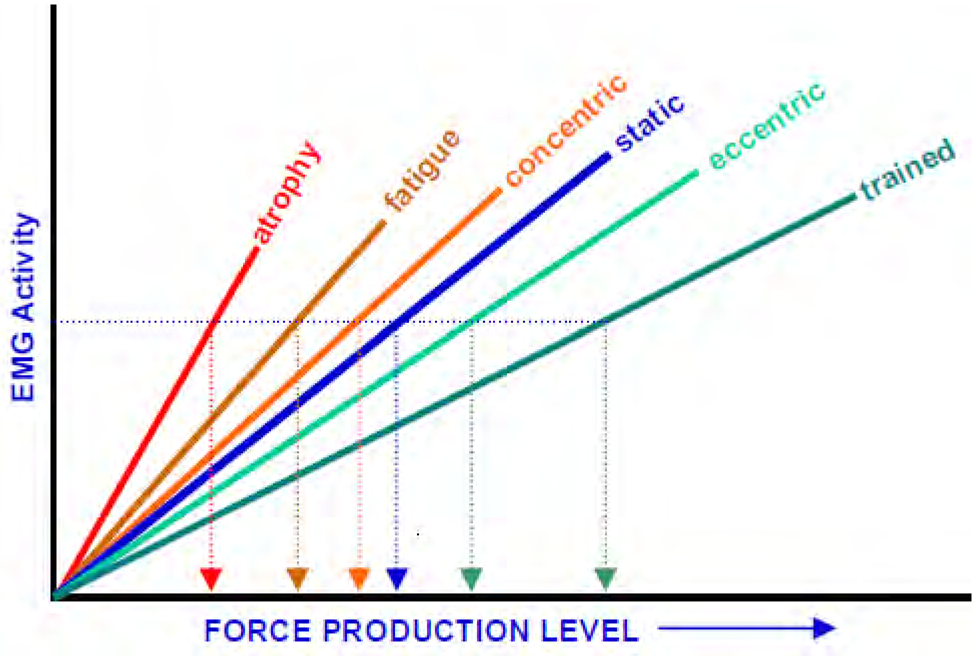


Figure 8: A schematic force-EMG relationship during ramping (increasing force output) muscle exertions. The figure shows the EMG activity during various conditions affecting the force production. Taken from Konrad (2006, p. 44).

It is important at this point to make the distinction between the two forms of eccentric muscle actions.

The first form of eccentric muscle exertion is when a muscle voluntarily lengthens, while in the second form the muscle is forcefully lengthened; referred to as "submaximal eccentric" and "maximal eccentric" muscle actions, respectively. Submaximal eccentric exertions are when the force produced by the muscle is greater than the external load thus the muscle is actively lengthening (Bubbico & Kravitz, 2010; Lindstedt et al., 2001; Potvin & Norman, 1996). Lindstedt et al. (2001) define a maximal eccentric muscle action as one that occurs when the external forces applied to the muscle exceeds the force the muscle can produce to counteract this external force, thus resulting in the forceful lengthening of the muscle-tendon system whilst the muscle is contracting against the external load. It is during this process that the energy developed by the external force is absorbed by the muscle, hence this muscle action is also referred to as "negative work" while a concentric muscle action as "positive work" (Abbott et al., 1952; Hody et al., 2019). Therefore, when comparing eccentric muscle actions with concentric and isometric actions at the same force level; one can expect to see a greater force produced with less motor unit activation as well as less oxygen and energy used to produce this force (Abbott et al., 1952; Hodson-Tole & Wakeling, 2008; Hody et al., 2019). This can be seen in Figure 9 taken from (Lindstedt et al., 2001), where the force to energy cost of eccentric and concentric muscle actions are compared. During eccentric muscle actions, the protein titin is also present in the muscle, adding a passive force enhancement (i.e., a tautness) to the muscle's force-producing capabilities while under load (Bubbico & Kravitz, 2010; Hody et al., 2019; Lindstedt et al., 2001). Hoppeler (2016) added that differences between muscle actions are not only found at the level of the muscle but also at the cortical level. This is indicated by an increased central activation (seen by higher EMG amplitudes) in both maximal concentric and isometric exertions (Hoppeler, 2016). Greater EMG amplitudes are also seen in concentric followed by eccentric exertions due to the increased number of activated muscle fibres (increased motor neuron recruitment and rate coding) (Bubbico & Kravitz, 2010; Hody et al., 2019; Hoppeler, 2016; Lindstedt et al., 2001).

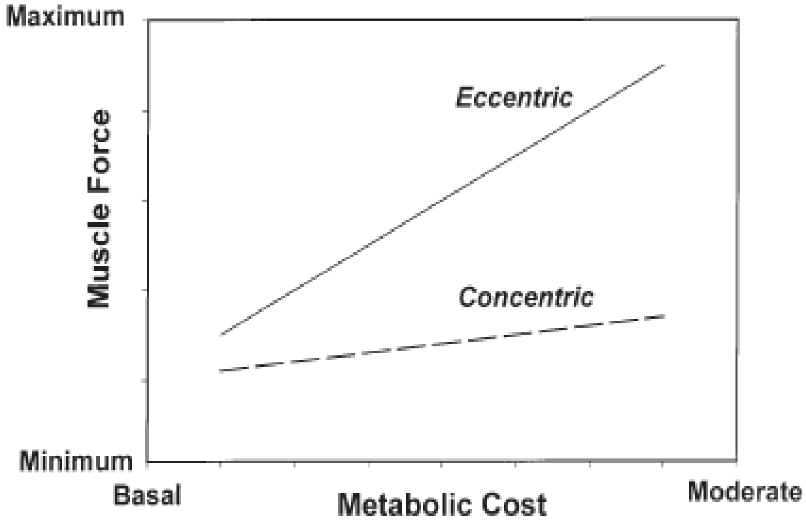


Figure 9: The force production of eccentric and concentric muscle actions vs the energy cost.

When considering the expressions of torque in the current study (peak torque, average torque, and peak torque to body weight percentage), the significantly lower eccentric torque may be because “maximal eccentric” muscle actions are tested at what is referred to as a near or supra-maximal load. This is an external load that is greater than the 1-repetition maximum of that muscle and is known to cause tears in muscle fibres and severe delayed-onset-muscle-soreness known as DOMS (Padron, 2018).

As this study focused on guidelines for the general population and therefore tested members of the general population, the eccentric muscle action in this study was not a “maximal eccentric” muscle action but rather a voluntary eccentric (“submaximal eccentric”) muscle action and therefore results may differ from those in the literature which used maximal eccentric actions.

5.2.2 Effect of force levels on sEMG

As the load increased, so did the sEMG activity in this study. This response was expected because a larger load moved increases the force demand on the muscle, recruiting additional motor units, and changing the firing rates, hence resulting in higher sEMG amplitudes (De Luca, 1985; Enoka & Duchateau, 2017; Heckman & Enoka, 2004; Milner-Brown & Stein, 1975; Søgaard et al., 1996). This study attempted to record sEMG activity that was comparable across exertion types due to the unique procedure of relativizing load levels by using the peak torque specific to each muscle action. This may provide a more accurate reflection of the relationship between force and sEMG when compared to studies that used fixed loads across exertion types and relativized all exertions to a static MVE.

Higher amplitudes of EMG during sub-maximal exertions have also been used to indicate muscle fatigue, as additional fibres are recruited in a fatigued muscle to help maintain and meet the given task demand (Heckman & Enoka, 2004; Hunter et al., 2002). This, however, was most likely not the case in this study, as none of the exertions lasted more than 10 seconds and were separated by an adequate rest period. Furthermore, conditions were permutated, which should have negated the effects of potential muscle fatigue accumulation.

Significant differences were found between the upper and lower force levels in this study, with no significant differences found between consecutive force levels. The 100% force level was significantly higher in sEMG activity when compared to all other force levels, as indicated by a p<0,001. For example, the 80% load level was significantly different to all other force levels except the 60% load level. With the lower force levels, no significant differences were found between 0%, 20% and 40% load levels, with only the 60% load being significantly higher than the no load condition. This was also expected as in most circumstances the force demands during activities of daily living rarely exceed that of 65% in unhealthy and 30% in healthy individuals' one-repetition-maximum (1 RM) exertions (Nieuwenburg-van Tilborg et al., 2014). For example, a study on manual labour resulted in a maximum of 67% MVE recorded on a work simulator (Marshall & Armstrong, 2004). This would mean that during sub-maximal exertions, the change of increments in force would be smaller as the pathways for rate-coding and recruitment patterns are better established to those above 75% and closer to 100% of maximal capacity (Enoka & Duchateau, 2017).

5.2.3 Interaction effect of muscle action & force levels on sEMG

The interaction between muscle actions and force levels deserves special mention because these two factors are not independent of one another when looking at sEMG (Ashnagar, 2013; Chasey, 2015; Clancy & Hogan, 1997; De Luca, 1997; Doheny et al., 2008; Konrad, 2006; Uliam et al., 2012). For all muscle actions, the sEMG activity increased with increasing force levels. The concentric and isometric actions followed a similar trajectory, even though the concentric muscle action showed significantly greater sEMG amplitudes compared with both the isometric and eccentric muscle actions at all force levels. The eccentric muscle action had significantly lower sEMG activity than the concentric and isometric muscle actions, but it did not follow the same trend as the other muscle actions as it increased more gradually with increasing loads, resulting in only a significant difference in muscle activity between the 0% and 100% conditions. This may be due to how the peak eccentric torque was calculated since this study made use of an “submaximal eccentric” muscle action rather than a forced or “maximal eccentric “muscle action. This would then mean that the peak torque used to calculate each force level would be lower than what would be expected from a forced eccentric muscle action (Abbott et al., 1952; Herzog, 2018; Hody et al., 2019; Konrad, 2006; Lindstedt et al., 2001), and the results from this study showed that all eccentric torque measurements were lower. Therefore, the slope of the curve for eccentric muscle actions (in this study) might be so gradual because the muscle may not have been stressed as much as previously thought, as each relativized force level would be less than what the muscle was truly capable of (Bubbico & Kravitz, 2010; Oliveira et al., 2012). Furthermore, as muscles do not work in isolation, it may also have been possible that during the eccentric action, synergistic muscles such as tibialis anterior assisted in the action, thus further decreasing sEMG activity of the soleus muscle since the force demands were not as great in the eccentric condition as they were in the isometric and concentric conditions (Tortora & Derrickson, 2011). Gastrocnemius may have increased sEMG activity for the isometric and concentric conditions as it is a synergistic muscle to the soleus muscle and is superficial to the soleus muscle (Rainoldi et al., 2004; Suzuki et al., 2014; Tortora & Derrickson, 2011; Vandervoort & McComas, 1983). However, as this study assumed the isolation of the soleus muscle from gastrocnemius, tibialis anterior potentially may have had a greater influence on sEMG amplitude as mentioned above (Gollnick et al., 1974; Rainoldi et al., 2004; Tortora & Derrickson, 2011).

This study found there to be a positive force-EMG relationship. It shows that as load levels increased for all muscle actions, the sEMG amplitudes increased in response to the increasing loads. This is in line with literature as it is expected that as the loads increase the muscle activity, modulated by rate coding and muscle recruitment, would also have to increase to match the force demand of the task (Chasey, 2015; Clancy & Hogan, 1997; De Luca, 1997; Konrad, 2006; Kuriki et al., 2012; Shortell, 2001). However, the shape of the relationship curve differed from one exertion type to the next. The eccentric curve appeared more linear, with a shallow gradient compared to the isometric and concentric exertions. This was likely due to the use of the submaximal eccentric maximum that was used to calculate the sub-maximum force levels. Therefore, true eccentric muscular capacity may not be reflected. The concentric and isometric curve differed from the eccentric as they followed a more non-linear trend especially in the lower force levels. This would agree with the literature as the demand on the muscle at the lower force levels increases more gradually than at higher force levels (Day, 2002; De Luca, 1997; Enoka & Duchateau, 2008; Hodson-Tole & Wakeling, 2008).

6 CONCLUSIONS & RECOMMENDATIONS

6.1 Purpose of the Study

Surface electromyography (sEMG) during static muscle actions has been extensively covered in the literature; however, far less attention has been given to research during dynamic muscle actions. While the number of investigations into dynamic muscle actions is steadily increasing, relatively few studies have investigated the force-EMG relationship of static and dynamic muscle actions. Furthermore, the study relativised each muscle action to its own maximal voluntary exertion (MVE), rather than relativising all conditions to a single isometric exertion (MVIE). The aim of this study was therefore two-fold, as it attempted to 1) gain a better understanding of the relationship between force and EMG at different force levels; as well as 2) show how this force-EMG relationship differed between static and dynamic (concentric and eccentric) muscle actions.

6.2 Summary of Procedures

Eighteen experimental conditions were tested, consisting of six load levels (0%, 20%, 40%, 60%, 80% and a full maximum voluntary exertion - 100%) and three muscle actions (isometric, eccentric, concentric exertions), resulting in 18 experimental conditions. 31 participants underwent an experimental protocol during which they were required to activate the soleus muscle by performing three repetitions of ankle plantarflexion (concentric or isometric activation) and dorsiflexion motions (eccentric activation of soleus) for each of the experimental condition. At the start of the experimental testing sessions, all participants had to produce three maximum voluntary exertions (MVE) for each of the three muscle actions on the isokinetic dynamometer. During these MVEs peak torque, average peak torque and peak torque to body weight percentage were recorded. Peak torque was selected to calculate the loads to be moved under the submaximal conditions on a pulley-system, and during which sEMG was recorded using the Biometrics data logger system.

6.3 Summary of Results

The peak torque in this study differed from the literature as peak torque was the lowest for the eccentric condition. The type of eccentric muscle action used in this study may have been the greatest cause followed by sex and time-of-day. As torque and sEMG are linked, the peak torque effected the sEMG amplitude recorded. The recorded sEMG however was not contradictory to literature. Significant differences in sEMG (RMS) occurred between all three types of muscle actions, with the concentric exertions recording the greatest levels of sEMG (RMS) activity, and the eccentric exertions being the lowest, this is in agreement with what would have been expected in the literature.

When comparing the effects of load on EMG, it was found that as the load levels increased, so did the sEMG activity with the 80% and 100% load levels being significantly greater than majority of all other force levels. This was in accordance with the literature as the correlation between force and sEMG is a positive one (Chasey, 2015; Clancy & Hogan, 1997; De Luca, 1997; Konrad, 2006; Kuriki et al., 2012; Uliam et al., 2012).

The interaction effect of muscle action and load showed that, as the load levels increased for all muscle actions, so did the sEMG activity. The greatest sEMG activity was recorded at the 80% and 100% force levels for all three muscle actions as indicated by significant differences with majority of all other force levels and muscle action types. These results showed that the concentric and isometric muscle actions followed similar sEMG increments. The eccentric muscle action results suggest that the type of eccentric muscle action used in the study may have been the reason for lower sEMG data recordings as maximal eccentric torque values should be greater than that of submaximal eccentric. The torque used for eccentric conditions in this study may have been lower than the calculated loads of the other conditions. If this was the case, then the sEMG recorded during the eccentric condition would by default be lower than the other conditions that had higher loads.

6.4 Responses to Hypotheses

Hypothesis 1: The null hypothesis stated that muscle action type would not have an effect on sEMG. This hypothesis was rejected as all three muscle actions were significantly different to one other (p<0,001).

Hypothesis 2: This null hypothesis, which stated that load levels would not affect sEMG activity. This hypothesis was also rejected (p<0,001) More specifically, the following load conditions were significantly different: 100%, 80% (compared with 0%, 20%, 40% & 100%), 60% (compare with 0%), but accepted for 80% (compared with 60%), 60% (compared with 20% & 40%), 40% (compared with 0% & 20%) and 20% (compared with 0%).

Hypothesis 3: The third null hypothesis stated that sEMG is not influenced by an interaction between muscle action and force levels. The null hypothesis was rejected for muscle actions and force levels (p<0,001) as significant correlations with moderate strength were shown for all muscle actions at every load level. This was a positive correlation indicating that as force increased so did the sEMG amplitude matching the task demand.

6.5 Delimitations

The aim was to identify any relationship between force and EMG at different force levels, taking into consideration the possible effects that different muscle actions may have on this relationship. More specifically, this study focused on the effects of muscle action and varying force levels on the force-EMG relationship.

This study consisted of eighteen different test conditions, including three muscle actions and six load levels. Each condition was performed for three repetitions with a sufficiently long rest period between each condition. Therefore, any muscle fatigue that could have developed as a result of preceding protocol was considered to be negligible.

The dependent variables were restricted to one biomechanical and one physiological measure. As a result, the peak torque (biomechanical) and EMG activity (physiological) of the participants' dominant leg soleus muscle was used to observe a potential force-EMG relationship over different muscle actions.

The sample used in this study was delimited to 31 participants from Rhodes University. An uneven number of male (n=10) and female (n=21) was used in the investigation. Participants were drawn from the student population and ranged in age between 18 and 28 years. All participants were considered physically healthy.

Data collection took place in a controlled laboratory setting to control potentially confounding environmental factors such as lighting and temperature. The testing protocol was also conducted in a single 2-hour testing session. While this ensured that various conditions such as climate, time-of-day, electrode placement, etc. remained constant for each individual, it could have resulted in fatigue accumulation in the muscle under investigation. However, to negate this possible effect, sufficient rest periods were allocated between each condition.

Learning effects are often experienced when participants are exposed to numerous repetitions of a given task. To reduce the test order effect and learning effects, protocol conditions were permutated for each participant thus ensuring that the order in which the tasks were performed was randomised.

6.6 Limitations and Recommendations for Future Studies

The sample size used in this study only allowed for one cycle of the permutated matrix. It would be beneficial to increase the sample size as this may allow for at least a second cycle of the permutation, thus potentially allowing for greater statistically significant differences to be observed. Since all participants used in this experimental study were young and healthy university students, the results of this research cannot necessarily be generalised to all populations such as elderly groups, previously injured or working-class individuals. It may be worthwhile considering how the force-EMG relationship is affected by different ages with varying social, educational, and physical demographics to make the research more applicable to the general workforce, particularly in the context of an industrially developing country such as South Africa.

Other limitations of this study were that the ratio of male to female participants was not equal, and the training status of participants was not monitored. Apart from the fact that this may have contributed to the large variance in physical responses between participants and test conditions, it may also have affected the motor control during the submaximal testing protocol. Given that efficient motor pathways and autonomy are developed with practice of movement, it would be worth considering how the force-EMG relationship is affected by participants of a similar training status and body mass.

Dynamic movements of any joint consist of agonist-antagonist movement pairs, as well as synergist muscles. These may also have influenced the EMG recordings during the test protocol particularly during the eccentric muscle actions. If this study were to be conducted again, it would be beneficial to conduct the eccentric muscle action MVE under “maximal eccentric” test protocols as well as monitoring other muscles around the joint being tested. This will aid in determining if the selected muscle has indeed been isolated. This would likely yield a greater torque and therefore potentially greater sEMG activity recordings during the submaximal load levels. Furthermore, a more reliable method to control angular velocity should be added to the study. This would aid in controlling the effects of the force-velocity relationship and thus sEMG amplitude.

The test session was long (approximately two hours) and the given task very monotonous. This could have affected the participant’s motivation, concentration as well as the effort invested at the later stages of the protocol. However, given that experimental conditions were conducted in a randomised order, it was expected that the impact of motivation and concentration on the results would be minimised.

Further considerations should be given to the validity of the methods for submaximal load level determination. It would be beneficial to consider the factors affecting torque and the variations in torque that could be used to calculate all submaximal load levels. These would include variables such as sex, time of day and torque measurement used. This study's results suggest that there is a greater increase in EMG activity specifically at load levels 80% and 100%, and this may be due to the variation of torque selected to calculate loads used.

Lastly, the test apparatus and habituation session could be improved upon. The pully system design could be re-designed to have less natural resistance from the cable. This could be achieved by fitting the system with a pulley equipped with bearings. This will reduce the friction from the pully and allow for a smoother transition between exertions. The system should also be fitted with an external lever arm that would allow the examiner to "re-load" the system before each exertion. This lever arm would allow the researcher to separate the exertions in a controlled manner rather than relying on participant timing. Participants would benefit greatly from more habituation session that allow them to familiarise themselves with the isokinetic dynamotor, pully system and to achieve the desired timing. These improvements would likely also improve inhibition during testing.

6.7 Significance of Findings

The findings from this study suggest that there is indeed a difference between the force-EMG relationship of each of the muscle actions and at the varying submaximal load levels. This therefore means that a static force-EMG relationship should not be inferred onto a dynamic relationship especially when being used to inform safety guidelines in the workplace. The significant differences found between muscle actions at different load levels create concerns of an increased injury risk in the workplace if the current guidelines do not take into consideration that a static safety guideline may not match a dynamic work environment. Therefore, it may be beneficial for future ergonomics studies on tasks demands to include dynamic normalisation, thus potentially increasing safety and productivity in the workplace.

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8 APPENDICES

8.1 Appendix A – Permutation Matrix & Raw sEMG Data

A.1. Permutation Matrix

Randomizing 18 conditions results in a very large number of combinations. Therefore, the five force levels and the three exertion types were permutated independently (Table x and Table xi) and were then combined in Table xii.

Table x: Permutation of exertion types.

Permutated order of Exertions			
A)	Con	Ecc	Iso
B)	Con	Iso	Ecc
C)	Ecc	Con	Iso
D)	Ecc	Iso	Con
E)	Iso	Con	Ecc
F)	Iso	Ecc	Con

Where: Con = concentric exertion
Ecc = eccentric exertion
Iso = isometric exertion

Table xi: Permutated order of force levels.

Permutated order of Force levels					
i)	0%	20%	40%	60%	80%
ii)	40%	80%	20%	0%	60%
iii)	20%	60%	80%	40%	20%
iv)	60%	40%	0%	80%	0%

v)	80%	0%	60%	20%	40%

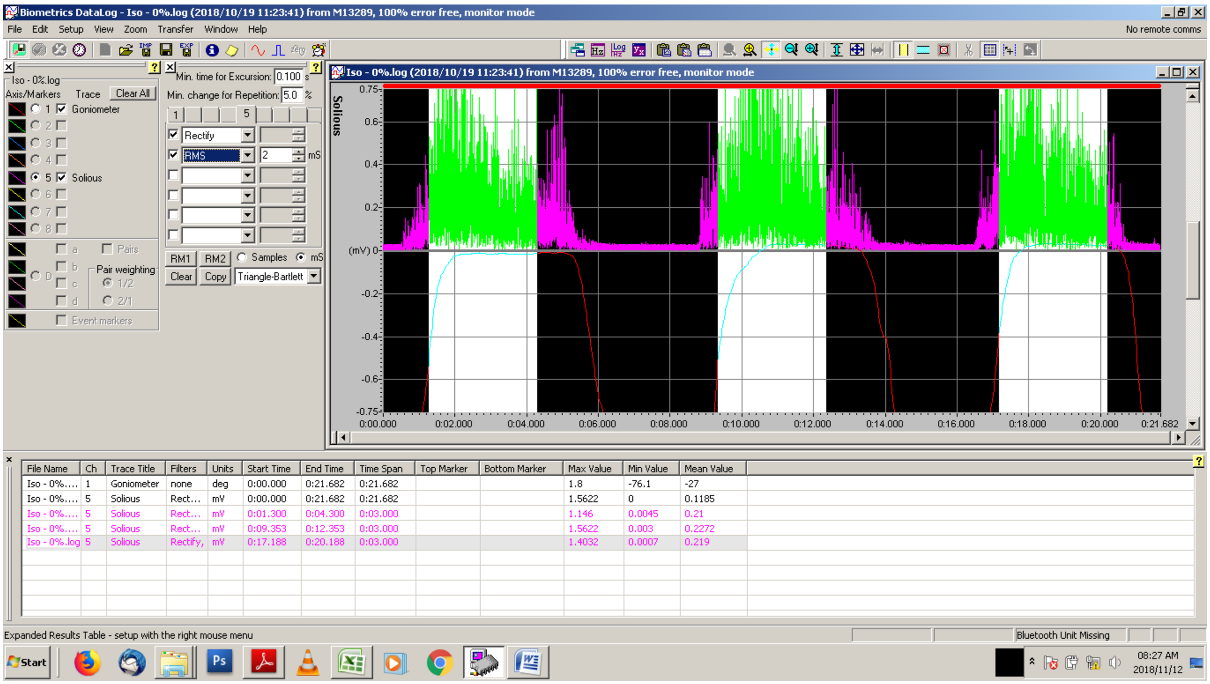
Where: 0%, 20%, 40%, 60%, 80% and 100% reflect the force levels tested as a percentage of maximum voluntary exertion (%MVE)

Table xii: Combination of table xi and table xii showing the order of participants.

Force levels	**Exertions**					
	A)	**B)**	**C)**	**D)**	**E)**	**F)**
i)	P1	P2	P3	P4	P5	P6
ii)	P7	P8	P9	P10	P11	P12
iii)	P13	P14	P15	P16	P17	P18
iv)	P19	P20	P21	P22	P23	P24
v)	P25	P26	P27	P28	P29	P30

Where: P refers to participant.

A.2. Raw sEMG Data of P02 at force levels 0% to 100%, isometric exertion



Biometrics DataLog - Iso - 0%.log (2018/10/19 11:23:41) from M13289, 100% error free, monitor mode

Iso - 0%.log (2018/10/19 11:23:41) from M13289, 100% error free, monitor mode

Min. time for Excursion: 0.100 s

Min. change for Repetition: 5.0 %

☑ Rectify

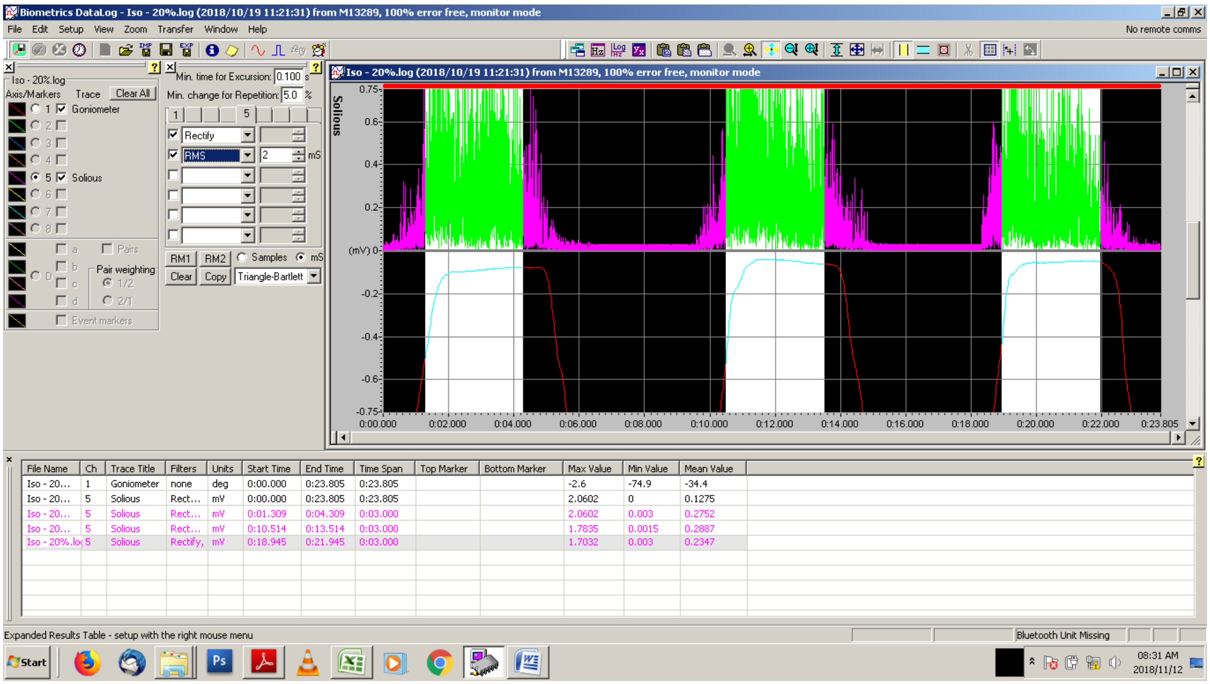
☑ RMS 2 mS

Triangle-Bartlett

File Name	Ch	Trace Title	Filters	Units	Start Time	End Time	Time Span	Top Marker	Bottom Marker	Max Value	Min Value	Mean Value
Iso - 0%....	1	Goniometer	none	deg	0:00.000	0:21.682	0:21.682			1.8	-76.1	-27
Iso - 0%....	5	Solious	Rect...	mV	0:00.000	0:21.682	0:21.682			1.5622	0	0.1185
Iso - 0%....	5	Solious	Rect...	mV	0:01.300	0:04.300	0:03.000			1.146	0.0045	0.21
Iso - 0%....	5	Solious	Rect...	mV	0:09.353	0:12.353	0:03.000			1.5622	0.003	0.2272
Iso - 0%.log	5	Solious	Rectify,	mV	0:17.188	0:20.188	0:03.000			1.4032	0.0007	0.219

Expanded Results Table - setup with the right mouse menu

Figure 10: Raw sEMG data of P02 at 0% force level isometric exertion.



Biometrics DataLog - Iso - 20%.log (2018/10/19 11:21:31) from M13289, 100% error free, monitor mode

Iso - 20%.log (2018/10/19 11:21:31) from M13289, 100% error free, monitor mode

Min. time for Excursion: 0.100 s

Min. change for Repetition: 5.0 %

☑ Rectify

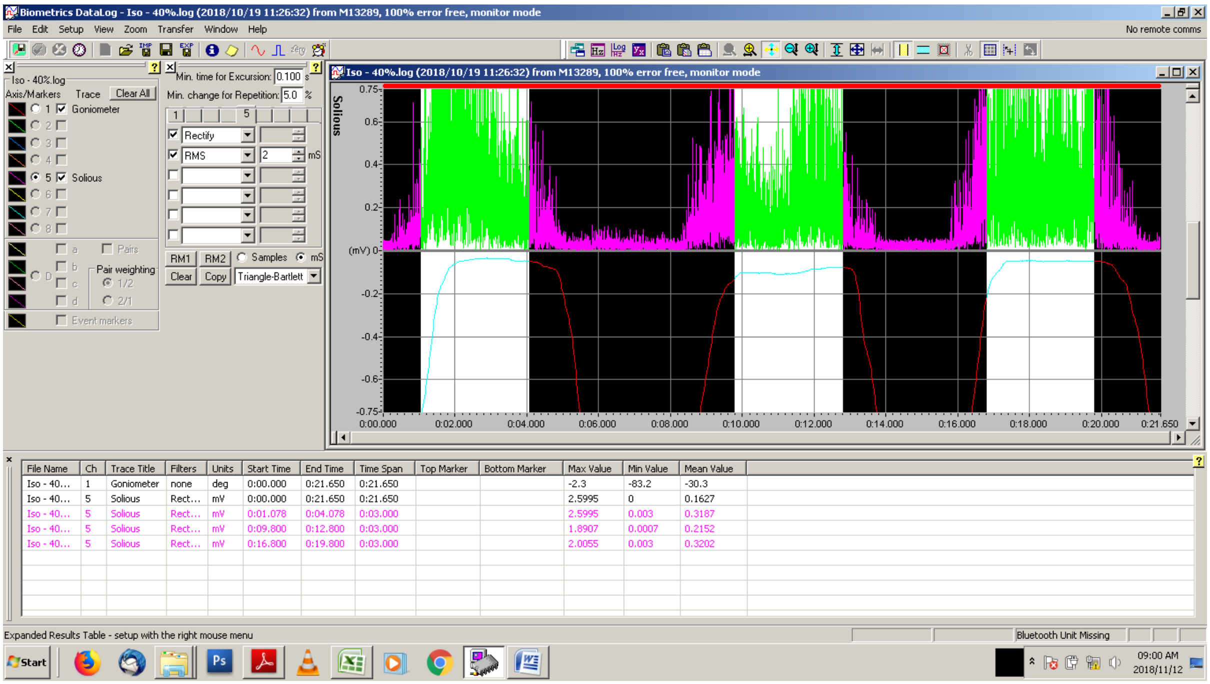
☑ RMS 2 mS

Triangle-Bartlett

File Name	Ch	Trace Title	Filters	Units	Start Time	End Time	Time Span	Top Marker	Bottom Marker	Max Value	Min Value	Mean Value
Iso - 20...	1	Goniometer	none	deg	0:00.000	0:23.805	0:23.805			-2.6	-74.9	-34.4
Iso - 20...	5	Solious	Rect...	mV	0:00.000	0:23.805	0:23.805			2.0602	0	0.1275
Iso - 20...	5	Solious	Rect...	mV	0:01.309	0:04.309	0:03.000			2.0602	0.003	0.2752
Iso - 20...	5	Solious	Rect...	mV	0:10.514	0:13.514	0:03.000			1.7835	0.0015	0.2887
Iso - 20%.lo	5	Solious	Rectify,	mV	0:18.945	0:21.945	0:03.000			1.7032	0.003	0.2347

Expanded Results Table - setup with the right mouse menu

Figure 11: Raw sEMG data of P02 at 20% force level isometric exertion.


Biometrics DataLog - Iso - 40%.log (2018/10/19 11:26:32) from M13289, 100% error free, monitor mode

Min. time for Excursion: 0.100 s

Min. change for Repetition: 5.0 %

☑ Rectify

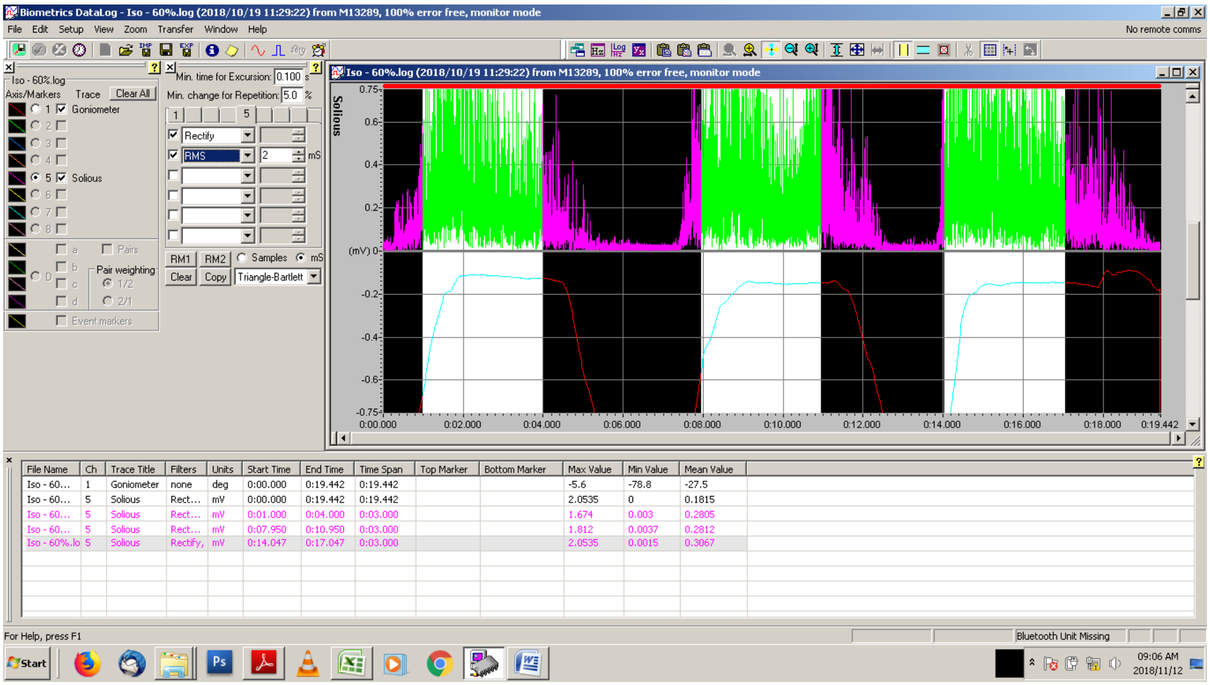
☑ RMS 2 mS

Triangle-Bartlett

File Name	Ch	Trace Title	Filters	Units	Start Time	End Time	Time Span	Top Marker	Bottom Marker	Max Value	Min Value	Mean Value
Iso - 40…	1	Goniometer	none	deg	0:00.000	0:21.650	0:21.650			-2.3	-83.2	-30.3
Iso - 40…	5	Solious	Rect…	mV	0:00.000	0:21.650	0:21.650			2.5995	0	0.1627
Iso - 40…	5	Solious	Rect…	mV	0:01.078	0:04.078	0:03.000			2.5995	0.003	0.3187
Iso - 40…	5	Solious	Rect…	mV	0:09.800	0:12.800	0:03.000			1.8907	0.0007	0.2152
Iso - 40…	5	Solious	Rect…	mV	0:16.800	0:19.800	0:03.000			2.0055	0.003	0.3202

Expanded Results Table - setup with the right mouse menu

Figure 12: Raw sEMG data of P02 at 40% force level isometric exertion.


Biometrics DataLog - Iso - 60%.log (2018/10/19 11:29:22) from M13289, 100% error free, monitor mode

Min. time for Excursion: 0.100 s

Min. change for Repetition: 5.0 %

☑ Rectify

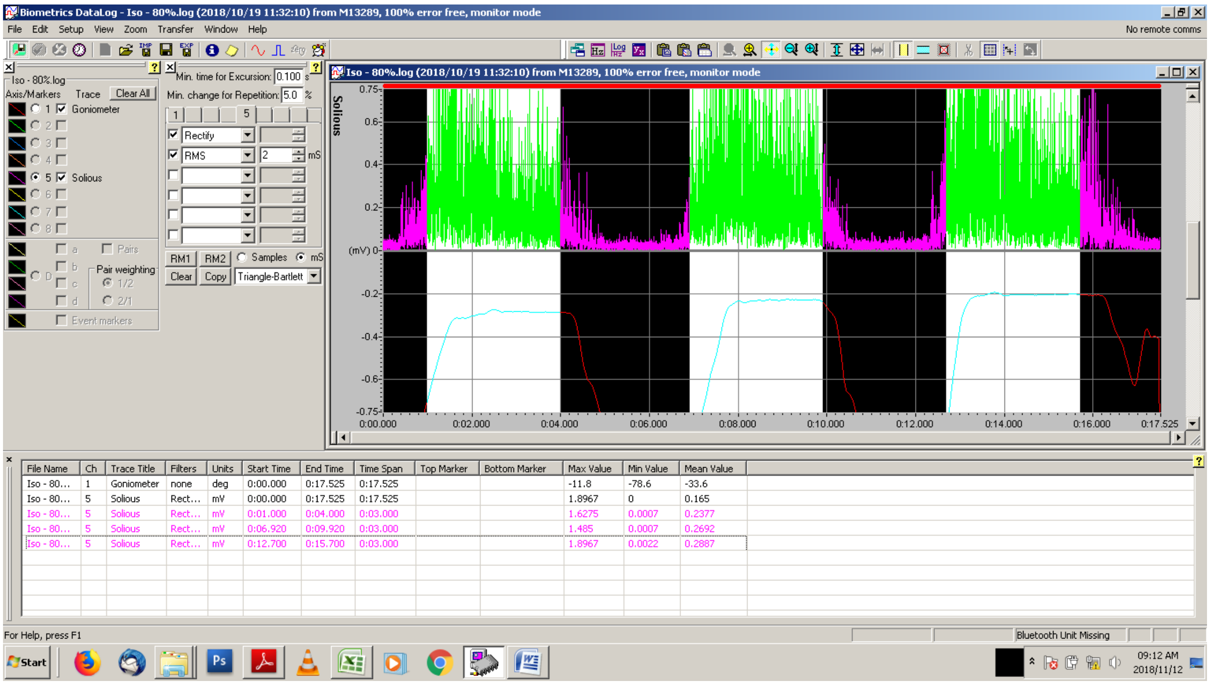
☑ RMS 2 mS

Triangle-Bartlett

File Name	Ch	Trace Title	Filters	Units	Start Time	End Time	Time Span	Top Marker	Bottom Marker	Max Value	Min Value	Mean Value
Iso - 60…	1	Goniometer	none	deg	0:00.000	0:19.442	0:19.442			-5.6	-78.8	-27.5
Iso - 60…	5	Solious	Rect…	mV	0:00.000	0:19.442	0:19.442			2.0535	0	0.1815
Iso - 60…	5	Solious	Rect…	mV	0:01.000	0:04.000	0:03.000			1.674	0.003	0.2805
Iso - 60…	5	Solious	Rect…	mV	0:07.950	0:10.950	0:03.000			1.812	0.0037	0.2812
Iso - 60%.lo	5	Solious	Rectify,	mV	0:14.047	0:17.047	0:03.000			2.0535	0.0015	0.3067

For Help, press F1

Figure 13: Raw sEMG data of P02 at 60% force level isometric exertion.



Biometrics DataLog - Iso - 80%.log (2018/10/19 11:32:10) from M13289, 100% error free, monitor mode

Iso - 80% log

Min. time for Excursion: 0.100 s

Min. change for Repetition: 5.0 %

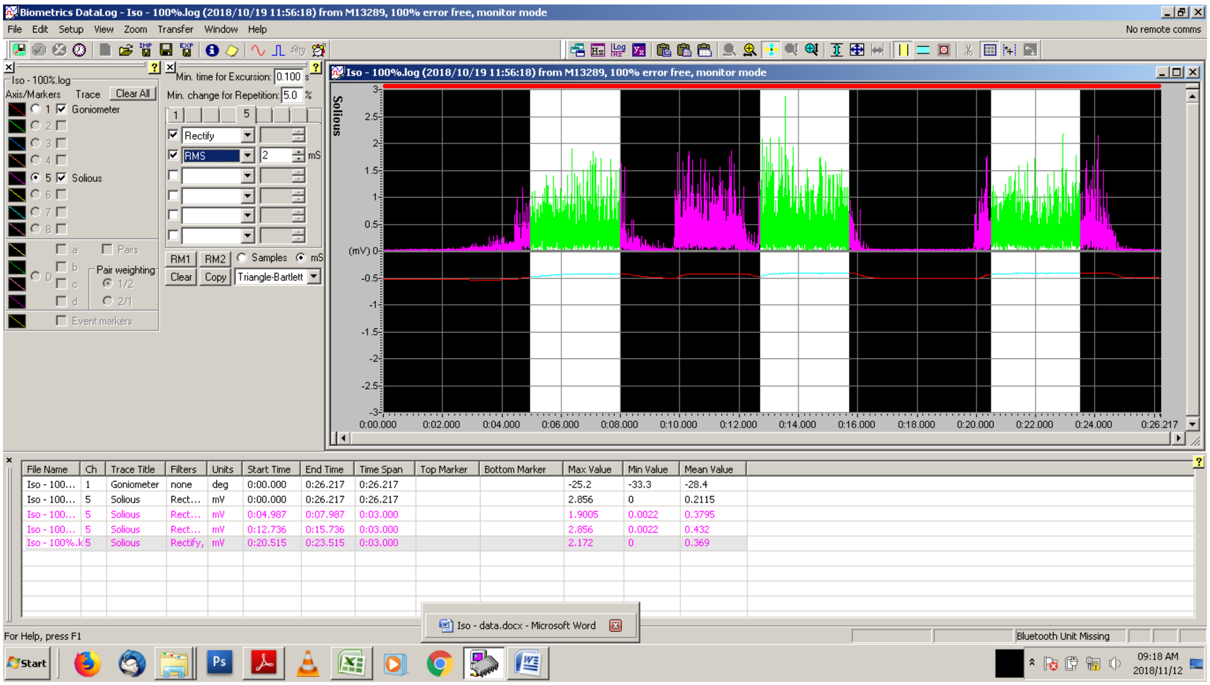
☑ Rectify

☑ RMS 2 mS

Iso - 80%.log (2018/10/19 11:32:10) from M13289, 100% error free, monitor mode

File Name	Ch	Trace Title	Filters	Units	Start Time	End Time	Time Span	Top Marker	Bottom Marker	Max Value	Min Value	Mean Value
Iso - 80…	1	Goniometer	none	deg	0:00.000	0:17.525	0:17.525			-11.8	-78.6	-33.6
Iso - 80…	5	Solious	Rect…	mV	0:00.000	0:17.525	0:17.525			1.8967	0	0.165
Iso - 80…	5	Solious	Rect…	mV	0:01.000	0:04.000	0:03.000			1.6275	0.0007	0.2377
Iso - 80…	5	Solious	Rect…	mV	0:06.920	0:09.920	0:03.000			1.485	0.0007	0.2692
Iso - 80…	5	Solious	Rect…	mV	0:12.700	0:15.700	0:03.000			1.8967	0.0022	0.2887

Figure 14: Raw sEMG data of P02 at 80% force level isometric exertion.



Biometrics DataLog - Iso - 100%.log (2018/10/19 11:56:18) from M13289, 100% error free, monitor mode

Iso - 100% log

Min. time for Excursion: 0.100 s

Min. change for Repetition: 5.0 %

☑ Rectify

☑ RMS 2 mS

Iso - 100%.log (2018/10/19 11:56:18) from M13289, 100% error free, monitor mode

File Name	Ch	Trace Title	Filters	Units	Start Time	End Time	Time Span	Top Marker	Bottom Marker	Max Value	Min Value	Mean Value
Iso - 100…	1	Goniometer	none	deg	0:00.000	0:26.217	0:26.217			-25.2	-33.3	-28.4
Iso - 100…	5	Solious	Rect…	mV	0:00.000	0:26.217	0:26.217			2.856	0	0.2115
Iso - 100…	5	Solious	Rect…	mV	0:04.987	0:07.987	0:03.000			1.9005	0.0022	0.3795
Iso - 100…	5	Solious	Rect…	mV	0:12.736	0:15.736	0:03.000			2.856	0.0022	0.432
Iso - 100%.l	5	Solious	Rectify,	mV	0:20.515	0:23.515	0:03.000			2.172	0	0.369

Figure 15: Raw sEMG data of P02 at 100% force level isometric exertion.

8.3 Appendix B – Ethical Considerations

B.1. Ethical Approval

RHODES UNIVERSITY

HUMAN KINETICS & ERGONOMICS
Tel: +27 (0)46 6038468
Fax: +27 (0)46 6038934
Email: m.mattison@ru.ac.za

10 September 2018

Wesley Koekemoer – g13k3163@campus.ru.ac.za
Miriam Mattison – m.mattison@ru.ac.za

Dear Wesley and Miriam,

Final Ethical Clearance – Application HKE-2018-15

Your application for ethical clearance for the study titled "An investigation into the force-EMG relationship for static and dynamic exertions at varying submaximal loads" (reference number HKE-2018-15) has been by the HKE Ethics Committee. This clearance is valid for a period of 1 year from the date of this letter.

Please note that any significant changes made to the study and procedures need to be communicated to the HKE Ethics Committee (this includes changes in investigators), and another full review may be requested.

Upon completion of your study, please submit a short report indicating when and whether the research was conducted successfully, if any aspects could not be completed, or if any problems arose that the HKE Ethics committee should be aware of.

Sincerely,

Dr J. P. Davy
Acting Chair - 2018 HKE Ethics
Department of Human Kinetics and Ergonomics
Rhodes University; Grahamstown
Tel: + 27-46-603 7369
Cell: +27-722260430

B.2. Gatekeeper Permission

RHODES UNIVERSITY
Grahamstown • 6140 • South Africa

OFFICE OF THE REGISTRAR
P O Box 94, Grahamstown, 6140
E-mail: registrar@ru.ac.za
Tel: +27 (0)46 603 8101
Fax: +27 (0)46 603 8127

Wesley Agostinho Koekemoer
G13K3163
Department of Human Kinetics and Ergonomics

5 September 2018

Dear Mr Koekemoer

Name of research proposal: "An investigation into the force-EMG relationship for static and dynamic exertions at varying submaximal loads"

This serves to confirm that you have been granted permission to conduct your proposed research at Rhodes University as requested.

Yours sincerely

Dr Adele Moodly
REGISTRAR

8.4 Appendix C – Information and Consent Letters

C.1. Information to Participants

RHODES UNIVERSITY
Grahamstown • 6140 • South Africa

Dear Participant,

Thank you for your interest in participating in my Masters research study:

“An investigation into the force-EMG relationship for static and dynamic exertions at varying submaximal loads”

<u>Background to the Study and Purpose:</u>

The value of this study is to add to the limited knowledge that currently exists in EMG research during dynamic muscle actions. This study aims to investigate whether a relationship exists between the force a muscle can produce and the electrical activity within a muscle stimulating the muscle to contract. This electrical activity is recorded by a method called electromyography (EMG). Understanding this relationship between EMG and the force produced during static exertions (i.e. muscle actions maintaining a stable position) and dynamic exertions (i.e. muscle actions that result in movement) will allow for better work guidelines to be developed and hopefully lead to a safer and more efficient work environment.

<u>Procedures:</u>

This study will require you to commit to two sessions in the Human Kinetics and Ergonomics Department. In the first session, which is an information and habituation session, and which will last about 45 minutes, the testing procedures will be explained to you and the equipment demonstrated. You will also be given the opportunity to ask any question to clarify any uncertainties. After this, should you wish to be involved in my study, you will be required to provide written consent by filling out a consent form and a Physical Activity Readiness questionnaire to make sure you don’t have any underlying conditions that may be aggravated by this experiment. Please know that this consent form does not, by any means, bind you to the study and you are free at to leave any point during the study without any negative consequences to you. After the consent form has been signed, your basic demographic data will be captured such as sex, age, weight, height, and exercise status. You will then be given time to familiarize yourself with the equipment and the procedures through practice with the equipment.

During the testing session (session 2), which will last about 2 hours, you will first be reminded of the study requirements, after which you be required to perform a gentle warm-up by pedalling for 5 minutes on exercise bicycle set to the lowest resistance. A small area on your calf muscle will be shaved, removing excess hair, to allow better contact of the EMG electrodes, which will record your muscle activity. Your maximum voluntary exertion (MVE) for the ankle will be recorded using the isokinetic dynamometer. As practiced during the habituation session, you will be strapped into the seat of the isokinetic dynamometer (to stabilize your body), while the ankle will move through its full range of motion at your maximum voluntary force. This maximal force is needed to calculate the sub-maximal weights used for the testing conditions, according to your force producing capabilities. You will then be asked to perform sub-maximal muscle actions at each of the following load conditions: 0%, 20%, 40%, 60% and 80% of the MVE for each of the following three contraction types (dynamic, concentric and static). The contraction types and the relative load will be conducted in a randomized order. Each muscle action will last 2 seconds and will be repeated three times for each condition. You will be given a sufficient rest break between conditions to avoid fatigue. Once you have completed all 18 conditions, the testing session has been completed.

Risks and Benefits

This study includes a risk that you may injure yourself (such as muscle strain) by exerting force to counter the external loads. However, since most loads will be sub-maximal and relativised to your own maximum strength, this risk is minimal. There is also the risk of this happening when conducting a maximal test, but since it is a voluntary test, the risk of overexertion is minimal. There is also the risk of minor cuts from the razor; however, a new razor will be used for each participant and in the unlikely case of a cut, the area will be cleaned and protected with a plaster to prevent any infections. To prevent any psychological risks such as embarrassment, all testing will be conducted on a one-on-one basis.

The benefit for you is that you will get exposure to a postgraduate testing procedure that will help you decide whether to pursue a postgraduate degree in HKE. You will be familiar with some of the equipment offered by the Human Kinetics and Ergonomics Department and receive exposure to this equipment. The results of this study may be beneficial to this field of study, and knowing you are part of that may be satisfactory.

Privacy, Anonymity and Confidentiality

Your personal information and data recorded will be kept strictly confidential by using a coding system and your email address will only be accessible by the primary researcher with the purpose of providing you with feedback on the study once it has been completed. Your personal details will be deleted upon completion of this study and cannot be linked with the data collected. Please note that participation in this study is completely voluntary and you have the right to withdraw your participation at any point without negative consequences.

If you decide to take part in the study, I will kindly as you to not smoke, drink alcohol or caffeine rich drinks 12 hours before testing, as well as avoiding any strenuous exercise two days before your testing session, as this may affect the results ether by improving or decreasing your muscle’s natural ability to produce force. Should you not feel well on the day of testing, kindly let me know as soon as possible.

Thank you for showing your interest and agreeing to participate in the study. Please do not hesitate to contact me if you have any further questions.

Yours sincerely,

Wesley Koekemoer
G13K3163@campus.ru.ac.za
Cell number: 084 055 6167

Supervisor details:
Mrs. Miriam Mattison (M.Mattison@ru.ac.za)
Cell number: 082 319 4626
Office number: 046 603 8468

C.2. Consent Form

RHODES UNIVERSITY
Grahamstown • 6140 • South Africa
Human Kinetics and Ergonomics Department

INFORMED CONSENT AND INDEMNITY

For research involving human participants

I, …………………………………………… have been fully informed of the research project entitled; "An investigation into the force-EMG relationship for static and dynamic exertions at varying submaximal loads".

I have read the information sheet and understand the testing procedure that will take place. All testing procedures associated risks and the benefits from partaking in this study have been verbally explained to me as well as in writing [*letter of information appended to this document*]. I have had ample opportunity to ask questions and to clarify any concerns or misunderstandings. I am satisfied that these have been answered satisfactorily. I understand that all data collected for publication purposes will be kept anonymous and all information gained in this regard will be treated confidentially. Furthermore, I consent to photographs, knowing that these will be altered to ensure my anonymity. I understand that I can withdraw from the study at any point, irrespective of external influences placed on me by the researcher.

In agreeing to participate in this research study I waive any legal recourse against the researchers from the Department of Human Kinetics and Ergonomics (HKE), Rhodes University, from claims resulting from personal injuries sustained whilst participating in the above mentioned research. I am aware and fully understand that the Department of Human Kinetics and Ergonomics is not responsible for any injuries due to my personal negligence and non-compliance with instructions. This waiver shall be binding upon my heirs and personal representatives.

I have read and understood the above information, as well as the information provided in the letter accompanying this form. I therefore consent to voluntarily participate in this research project.

PARTICIPANT PROVIDING CONSENT:

____________________	____________________	____________________
(Print Name)	(Signed)	(Date)

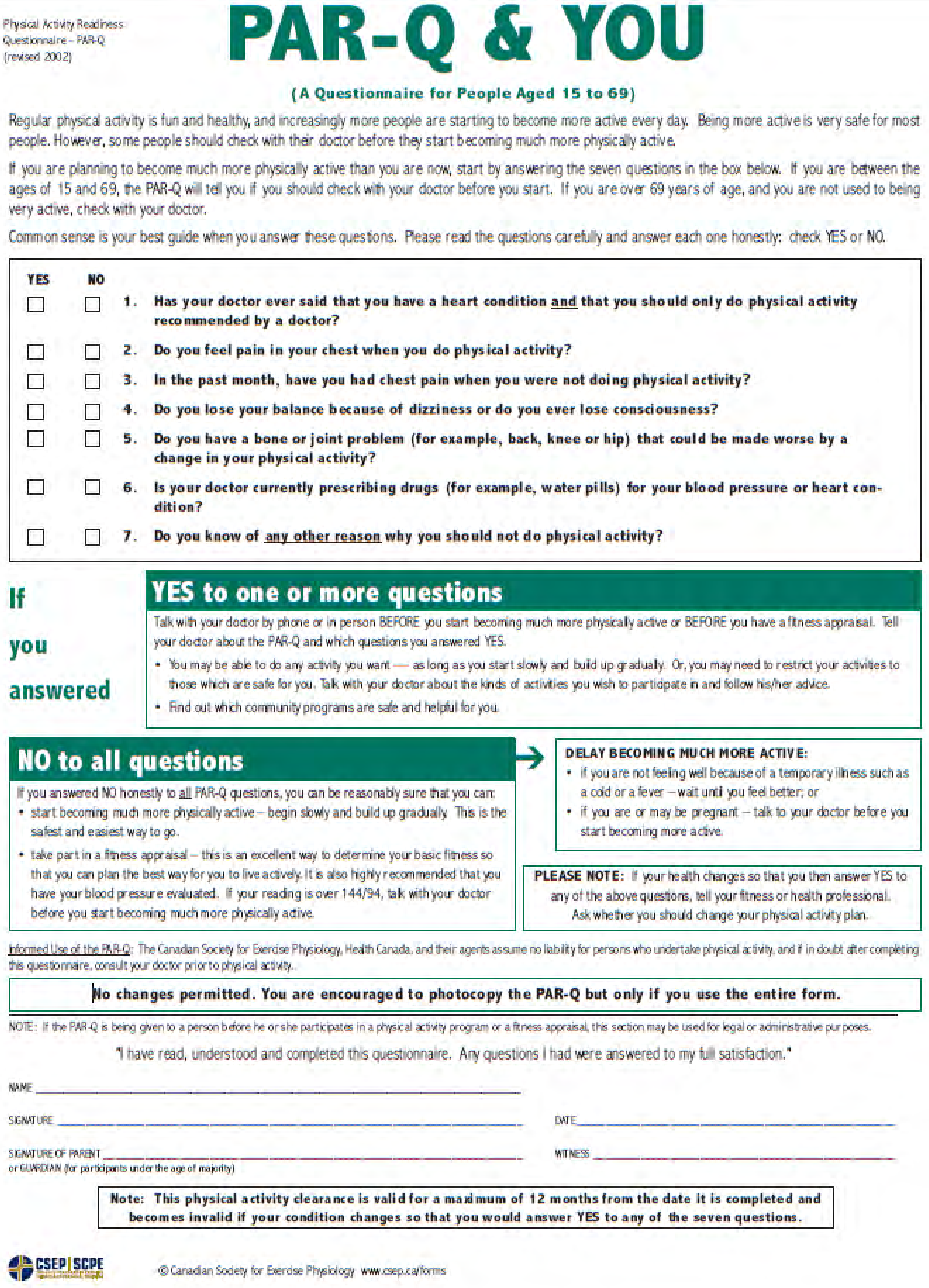
WITNESS:

____________________	____________________	____________________
(Print Name)	(Signed)	(Date)

PRINCIPAL RESEARCHER:

____________________	____________________	____________________
(Print Name)	(Signed)	(Date)

C.3. Physical Activity Readiness Questionnaire (PAR-Q)



Physical Activity Readiness
Questionnaire - PAR-Q
(revised 2002)

PAR-Q & YOU

(A Questionnaire for People Aged 15 to 69)

Regular physical activity is fun and healthy, and increasingly more people are starting to become more active every day. Being more active is very safe for most people. However, some people should check with their doctor before they start becoming much more physically active.

If you are planning to become much more physically active than you are now, start by answering the seven questions in the box below. If you are between the ages of 15 and 69, the PAR-Q will tell you if you should check with your doctor before you start. If you are over 69 years of age, and you are not used to being very active, check with your doctor.

Common sense is your best guide when you answer these questions. Please read the questions carefully and answer each one honestly: check YES or NO.

YES	NO		
☐	☐	1.	**Has your doctor ever said that you have a heart condition <u>and</u> that you should only do physical activity recommended by a doctor?**
☐	☐	2.	**Do you feel pain in your chest when you do physical activity?**
☐	☐	3.	**In the past month, have you had chest pain when you were not doing physical activity?**
☐	☐	4.	**Do you lose your balance because of dizziness or do you ever lose consciousness?**
☐	☐	5.	**Do you have a bone or joint problem (for example, back, knee or hip) that could be made worse by a change in your physical activity?**
☐	☐	6.	**Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?**
☐	☐	7.	**Do you know of <u>any other reason</u> why you should not do physical activity?**

If you answered

YES to one or more questions

Talk with your doctor by phone or in person BEFORE you start becoming much more physically active or BEFORE you have a fitness appraisal. Tell your doctor about the PAR-Q and which questions you answered YES.

- You may be able to do any activity you want — as long as you start slowly and build up gradually. Or, you may need to restrict your activities to those which are safe for you. Talk with your doctor about the kinds of activities you wish to participate in and follow his/her advice.
- Find out which community programs are safe and helpful for you.

NO to all questions

If you answered NO honestly to <u>all</u> PAR-Q questions, you can be reasonably sure that you can:

- start becoming much more physically active – begin slowly and build up gradually. This is the safest and easiest way to go.
- take part in a fitness appraisal – this is an excellent way to determine your basic fitness so that you can plan the best way for you to live actively. It is also highly recommended that you have your blood pressure evaluated. If your reading is over 144/94, talk with your doctor before you start becoming much more physically active.

DELAY BECOMING MUCH MORE ACTIVE:

- if you are not feeling well because of a temporary illness such as a cold or a fever – wait until you feel better; or
- if you are or may be pregnant – talk to your doctor before you start becoming more active.

PLEASE NOTE: If your health changes so that you then answer YES to any of the above questions, tell your fitness or health professional. Ask whether you should change your physical activity plan.

<u>Informed Use of the PAR-Q</u>: The Canadian Society for Exercise Physiology, Health Canada, and their agents assume no liability for persons who undertake physical activity, and if in doubt after completing this questionnaire, consult your doctor prior to physical activity.

No changes permitted. You are encouraged to photocopy the PAR-Q but only if you use the entire form.

NOTE: If the PAR-Q is being given to a person before he or she participates in a physical activity program or a fitness appraisal, this section may be used for legal or administrative purposes.

"I have read, understood and completed this questionnaire. Any questions I had were answered to my full satisfaction."

NAME ____________________

SIGNATURE ____________________ DATE ____________________

SIGNATURE OF PARENT ____________________ WITNESS ____________________
or GUARDIAN (for participants under the age of majority)

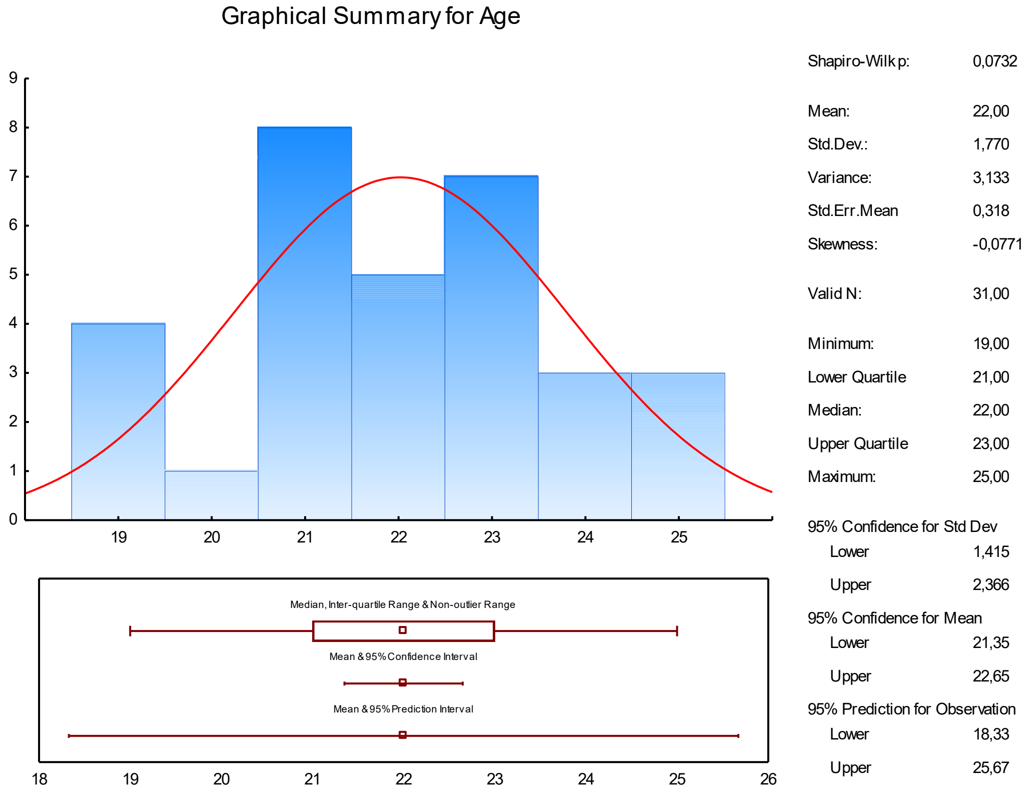
Note: This physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if your condition changes so that you would answer YES to any of the seven questions.

8.5 Appendix D – Statistical Tables

D.1. Outliers and Normality Testing

D.1.1. Basic Anthropometric and Demographic Data

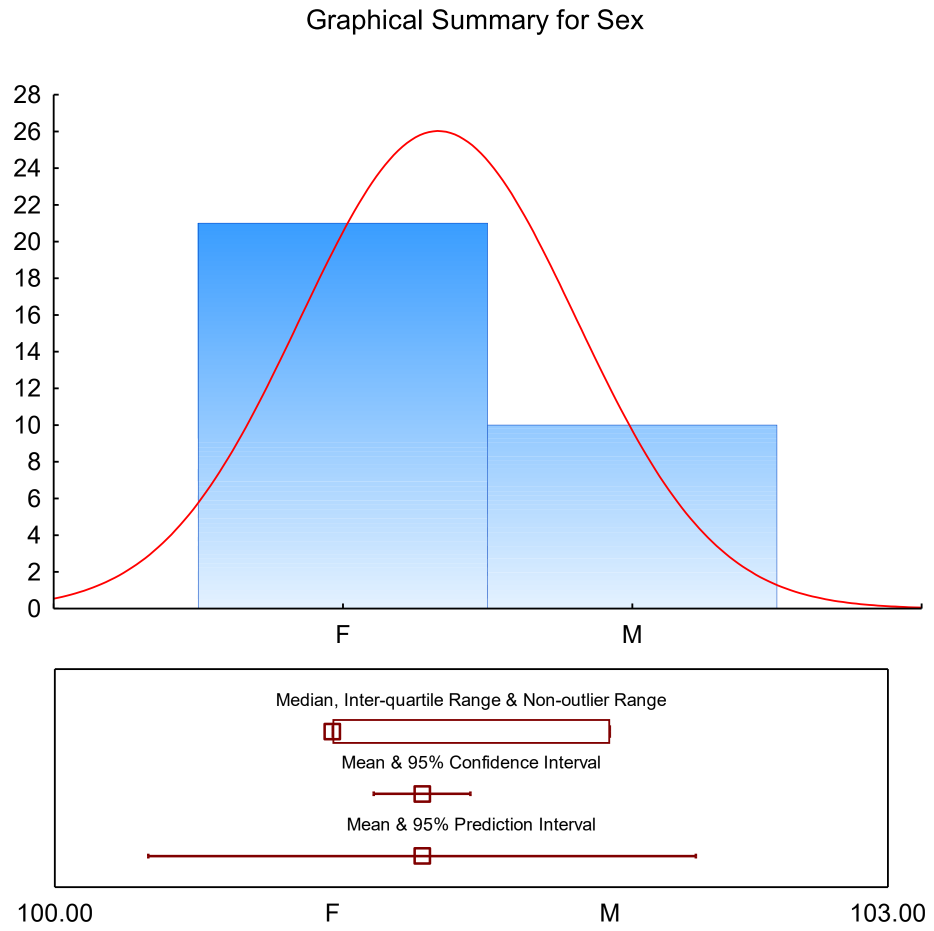
D.1.1.1. Age



```
Shapiro-Wilk p:                 0,0732

Mean:                           22,00
Std.Dev.:                       1,770
Variance:                       3,133
Std.Err.Mean                    0,318
Skewness:                       -0,0771

Valid N:                        31,00

Minimum:                        19,00
Lower Quartile                  21,00
Median:                         22,00
Upper Quartile                  23,00
Maximum:                        25,00

95% Confidence for Std Dev
    Lower                       1,415
    Upper                       2,366
95% Confidence for Mean
    Lower                       21,35
    Upper                       22,65
95% Prediction for Observation
    Lower                       18,33
    Upper                       25,67
```

Figure 16: Shapiro-Wilks test and Box & whisker plots for age.

D.1.1.2. Sex

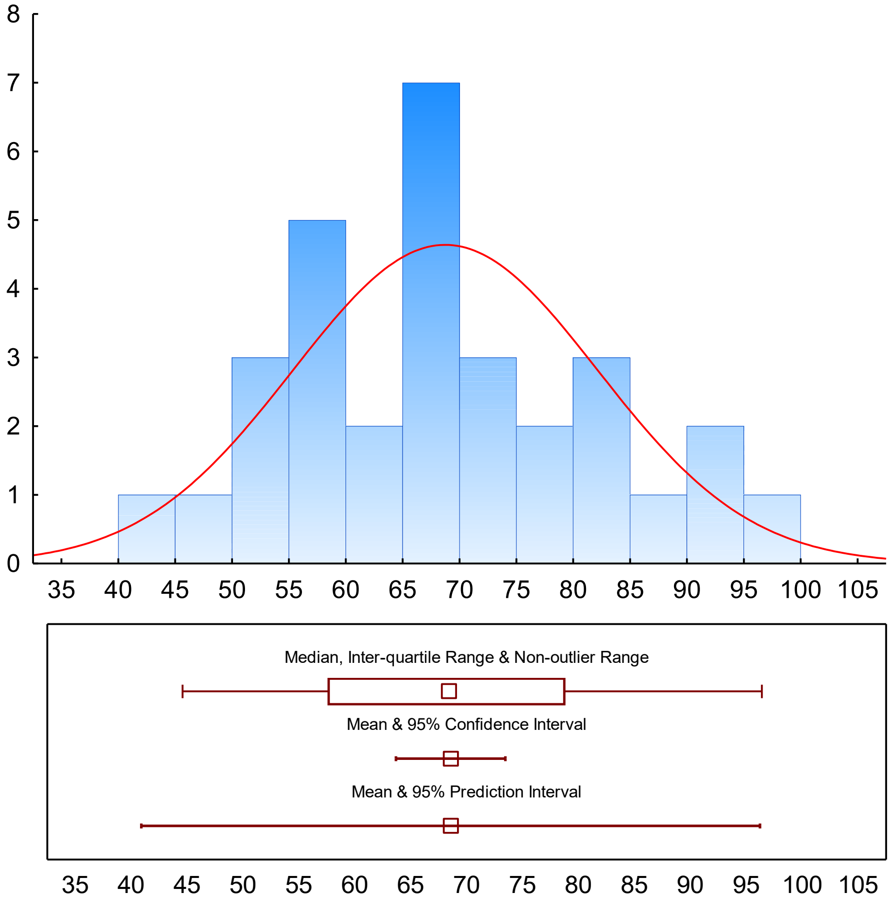


Shapiro-Wilk p:	< 0,00001
Mean:	101
Std.Dev.:	0,475
Variance:	0,226
Std.Err.Mean	0,0853
Skewness:	0,798
Valid N:	31,00
Minimum:	101
Lower Quartile	101
Median:	101
Upper Quartile	102
Maximum:	102
95% Confidence for Std Dev	
Lower	0,380
Upper	0,635
95% Confidence for Mean	
Lower	101
Upper	101
95% Prediction for Observation	
Lower	100
Upper	102

Figure 17: Shapiro-Wilks test and Box & whisker plots for sex.

D.1.1.3. Body Mass

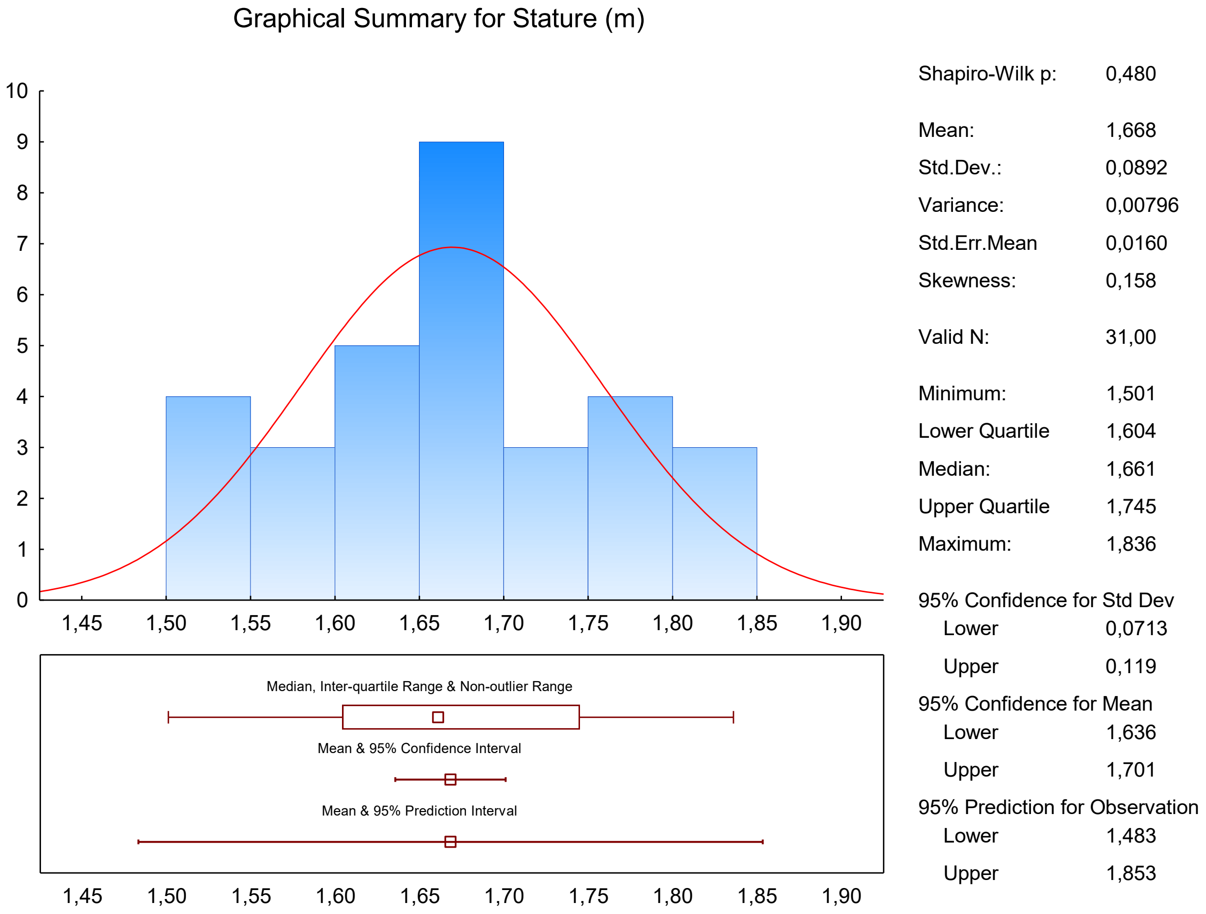
Graphical Summary for Body Weight in Kg



Shapiro-Wilk p:	0,710
Mean:	68,57
Std.Dev.:	13,33
Variance:	178
Std.Err.Mean	2,394
Skewness:	0,280
Valid N:	31,00
Minimum:	44,60
Lower Quartile	57,60
Median:	68,40
Upper Quartile	78,80
Maximum:	96,40
95% Confidence for Std Dev	
Lower	10,65
Upper	17,82
95% Confidence for Mean	
Lower	63,68
Upper	73,46
95% Prediction for Observation	
Lower	40,92
Upper	96,23

Figure 18: Shapiro-Wilks test and Box & whisker plots for mass.

D.1.1.4. Stature



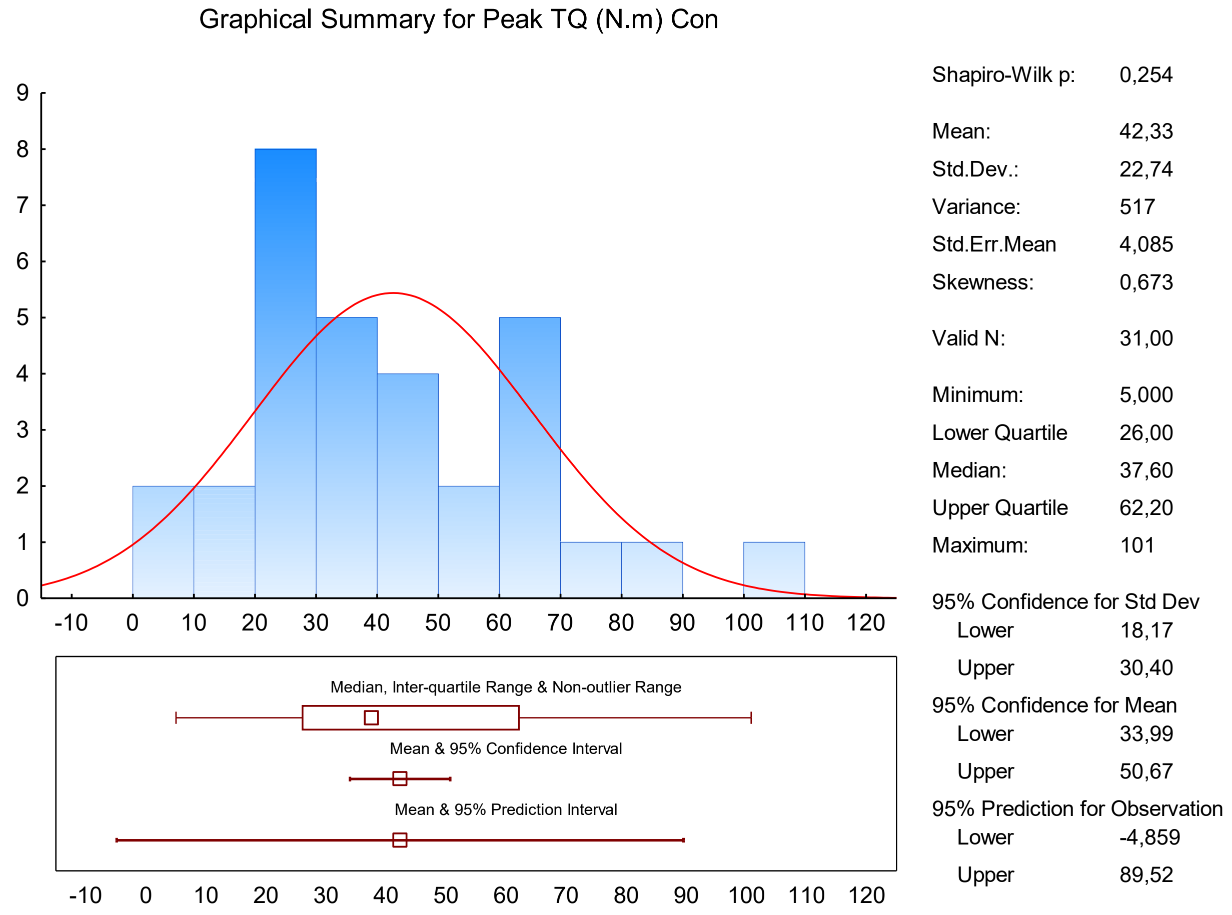
Shapiro-Wilk p:	0,480
Mean:	1,668
Std.Dev.:	0,0892
Variance:	0,00796
Std.Err.Mean	0,0160
Skewness:	0,158
Valid N:	31,00
Minimum:	1,501
Lower Quartile	1,604
Median:	1,661
Upper Quartile	1,745
Maximum:	1,836
95% Confidence for Std Dev	
Lower	0,0713
Upper	0,119
95% Confidence for Mean	
Lower	1,636
Upper	1,701
95% Prediction for Observation	
Lower	1,483
Upper	1,853

Figure 19: Shapiro-Wilks test and Box & whisker plots for stature.

D.1.2. Strength determinants (torque)

D.1.2.1. Peak torque (PT)

Concentric

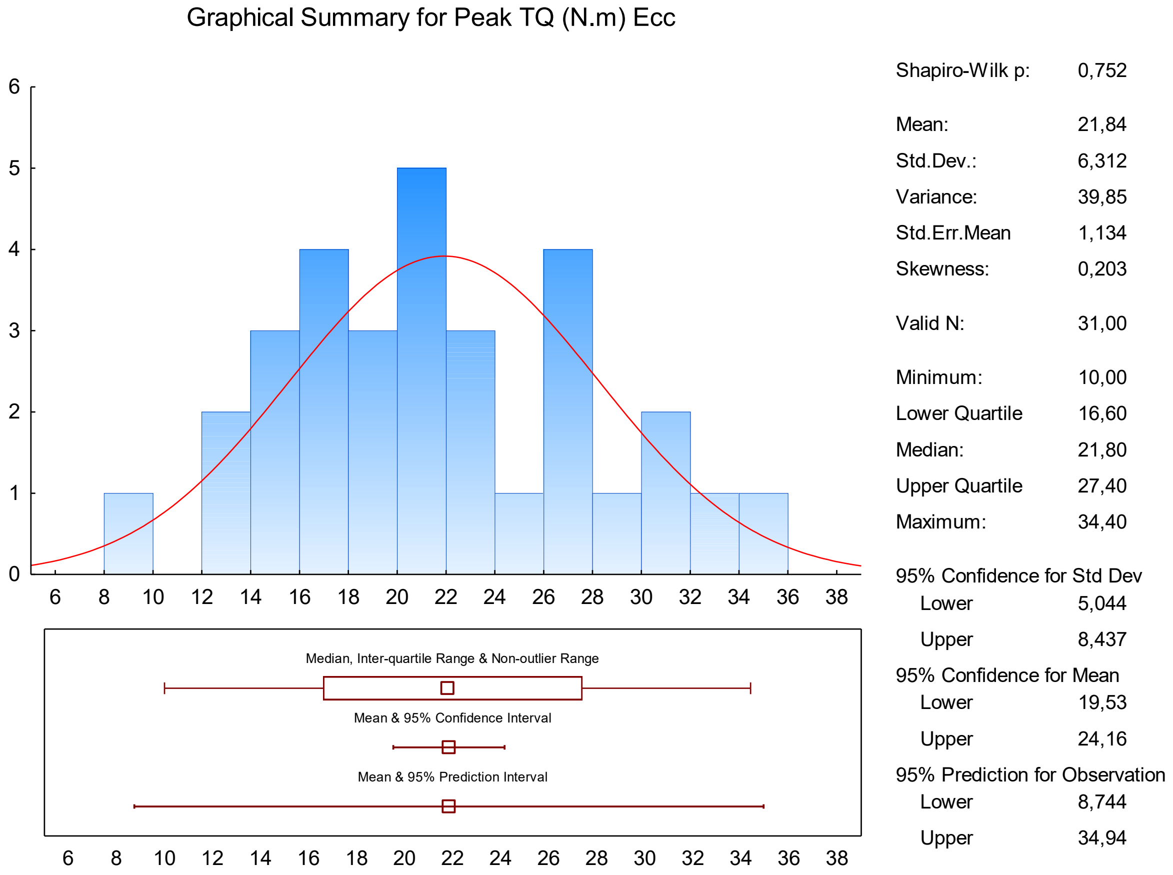


Graphical Summary for Peak TQ (N.m) Con

Shapiro-Wilk p:	0,254
Mean:	42,33
Std.Dev.:	22,74
Variance:	517
Std.Err.Mean	4,085
Skewness:	0,673
Valid N:	31,00
Minimum:	5,000
Lower Quartile	26,00
Median:	37,60
Upper Quartile	62,20
Maximum:	101
95% Confidence for Std Dev	
Lower	18,17
Upper	30,40
95% Confidence for Mean	
Lower	33,99
Upper	50,67
95% Prediction for Observation	
Lower	-4,859
Upper	89,52

Figure 20: Shapiro-Wilks test and Box & whisker plots for peak torque concentric exertion.

Eccentric

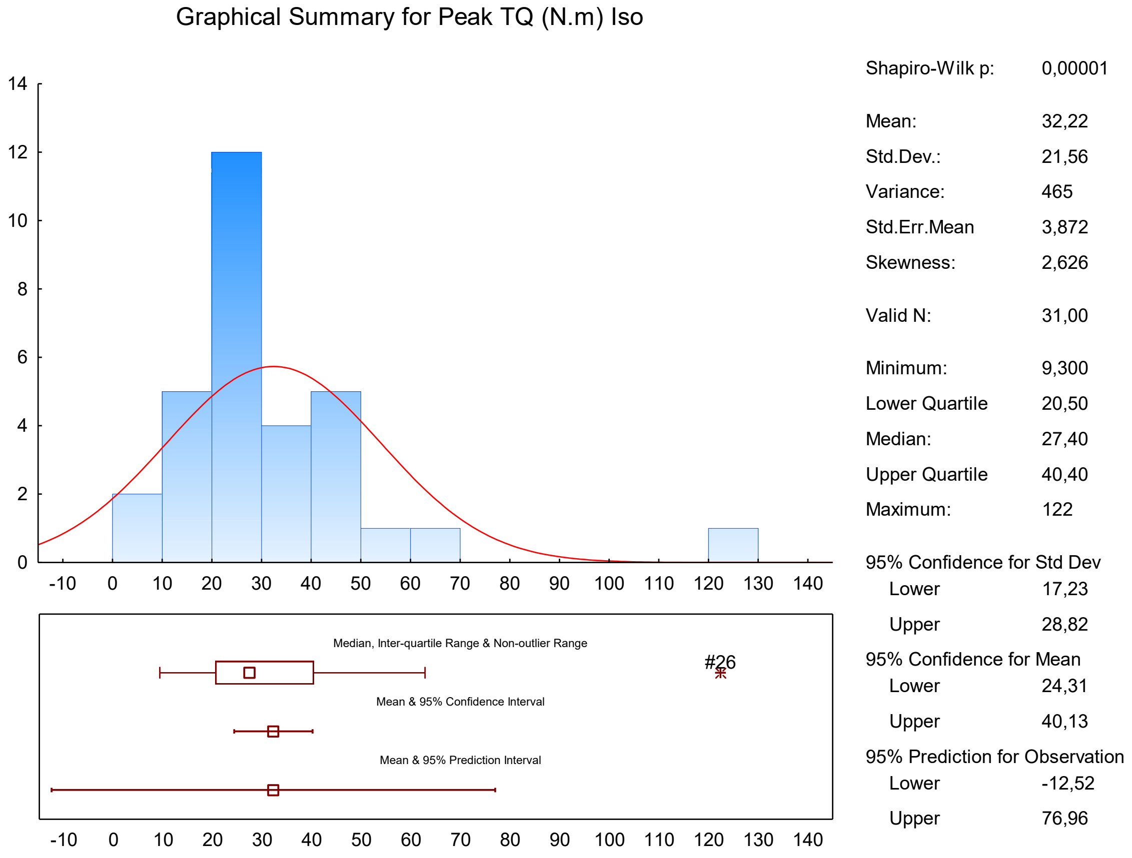


Graphical Summary for Peak TQ (N.m) Ecc

Shapiro-Wilk p:	0,752
Mean:	21,84
Std.Dev.:	6,312
Variance:	39,85
Std.Err.Mean	1,134
Skewness:	0,203
Valid N:	31,00
Minimum:	10,00
Lower Quartile	16,60
Median:	21,80
Upper Quartile	27,40
Maximum:	34,40
95% Confidence for Std Dev	
Lower	5,044
Upper	8,437
95% Confidence for Mean	
Lower	19,53
Upper	24,16
95% Prediction for Observation	
Lower	8,744
Upper	34,94

Figure 21: Shapiro-Wilks test and Box & whisker plots for peak torque eccentric exertion.

Isometric

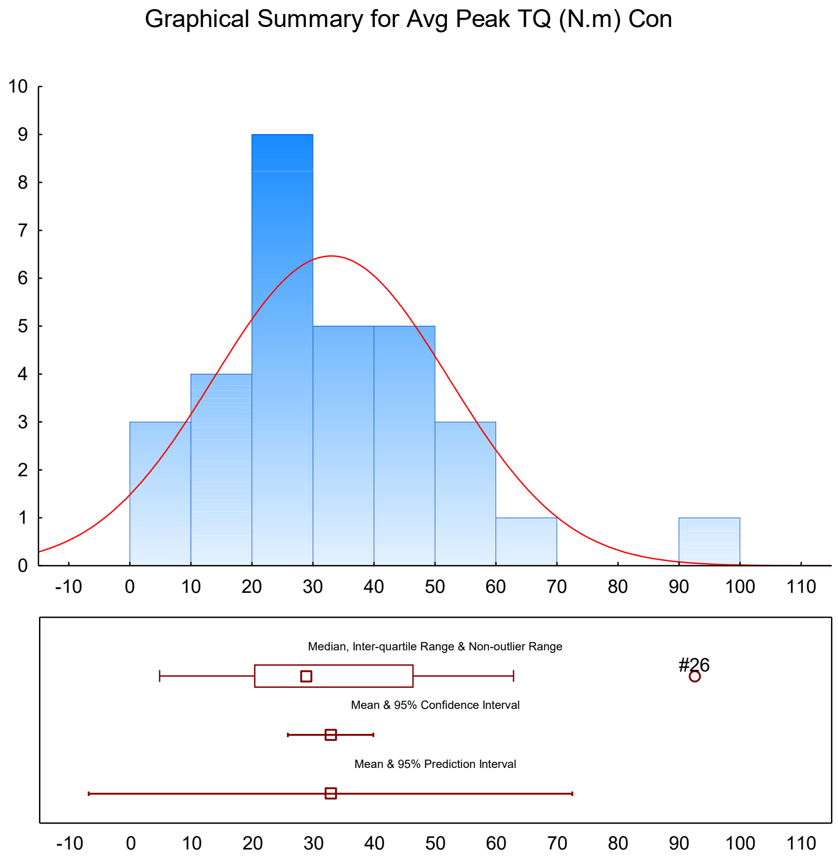


Shapiro-Wilk p:	0,00001
Mean:	32,22
Std.Dev.:	21,56
Variance:	465
Std.Err.Mean	3,872
Skewness:	2,626
Valid N:	31,00
Minimum:	9,300
Lower Quartile	20,50
Median:	27,40
Upper Quartile	40,40
Maximum:	122
95% Confidence for Std Dev	
Lower	17,23
Upper	28,82
95% Confidence for Mean	
Lower	24,31
Upper	40,13
95% Prediction for Observation	
Lower	-12,52
Upper	76,96

Figure 22: Shapiro-Wilks test and Box & whisker plots for peak torque isometric exertion.

D.1.2.2. Average torque (AveT)

Concentric

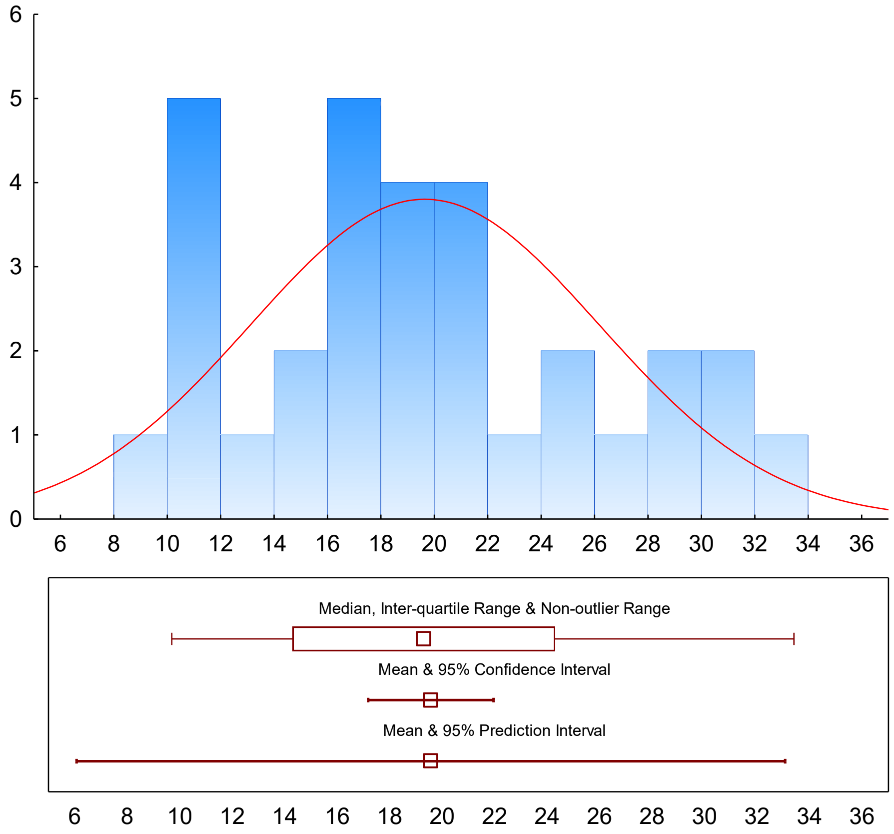


Shapiro-Wilk p:	0,0568
Mean:	32,76
Std.Dev.:	19,13
Variance:	366
Std.Err.Mean	3,436
Skewness:	0,992
Valid N:	31,00
Minimum:	4,700
Lower Quartile	20,20
Median:	28,80
Upper Quartile	46,40
Maximum:	92,50
95% Confidence for Std Dev	
Lower	15,29
Upper	25,57
95% Confidence for Mean	
Lower	25,74
Upper	39,77
95% Prediction for Observation	
Lower	-6,932
Upper	72,45

Figure 23: Shapiro-Wilks testand Box & whisker plots for peak torque concentric exertion.

Eccentric

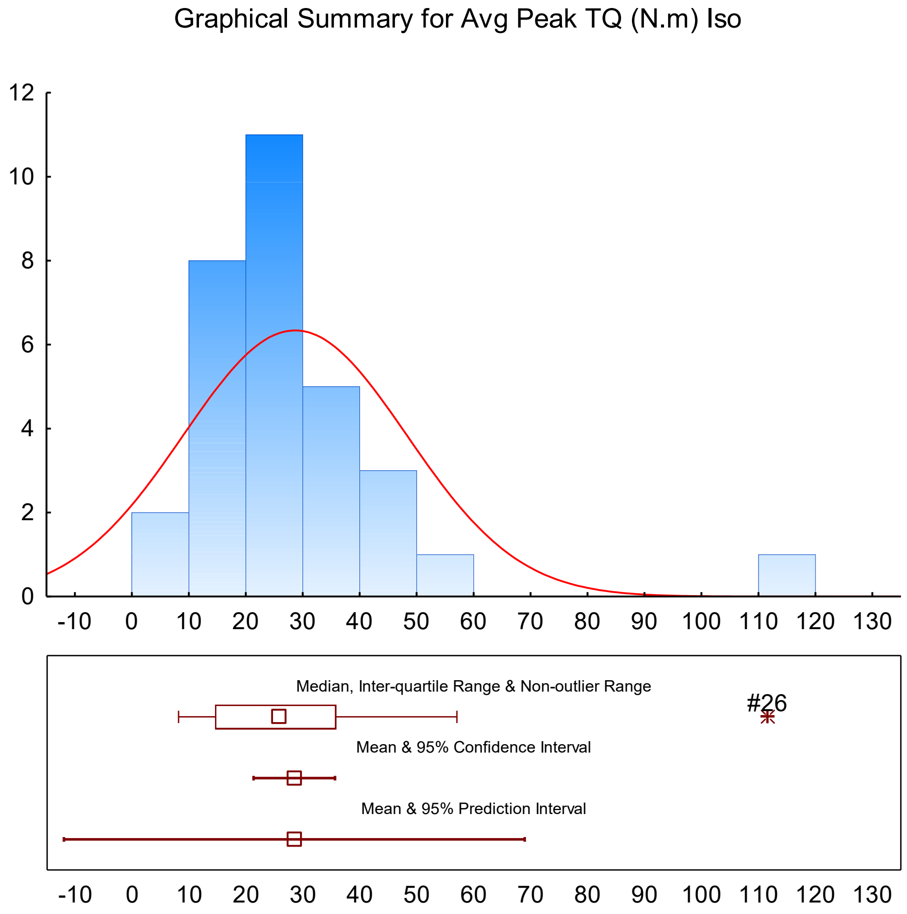
Graphical Summary for Avg Peak TQ (N.m) Ecc



Shapiro-Wilk p:	0,189
Mean:	19,57
Std.Dev.:	6,506
Variance:	42,33
Std.Err.Mean	1,169
Skewness:	0,466
Valid N:	31,00
Minimum:	9,700
Lower Quartile	14,30
Median:	19,30
Upper Quartile	24,30
Maximum:	33,40
95% Confidence for Std Dev	
Lower	5,199
Upper	8,696
95% Confidence for Mean	
Lower	17,18
Upper	21,96
95% Prediction for Observation	
Lower	6,071
Upper	33,07

Figure 24: Shapiro-Wilks test and Box & whisker plots for peak torque eccentric exertion.

Isometric


Graphical Summary for Avg Peak TQ (N.m) Iso

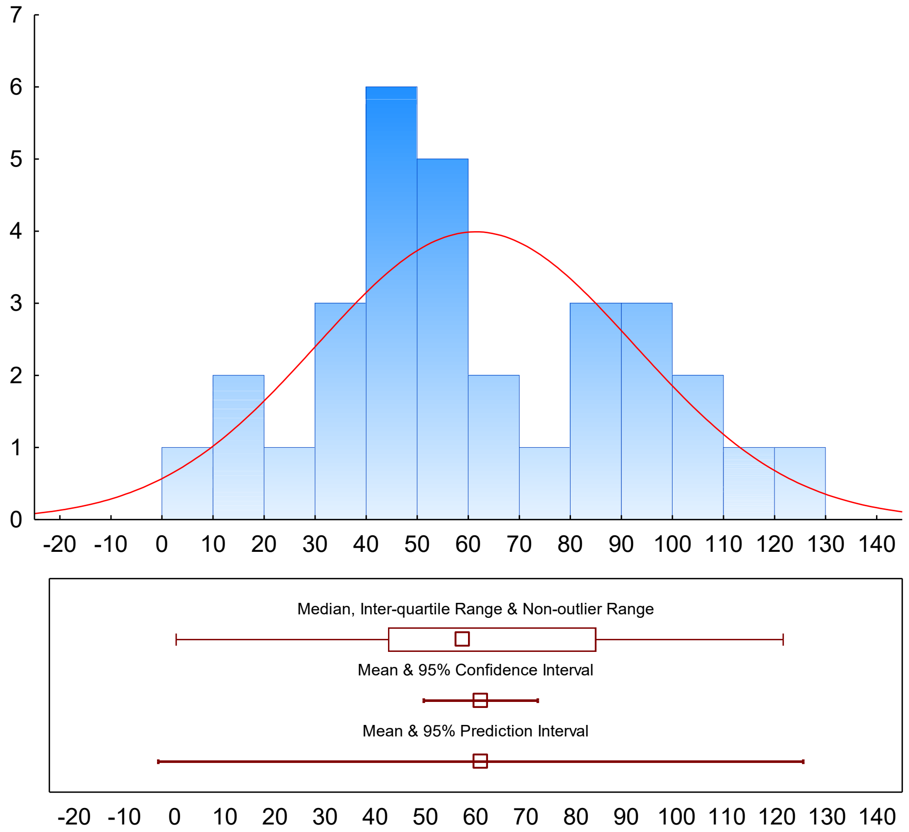
Shapiro-Wilk p:	0,00001
Mean:	28,44
Std.Dev.:	19,51
Variance:	381
Std.Err.Mean	3,504
Skewness:	2,730
Valid N:	31,00
Minimum:	8,100
Lower Quartile	14,50
Median:	25,80
Upper Quartile	35,80
Maximum:	112
95% Confidence for Std Dev	
Lower	15,59
Upper	26,08
95% Confidence for Mean	
Lower	21,28
Upper	35,59
95% Prediction for Observation	
Lower	-12,05
Upper	68,92

Figure 25: Shapiro-Wilks tests and Box & whisker plots for peak torque isometric exertion.

D.1.2.3. Peak torque to body weight % (PT/BW%)

Concentric

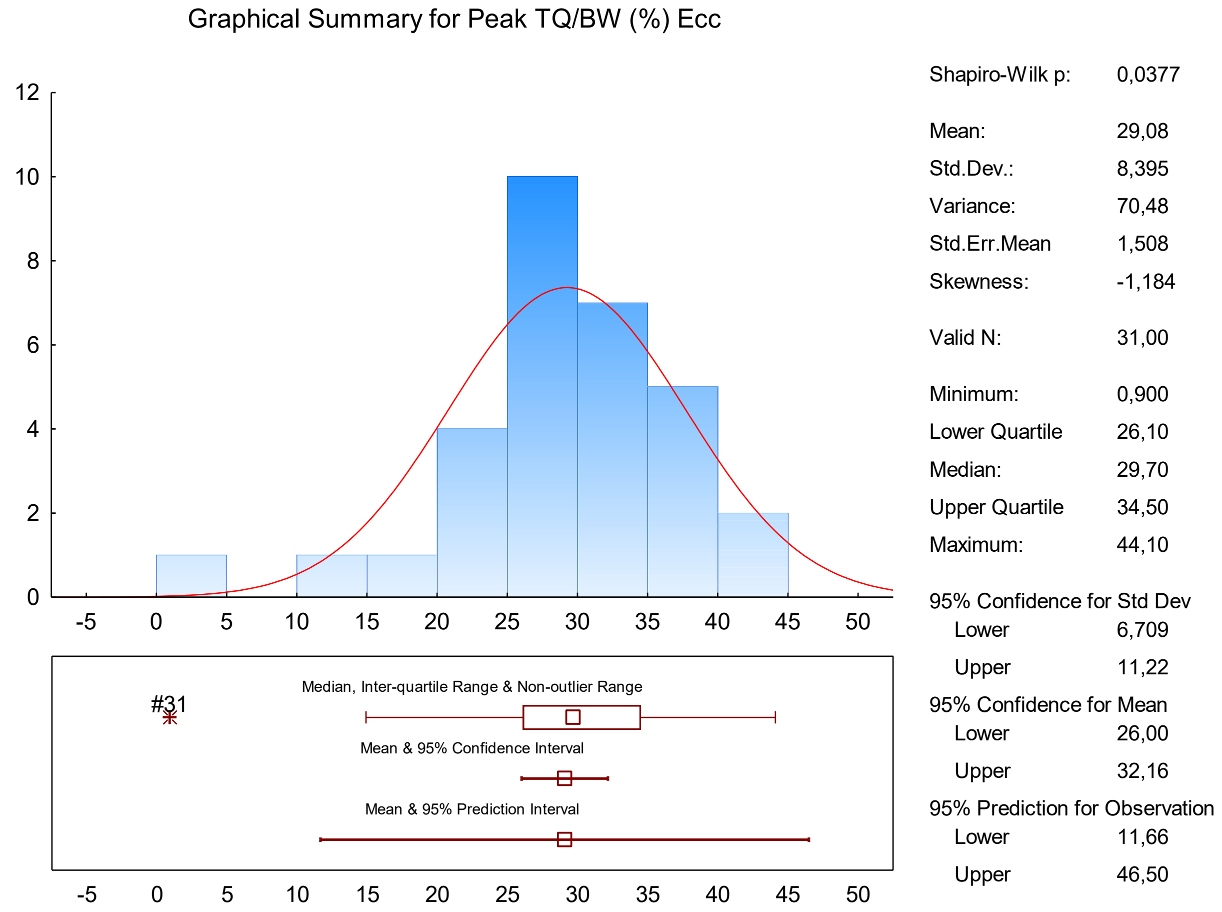
Graphical Summary for Peak TQ/BW (%) Con



Shapiro-Wilk p:	0,805
Mean:	61,01
Std.Dev.:	30,98
Variance:	960
Std.Err.Mean	5,564
Skewness:	0,117
Valid N:	31,00
Minimum:	0,300
Lower Quartile	42,50
Median:	57,40
Upper Quartile	84,00
Maximum:	121
95% Confidence for Std Dev	
Lower	24,76
Upper	41,41
95% Confidence for Mean	
Lower	49,64
Upper	72,37
95% Prediction for Observation	
Lower	-3,274
Upper	125

Figure 26: Shapiro-Wilks test and Box & whisker plots for peak torque concentric exertion.

Eccentric

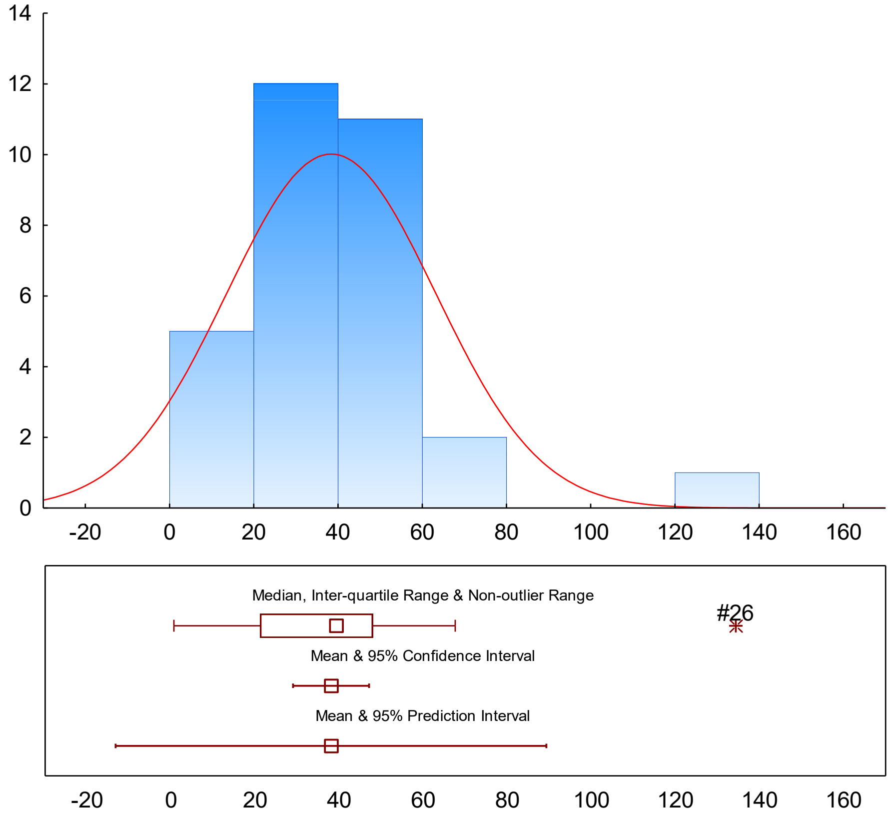


Shapiro-Wilk p:	0,0377
Mean:	29,08
Std.Dev.:	8,395
Variance:	70,48
Std.Err.Mean	1,508
Skewness:	-1,184
Valid N:	31,00
Minimum:	0,900
Lower Quartile	26,10
Median:	29,70
Upper Quartile	34,50
Maximum:	44,10
95% Confidence for Std Dev	
Lower	6,709
Upper	11,22
95% Confidence for Mean	
Lower	26,00
Upper	32,16
95% Prediction for Observation	
Lower	11,66
Upper	46,50

Figure 27: Shapiro-Wilks test and Box & whisker plots for peak torque eccentric exertion.

Isometric

Graphical Summary for Peak TQ/BW (%) Iso



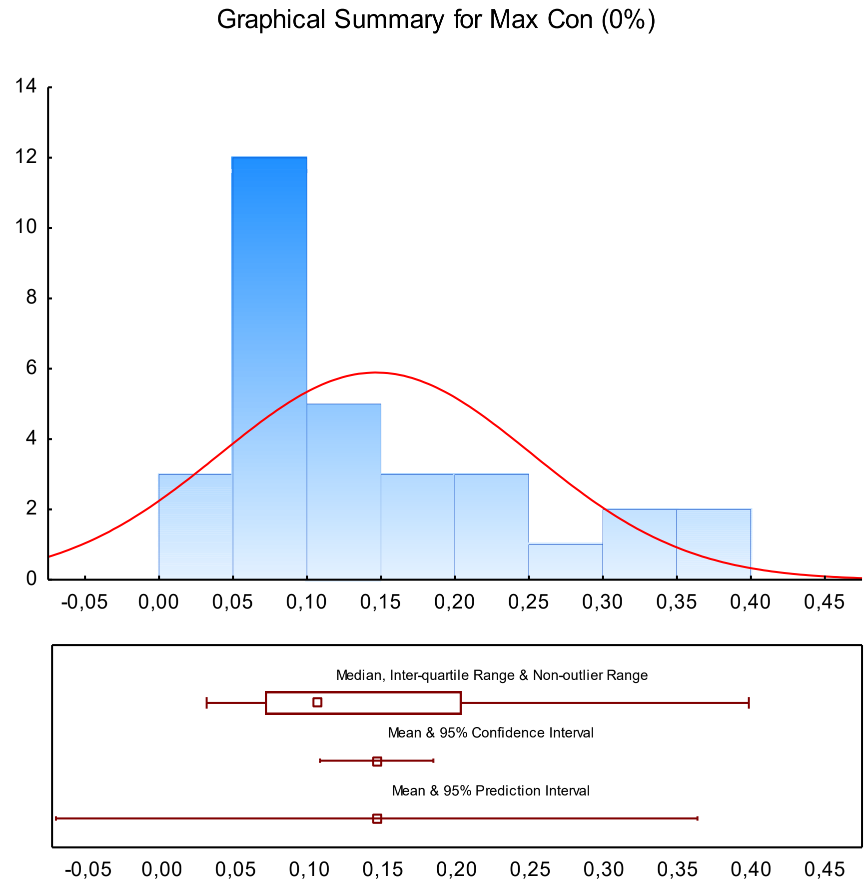
Shapiro-Wilk p:	0,00066
Mean:	38,05
Std.Dev.:	24,70
Variance:	610
Std.Err.Mean	4,436
Skewness:	1,841
Valid N:	31,00
Minimum:	0,661
Lower Quartile	21,20
Median:	39,40
Upper Quartile	48,00
Maximum:	134
95% Confidence for Std Dev	
Lower	19,74
Upper	33,02
95% Confidence for Mean	
Lower	28,99
Upper	47,11
95% Prediction for Observation	
Lower	-13,20
Upper	89,30

Figure 28: Shapiro-Wilks test and Box & whisker plots for peak torque isometric.

D.1.3. Muscle Actions (%MVE)

D.1.3.1. Muscle Actions (%MVE) maximal sEMG

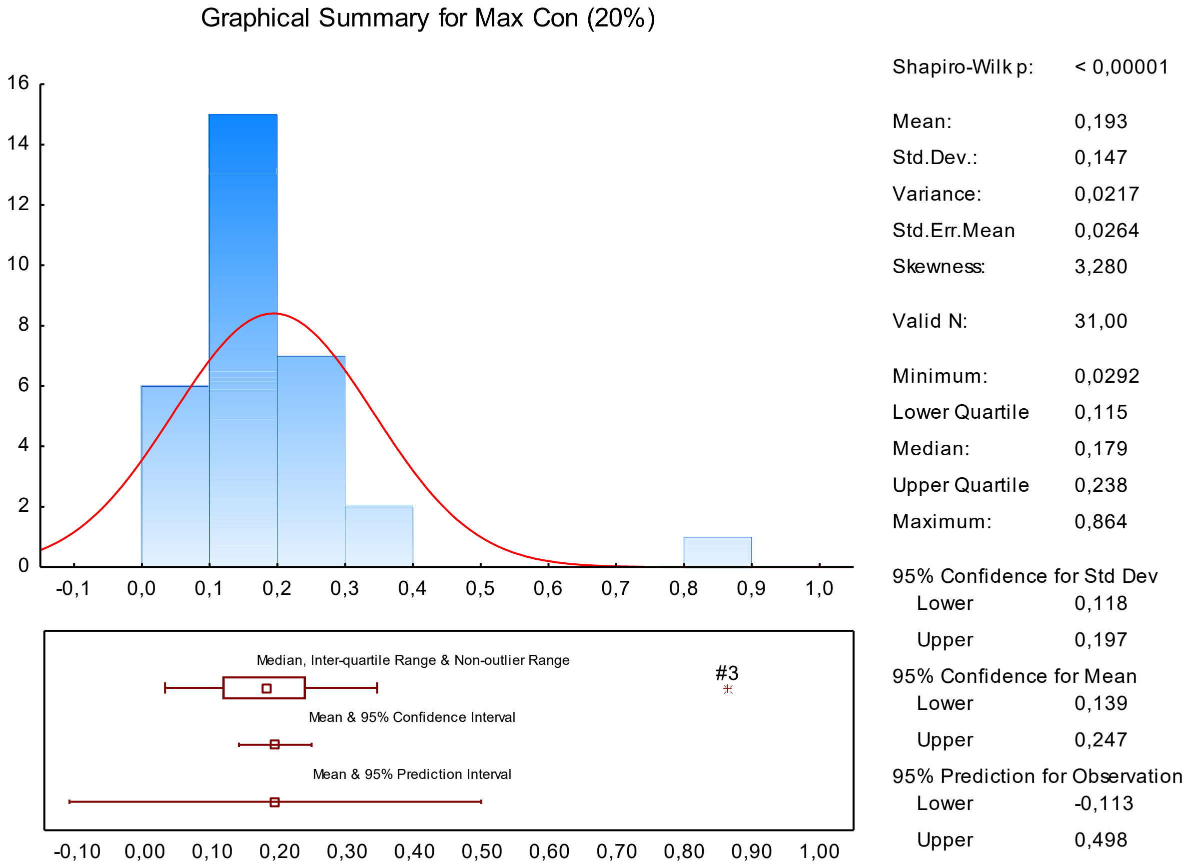
Concentric 0%



Shapiro-Wilk p:	0,00038
Mean:	0,145
Std.Dev.:	0,105
Variance:	0,0110
Std.Err.Mean	0,0189
Skewness:	1,234
Valid N:	31,00
Minimum:	0,0300
Lower Quartile	0,0697
Median:	0,106
Upper Quartile	0,203
Maximum:	0,398
95% Confidence for Std Dev	
Lower	0,0839
Upper	0,140
95% Confidence for Mean	
Lower	0,107
Upper	0,184
95% Prediction for Observation	
Lower	-0,0723
Upper	0,363

Figure 29: Shapiro-Wilks test and Box & whisker plots for Maximal EMG during concentric 0% of MVE

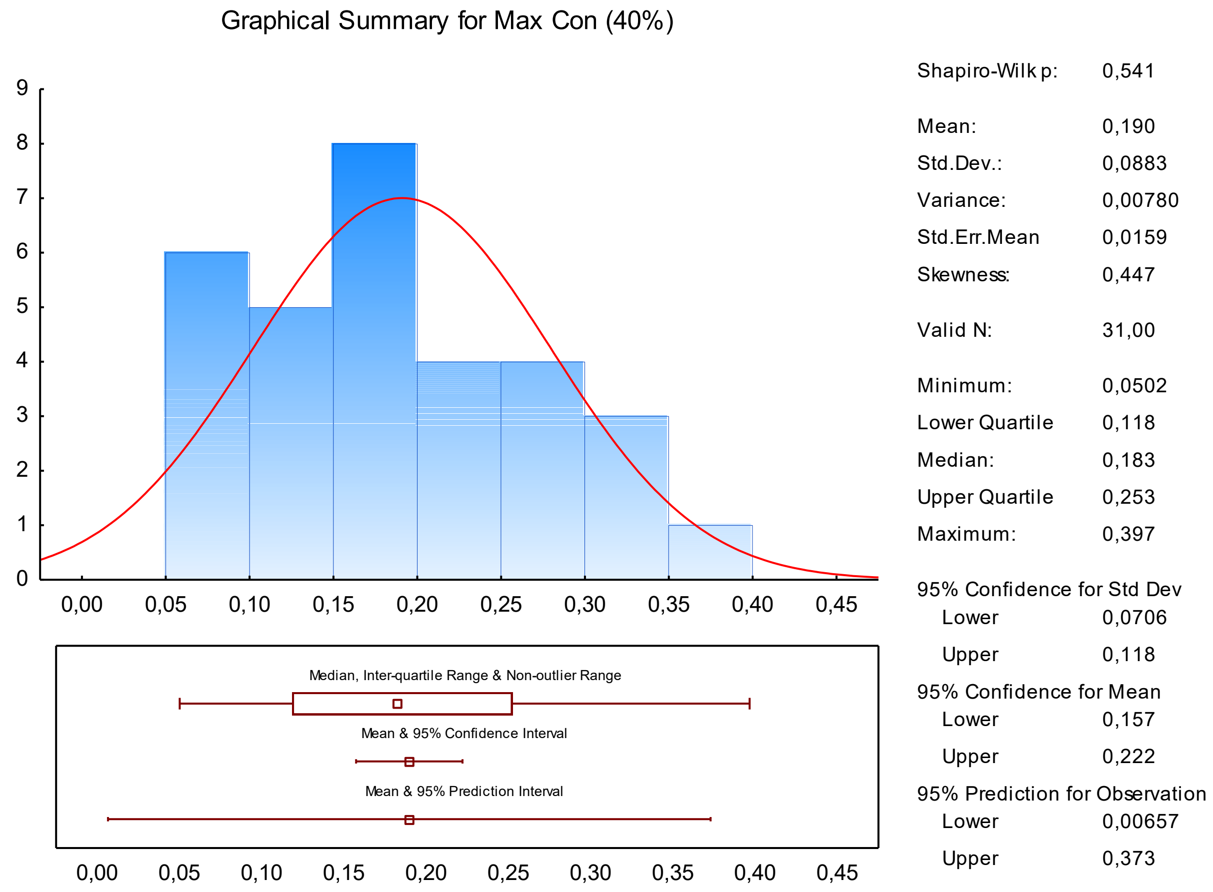
Concentric 20%



Shapiro-Wilk p:	< 0,00001
Mean:	0,193
Std.Dev.:	0,147
Variance:	0,0217
Std.Err.Mean	0,0264
Skewness:	3,280
Valid N:	31,00
Minimum:	0,0292
Lower Quartile	0,115
Median:	0,179
Upper Quartile	0,238
Maximum:	0,864
95% Confidence for Std Dev	
Lower	0,118
Upper	0,197
95% Confidence for Mean	
Lower	0,139
Upper	0,247
95% Prediction for Observation	
Lower	-0,113
Upper	0,498

Figure 30: Shapiro-Wilks test and Box & whisker plots for Maximal EMG during concentric 20% of MVE.

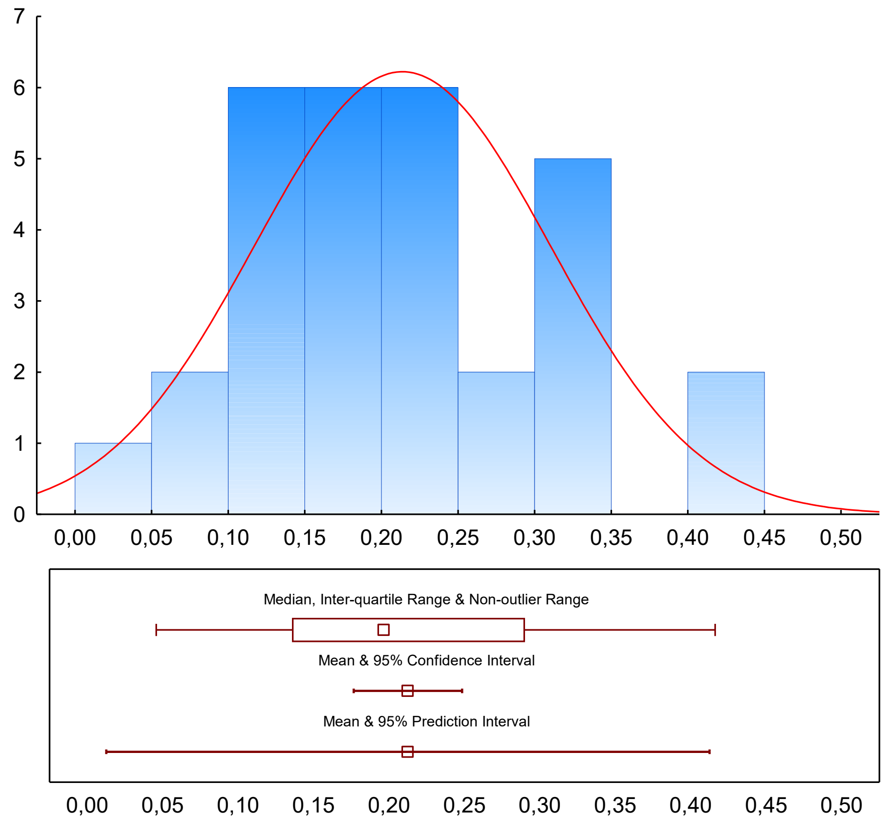
Concentric 40%



Shapiro-Wilk p:	0,541
Mean:	0,190
Std.Dev.:	0,0883
Variance:	0,00780
Std.Err.Mean	0,0159
Skewness:	0,447
Valid N:	31,00
Minimum:	0,0502
Lower Quartile	0,118
Median:	0,183
Upper Quartile	0,253
Maximum:	0,397
95% Confidence for Std Dev	
Lower	0,0706
Upper	0,118
95% Confidence for Mean	
Lower	0,157
Upper	0,222
95% Prediction for Observation	
Lower	0,00657
Upper	0,373

Figure 31: Shapiro-Wilks test and Box & whisker plots for Maximal EMG during concentric 40% of MVE.

Concentric 60%

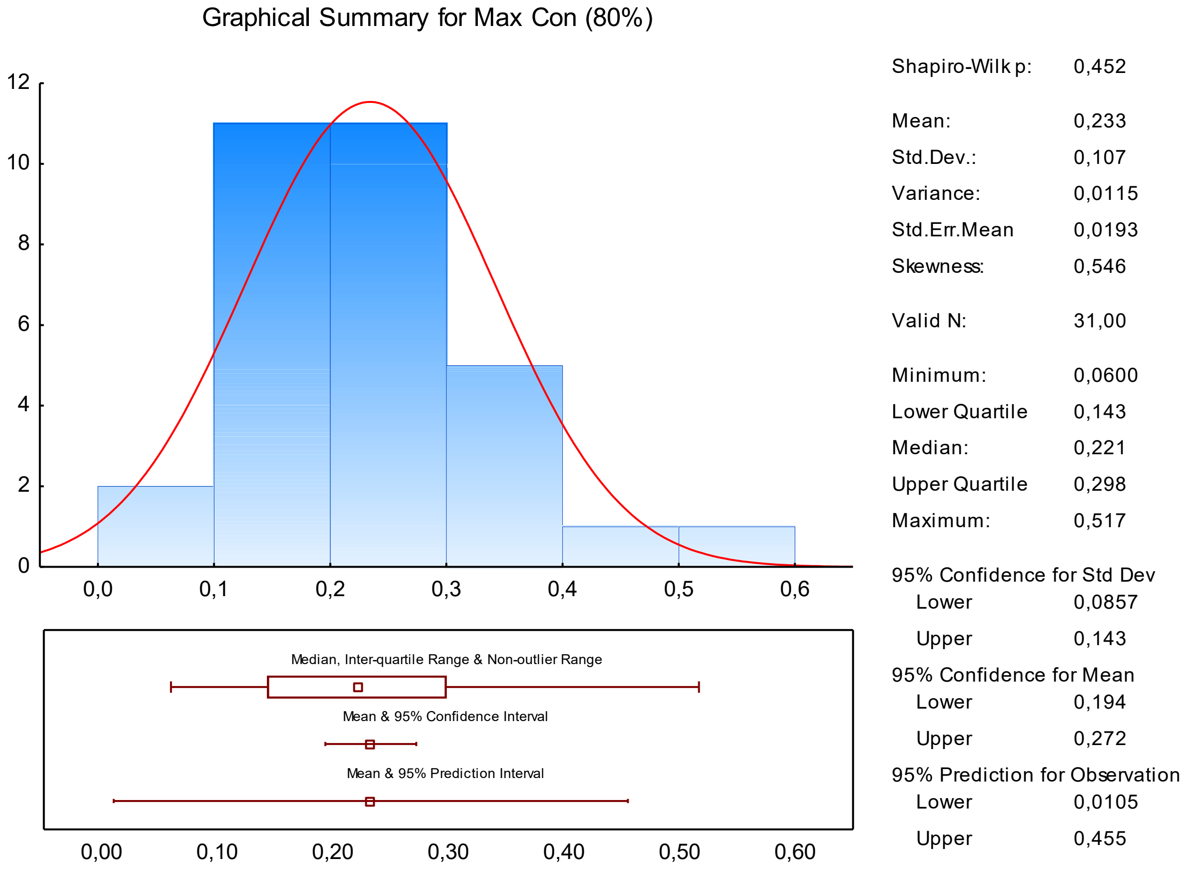


Graphical Summary for Max Con (60%)

Shapiro-Wilk p:	0,569
Mean:	0,213
Std.Dev.:	0,0962
Variance:	0,00925
Std.Err.Mean	0,0176
Skewness:	0,377
Valid N:	30,00
Minimum:	0,0457
Lower Quartile	0,136
Median:	0,196
Upper Quartile	0,290
Maximum:	0,416
95% Confidence for Std Dev	
Lower	0,0766
Upper	0,129
95% Confidence for Mean	
Lower	0,177
Upper	0,248
95% Prediction for Observation	
Lower	0,0126
Upper	0,412

Figure 32: Shapiro-Wilks test and Box & whisker plots for Maximal EMG during concentric 60% of MVE.

Concentric 80%

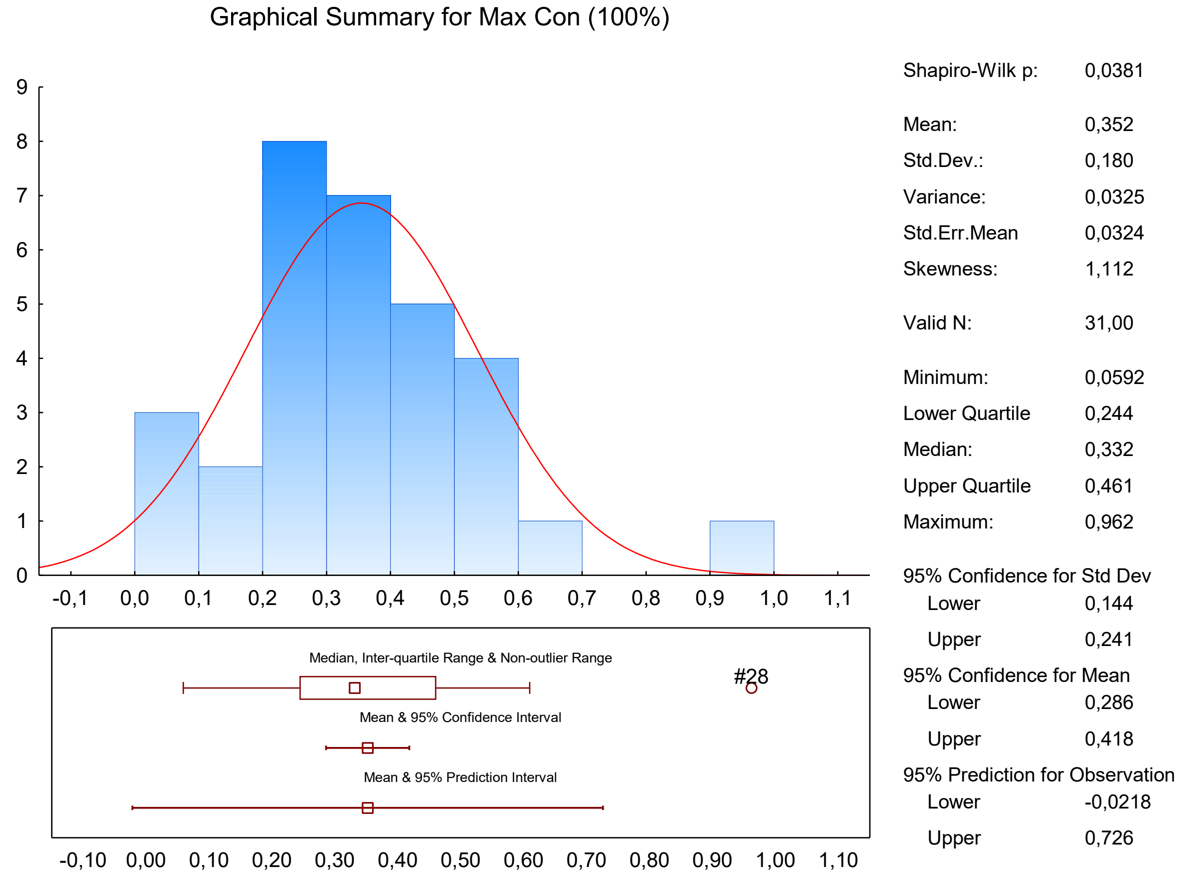


Shapiro-Wilk p:	0,452
Mean:	0,233
Std.Dev.:	0,107
Variance:	0,0115
Std.Err.Mean	0,0193
Skewness:	0,546
Valid N:	31,00
Minimum:	0,0600
Lower Quartile	0,143
Median:	0,221
Upper Quartile	0,298
Maximum:	0,517
95% Confidence for Std Dev	
Lower	0,0857
Upper	0,143
95% Confidence for Mean	
Lower	0,194
Upper	0,272
95% Prediction for Observation	
Lower	0,0105
Upper	0,455

Figure 33: Shapiro-Wilks test and Box & whisker plots for Maximal EMG during concentric 80% of MVE.

.

Concentric 100%



Shapiro-Wilk p:	0,0381
Mean:	0,352
Std.Dev.:	0,180
Variance:	0,0325
Std.Err.Mean	0,0324
Skewness:	1,112
Valid N:	31,00
Minimum:	0,0592
Lower Quartile	0,244
Median:	0,332
Upper Quartile	0,461
Maximum:	0,962
95% Confidence for Std Dev	
Lower	0,144
Upper	0,241
95% Confidence for Mean	
Lower	0,286
Upper	0,418
95% Prediction for Observation	
Lower	-0,0218
Upper	0,726

Figure 34: Shapiro-Wilks test and Box & whisker plots for Maximal EMG during concentric 100% of MVE.

Eccentric 0%

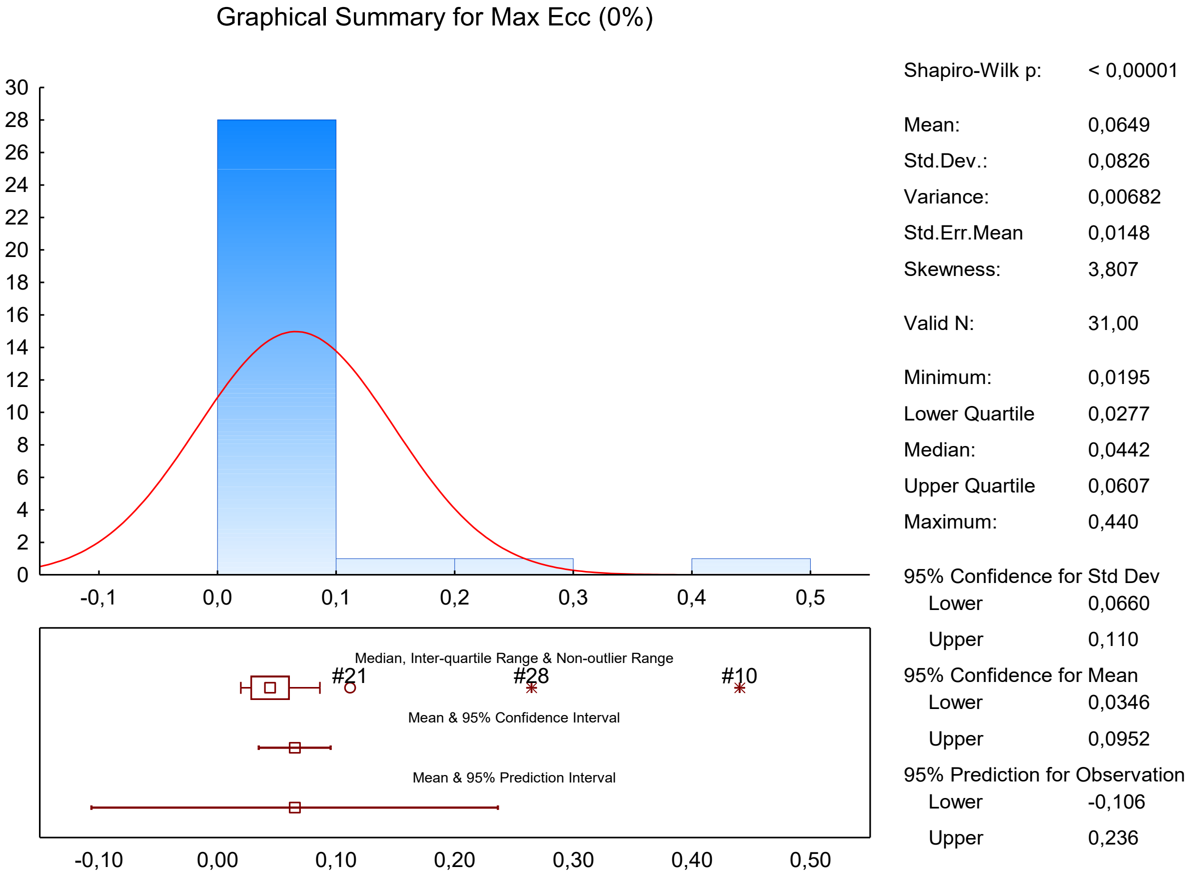
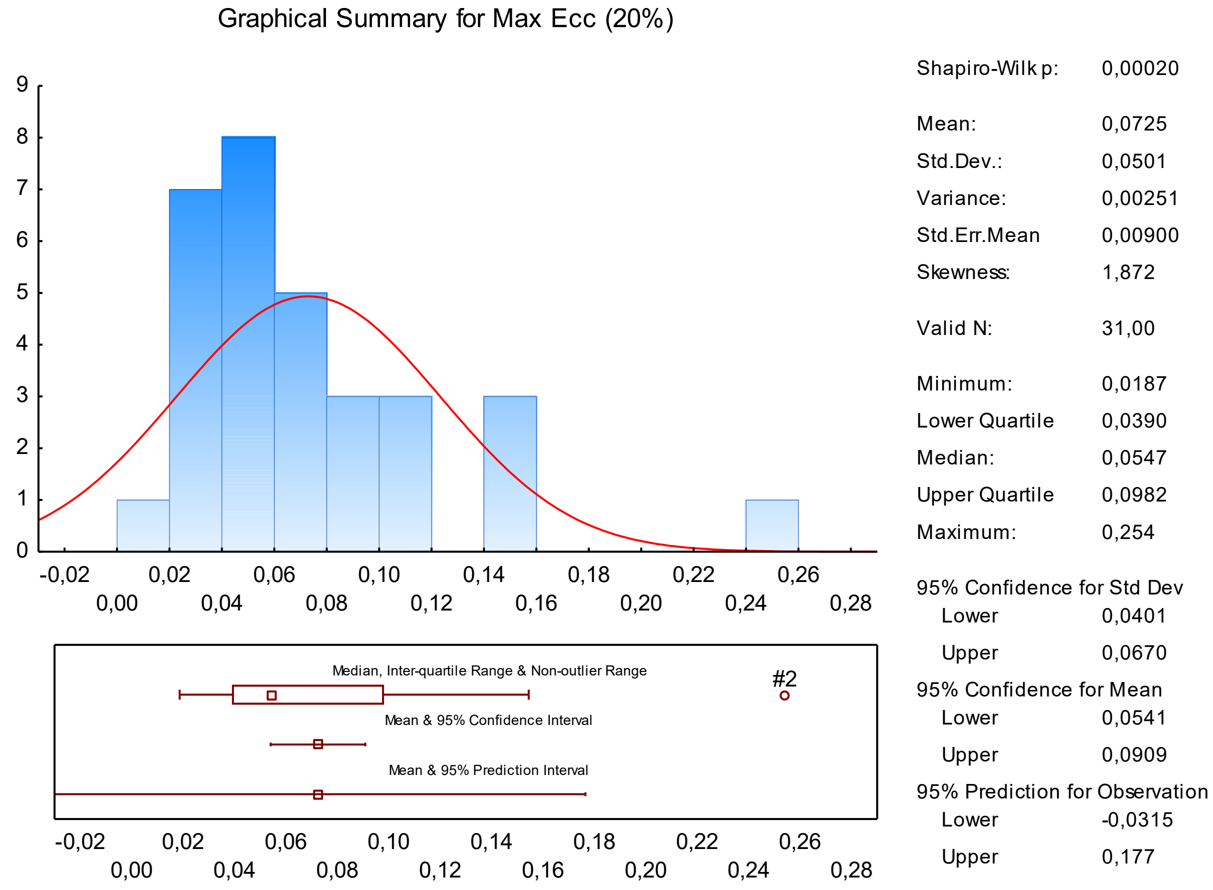


Figure 35: Shapiro-Wilks test and Box & whisker plots for Maximal EMG during eccentric 0% of MVE.

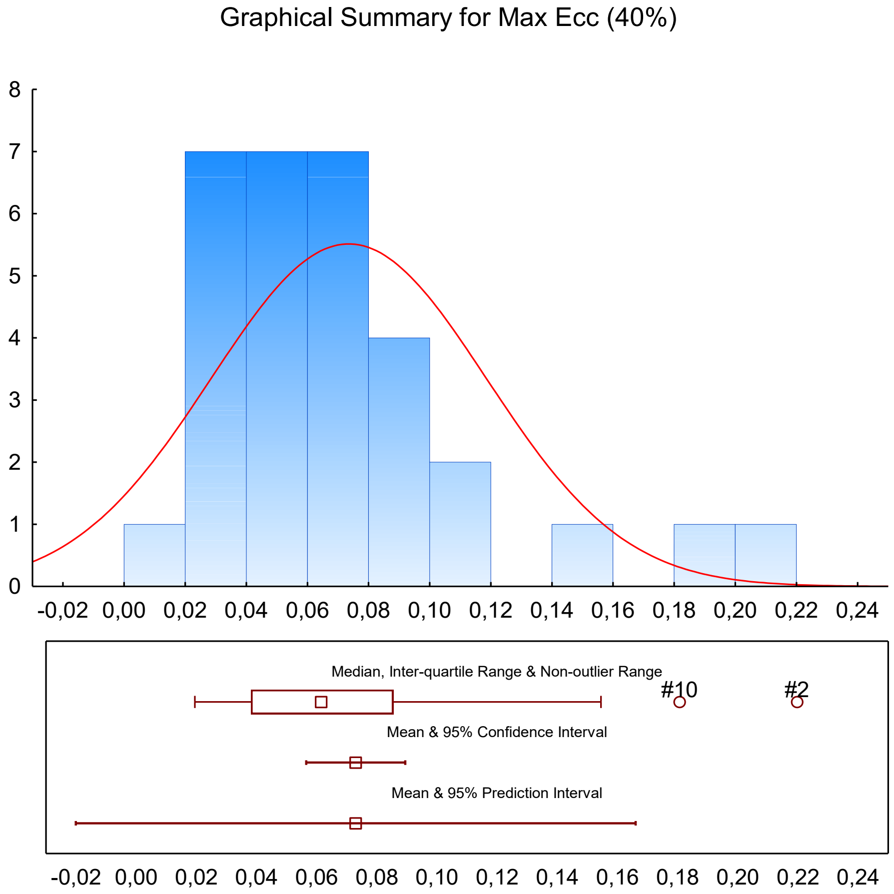
Eccentric 20%



Shapiro-Wilk p:	0,00020
Mean:	0,0725
Std.Dev.:	0,0501
Variance:	0,00251
Std.Err.Mean	0,00900
Skewness:	1,872
Valid N:	31,00
Minimum:	0,0187
Lower Quartile	0,0390
Median:	0,0547
Upper Quartile	0,0982
Maximum:	0,254
95% Confidence for Std Dev	
Lower	0,0401
Upper	0,0670
95% Confidence for Mean	
Lower	0,0541
Upper	0,0909
95% Prediction for Observation	
Lower	-0,0315
Upper	0,177

Figure 36: Shapiro-Wilks test and Box & whisker plots for Maximal EMG during eccentric 20% of MVE.

Eccentric 40%

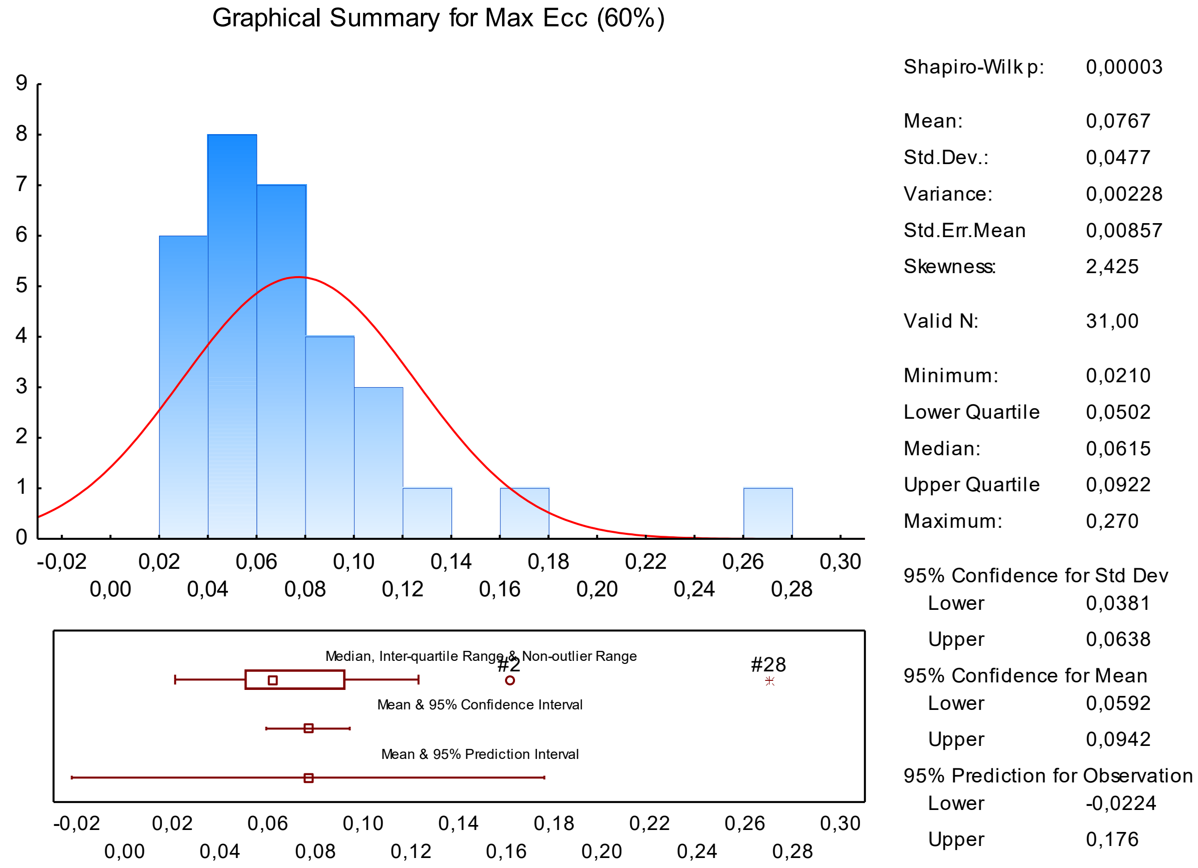


Shapiro-Wilk p:	0,00022
Mean:	0,0730
Std.Dev.:	0,0449
Variance:	0,00201
Std.Err.Mean	0,00806
Skewness:	1,765
Valid N:	31,00
Minimum:	0,0195
Lower Quartile	0,0382
Median:	0,0615
Upper Quartile	0,0855
Maximum:	0,220
95% Confidence for Std Dev	
Lower	0,0359
Upper	0,0600
95% Confidence for Mean	
Lower	0,0565
Upper	0,0895
95% Prediction for Observation	
Lower	-0,0201
Upper	0,166

Figure 37: Shapiro-Wilks test and Box & whisker plots for Maximal EMG during eccentric 40% of MVE.

.

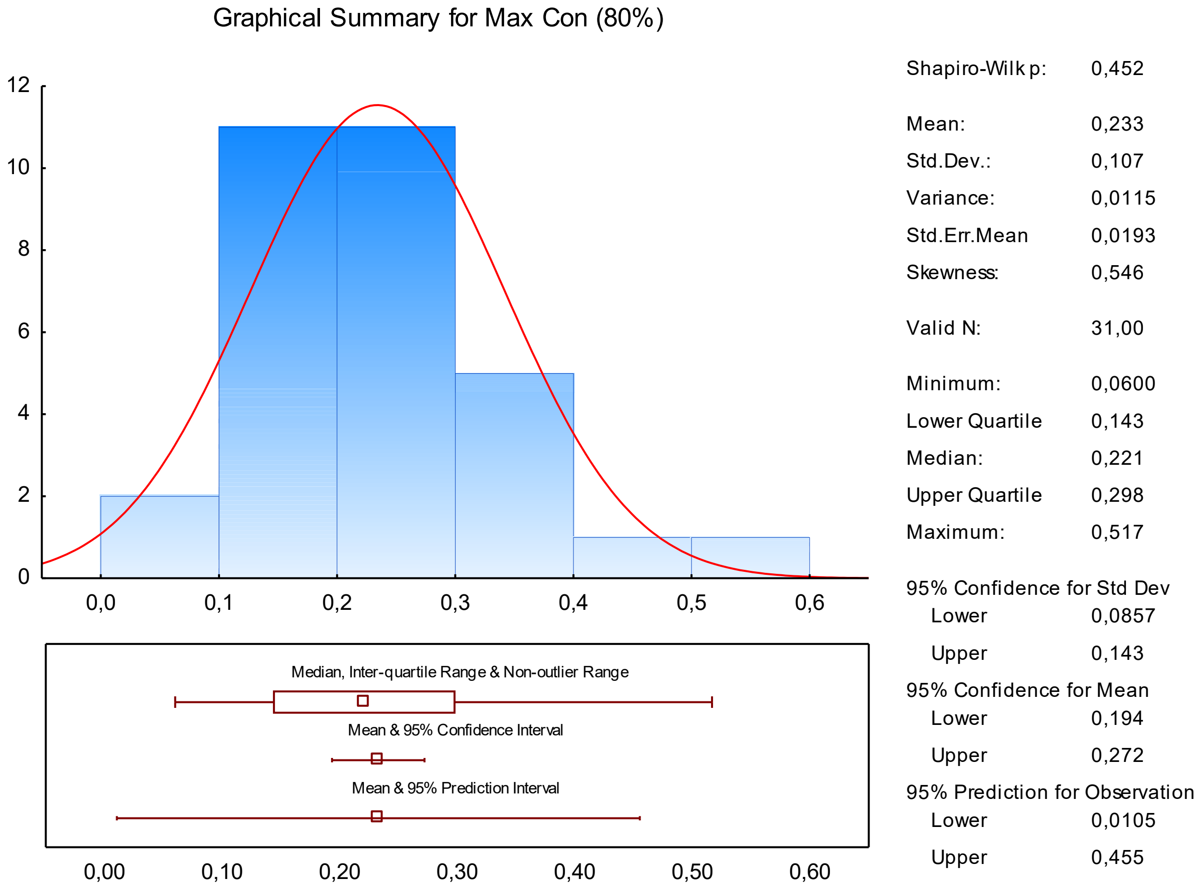
Eccentric 60%



Shapiro-Wilk p:	0,00003
Mean:	0,0767
Std.Dev.:	0,0477
Variance:	0,00228
Std.Err.Mean	0,00857
Skewness:	2,425
Valid N:	31,00
Minimum:	0,0210
Lower Quartile	0,0502
Median:	0,0615
Upper Quartile	0,0922
Maximum:	0,270
95% Confidence for Std Dev	
Lower	0,0381
Upper	0,0638
95% Confidence for Mean	
Lower	0,0592
Upper	0,0942
95% Prediction for Observation	
Lower	-0,0224
Upper	0,176

Figure 38: Shapiro-Wilks test and Box & whisker plots for Maximal EMG during eccentric 60% of MVE.

Eccentric 80%



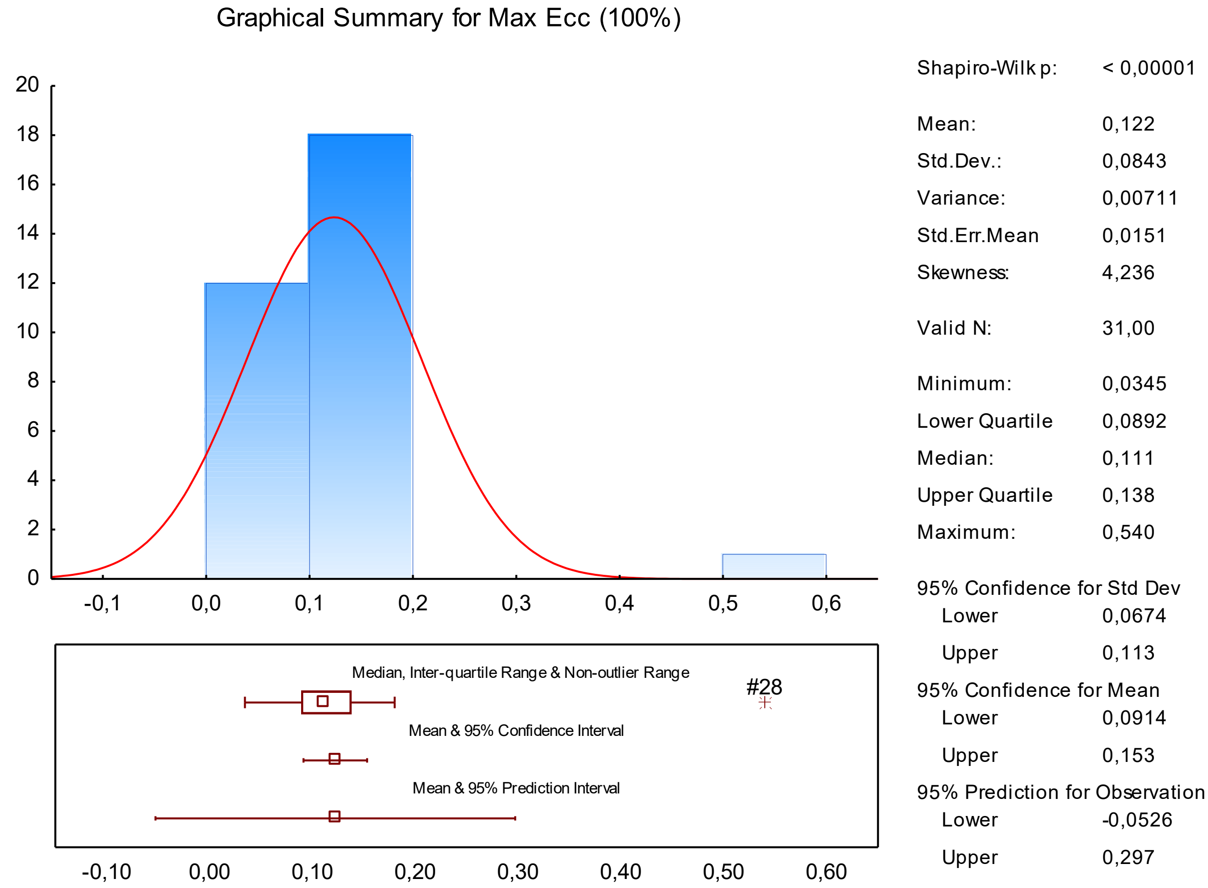
Graphical Summary for Max Con (80%)

Shapiro-Wilk p:	0,452
Mean:	0,233
Std.Dev.:	0,107
Variance:	0,0115
Std.Err.Mean	0,0193
Skewness:	0,546
Valid N:	31,00
Minimum:	0,0600
Lower Quartile	0,143
Median:	0,221
Upper Quartile	0,298
Maximum:	0,517
95% Confidence for Std Dev	
Lower	0,0857
Upper	0,143
95% Confidence for Mean	
Lower	0,194
Upper	0,272
95% Prediction for Observation	
Lower	0,0105
Upper	0,455

Figure 39: Shapiro-Wilks test and Box & whisker plots for Maximal EMG during eccentric 80% of MVE.

.

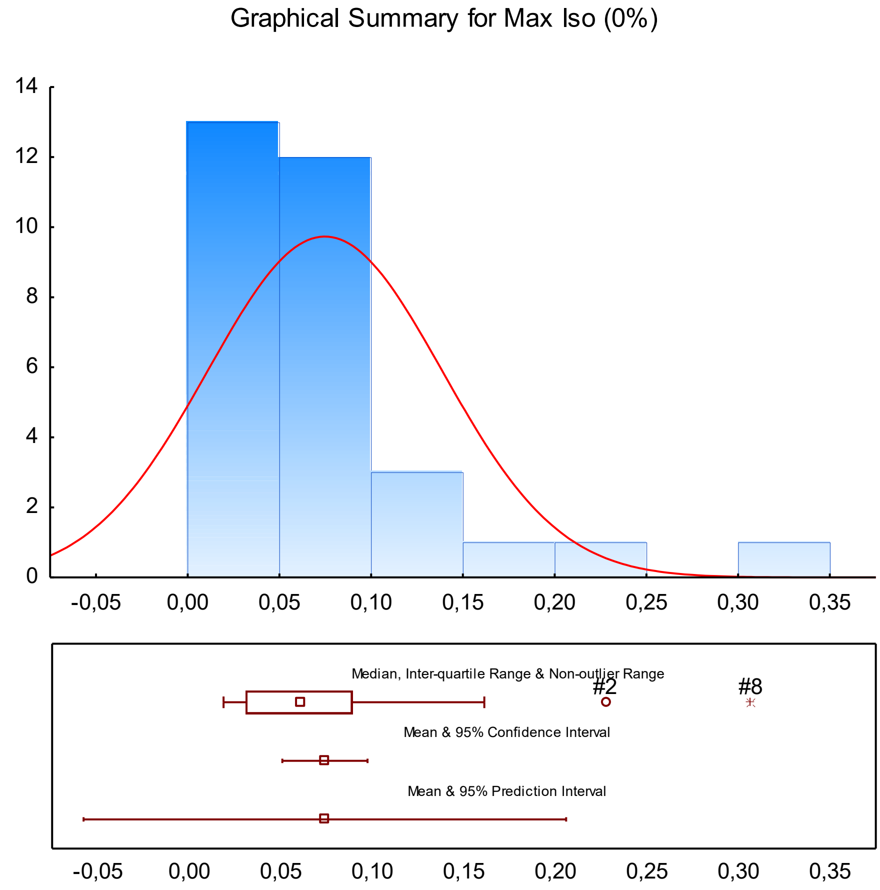
Eccentric 100%



Shapiro-Wilk p:	< 0,00001
Mean:	0,122
Std.Dev.:	0,0843
Variance:	0,00711
Std.Err.Mean	0,0151
Skewness:	4,236
Valid N:	31,00
Minimum:	0,0345
Lower Quartile	0,0892
Median:	0,111
Upper Quartile	0,138
Maximum:	0,540
95% Confidence for Std Dev	
Lower	0,0674
Upper	0,113
95% Confidence for Mean	
Lower	0,0914
Upper	0,153
95% Prediction for Observation	
Lower	-0,0526
Upper	0,297

Figure 40: Shapiro-Wilks test and Box & whisker plots for Maximal EMG during concentric 100% of MVE.

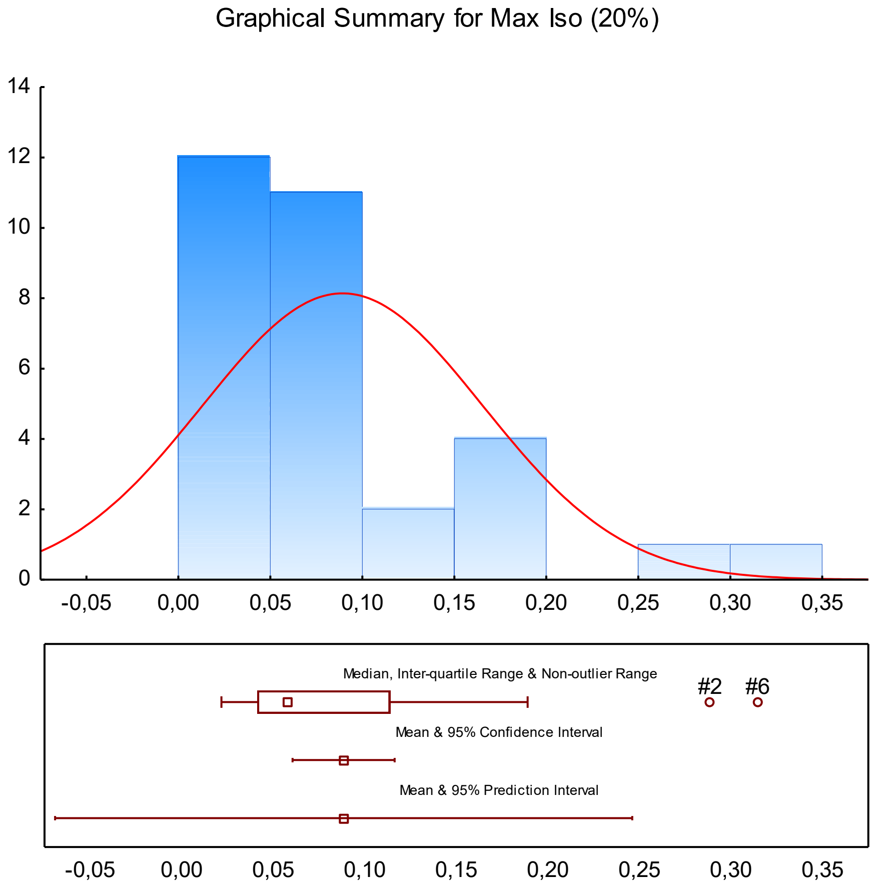
Isometric 0%



Shapiro-Wilk p:	0,00001
Mean:	0,0741
Std.Dev.:	0,0635
Variance:	0,00404
Std.Err.Mean	0,0114
Skewness:	2,241
Valid N:	31,00
Minimum:	0,0187
Lower Quartile	0,0307
Median:	0,0600
Upper Quartile	0,0892
Maximum:	0,307
95% Confidence for Std Dev	
Lower	0,0508
Upper	0,0849
95% Confidence for Mean	
Lower	0,0508
Upper	0,0974
95% Prediction for Observation	
Lower	-0,0578
Upper	0,206

Figure 41: Shapiro-Wilks test and Box & whisker plots for Maximal EMG during isometric 0% of MVE.

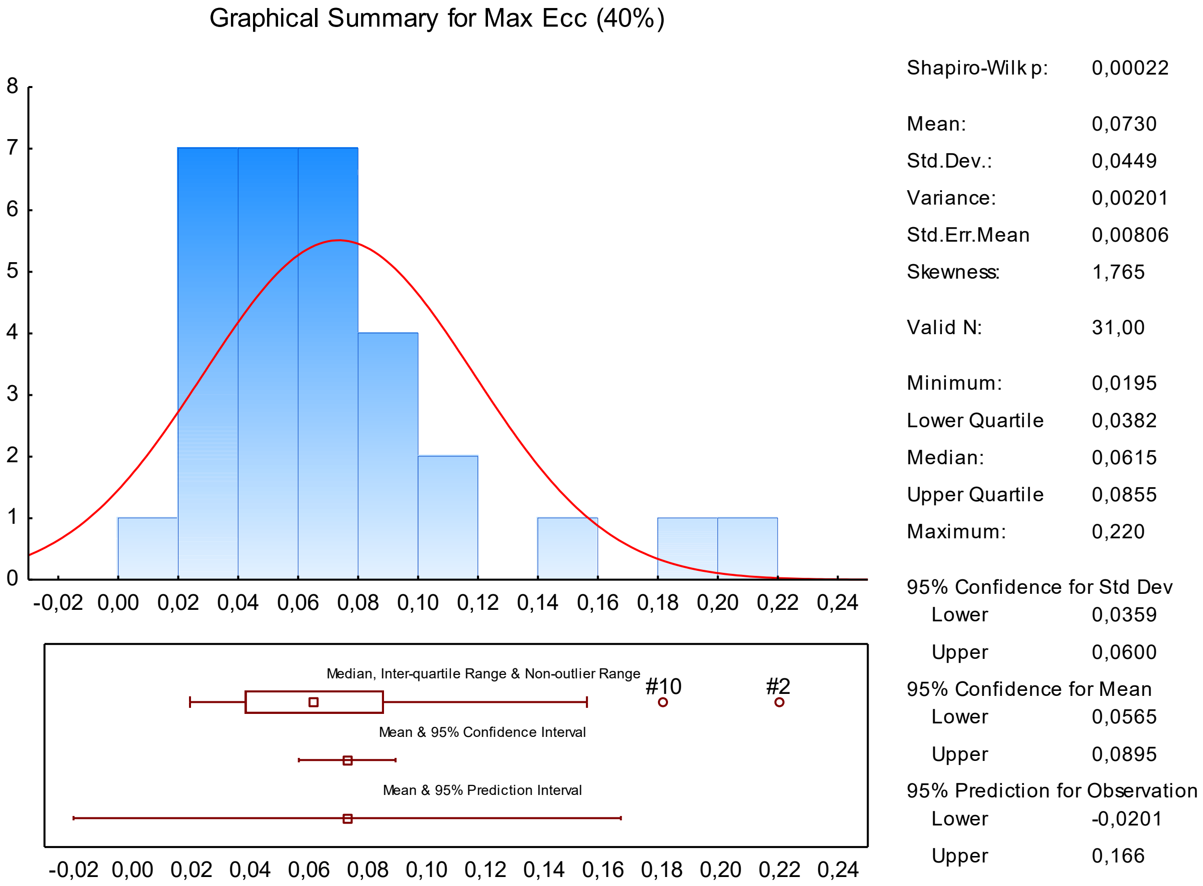
Isometric 20%



Shapiro-Wilk p:	0,00001
Mean:	0,0884
Std.Dev.:	0,0760
Variance:	0,00577
Std.Err.Mean	0,0136
Skewness:	1,719
Valid N:	31,00
Minimum:	0,0217
Lower Quartile	0,0412
Median:	0,0577
Upper Quartile	0,114
Maximum:	0,315
95% Confidence for Std Dev	
Lower	0,0607
Upper	0,102
95% Confidence for Mean	
Lower	0,0606
Upper	0,116
95% Prediction for Observation	
Lower	-0,0692
Upper	0,246

Figure 42: Shapiro-Wilks test and Box & whisker plots for Maximal EMG during isometric 20% of MVE.

Isometric 40%



Shapiro-Wilk p:	0,00022
Mean:	0,0730
Std.Dev.:	0,0449
Variance:	0,00201
Std.Err.Mean	0,00806
Skewness:	1,765
Valid N:	31,00
Minimum:	0,0195
Lower Quartile	0,0382
Median:	0,0615
Upper Quartile	0,0855
Maximum:	0,220
95% Confidence for Std Dev	
Lower	0,0359
Upper	0,0600
95% Confidence for Mean	
Lower	0,0565
Upper	0,0895
95% Prediction for Observation	
Lower	-0,0201
Upper	0,166

Figure 43: Shapiro-Wilks test and Box & whisker plots for Maximal EMG during isometric 40% of MVE.

.

Isometric 60%

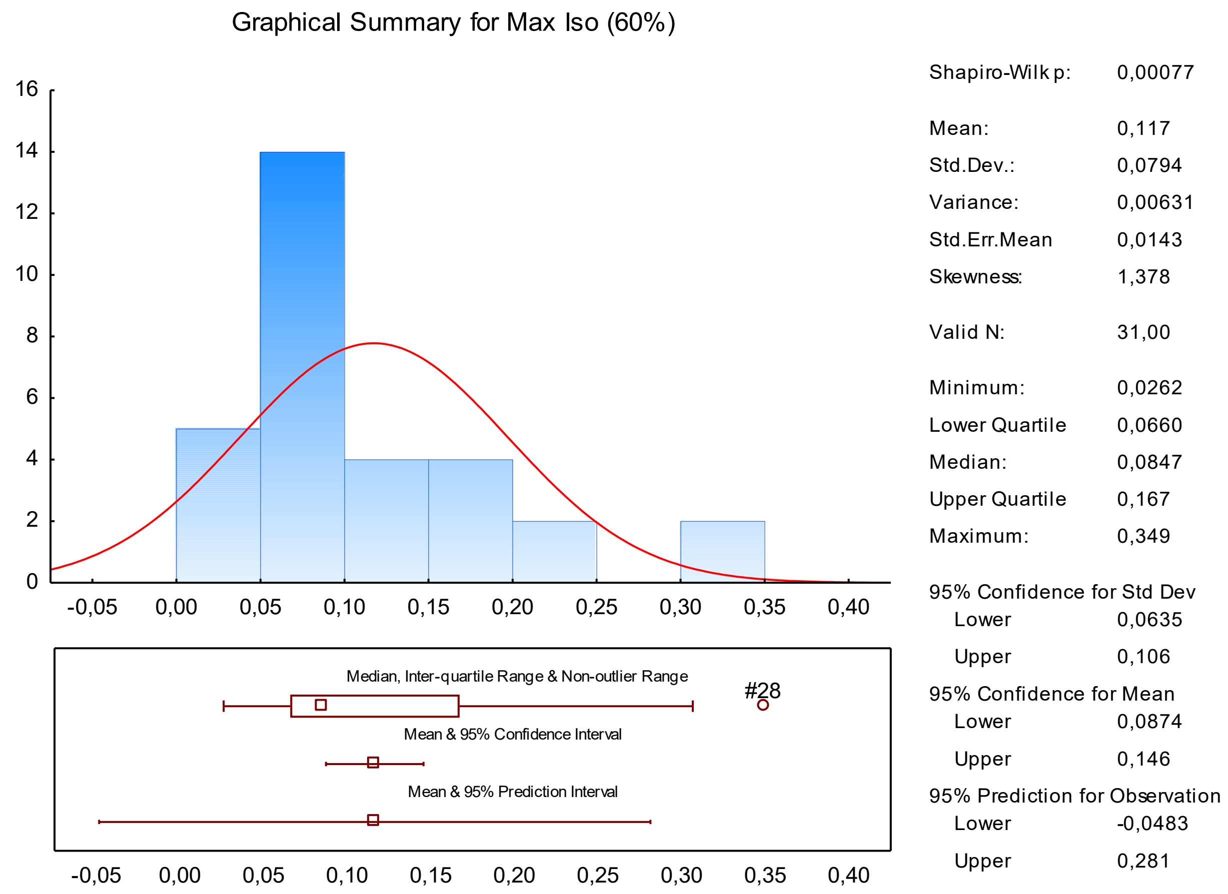
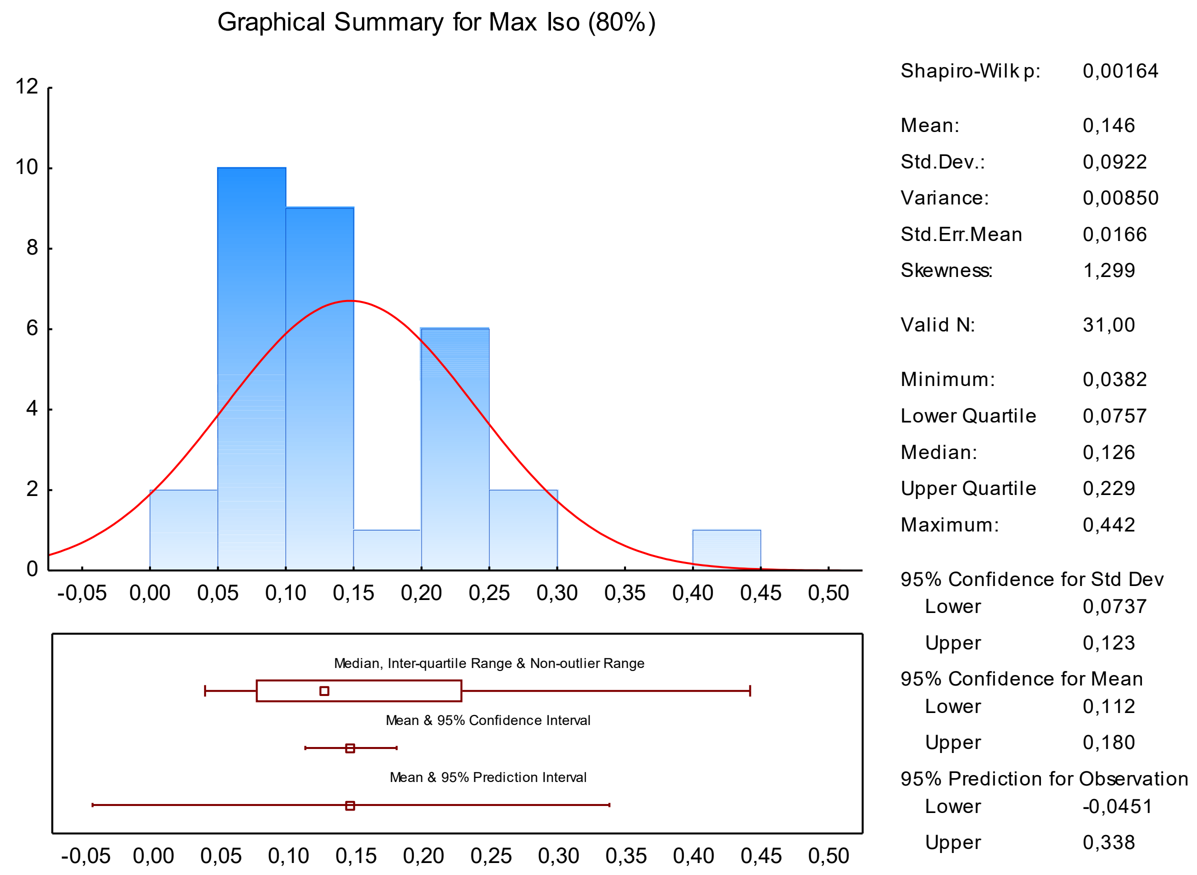


Figure 44: Shapiro-Wilks test and Box & whisker plots for Maximal EMG during isometric 60% of MVE.

Isometric 80%

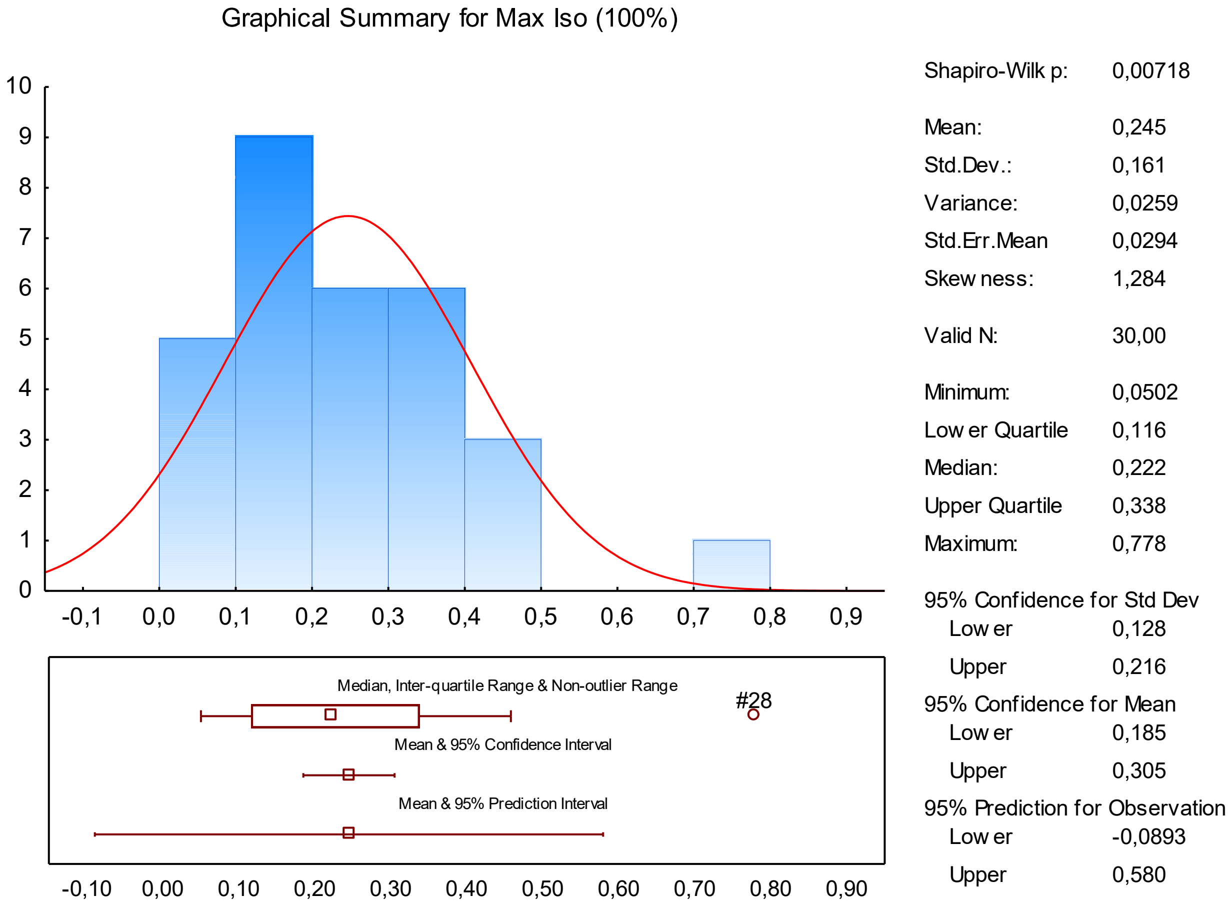


Shapiro-Wilk p:	0,00164
Mean:	0,146
Std.Dev.:	0,0922
Variance:	0,00850
Std.Err.Mean	0,0166
Skewness:	1,299
Valid N:	31,00
Minimum:	0,0382
Lower Quartile	0,0757
Median:	0,126
Upper Quartile	0,229
Maximum:	0,442
95% Confidence for Std Dev	
Lower	0,0737
Upper	0,123
95% Confidence for Mean	
Lower	0,112
Upper	0,180
95% Prediction for Observation	
Lower	-0,0451
Upper	0,338

Figure 45: Shapiro-Wilks test and Box & whisker plots for Maximal EMG during isometric 80% of MVE.

.

Isometric 100%

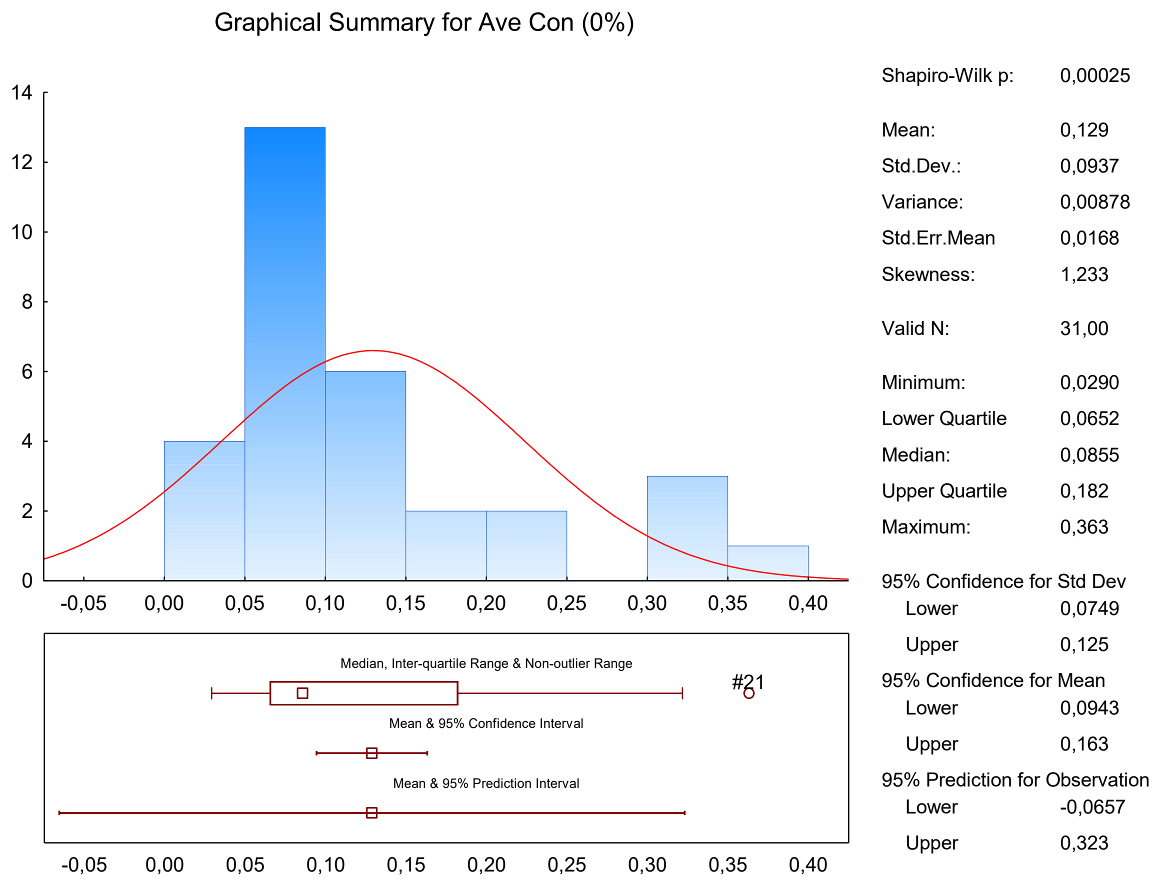


Shapiro-Wilk p:	0,00718
Mean:	0,245
Std.Dev.:	0,161
Variance:	0,0259
Std.Err.Mean	0,0294
Skewness:	1,284
Valid N:	30,00
Minimum:	0,0502
Lower Quartile	0,116
Median:	0,222
Upper Quartile	0,338
Maximum:	0,778
95% Confidence for Std Dev	
Lower	0,128
Upper	0,216
95% Confidence for Mean	
Lower	0,185
Upper	0,305
95% Prediction for Observation	
Lower	-0,0893
Upper	0,580

Figure 46: Shapiro-Wilks test and Box & whisker plots for Maximal EMG during isometric 100% of MVE.

D.1.3.2. Muscle Actions (%MVE) average sEMG

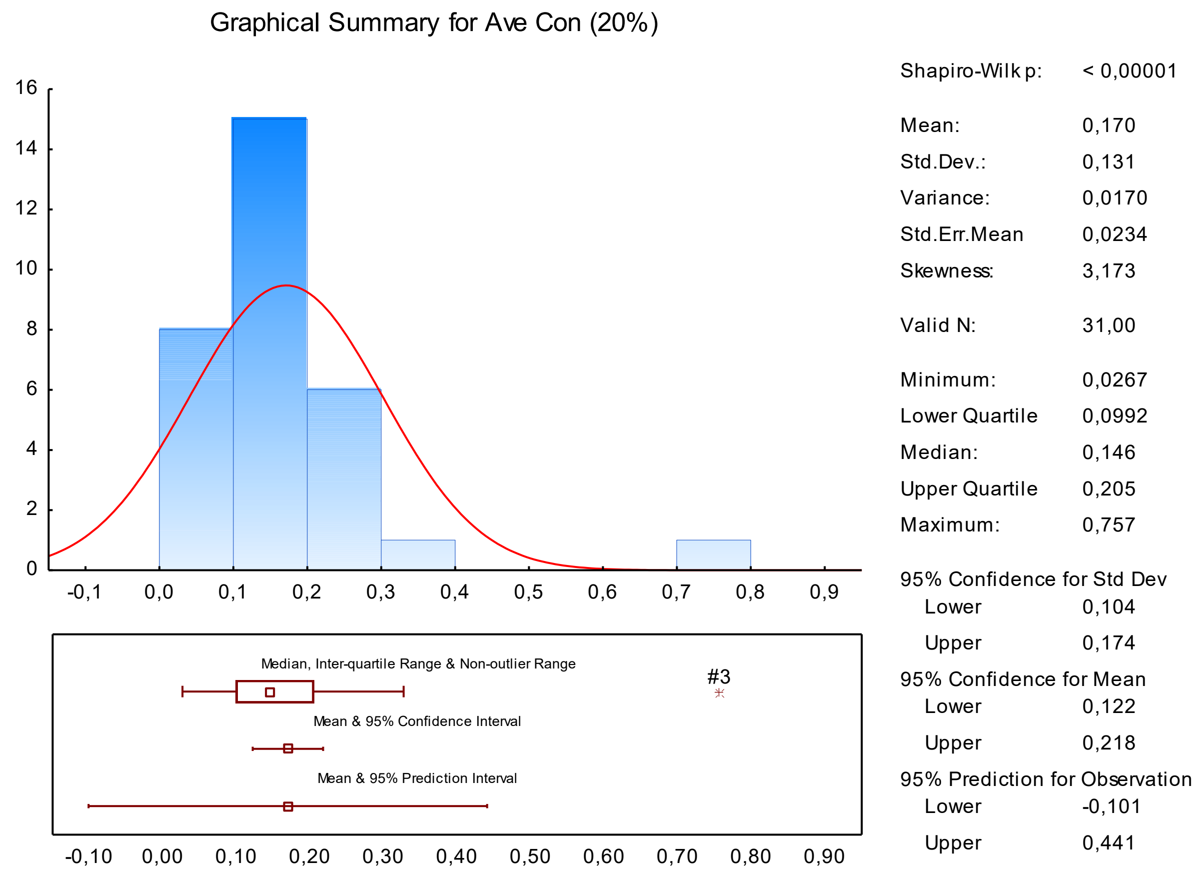
Concentric 0%


Graphical Summary for Ave Con (0%)

Shapiro-Wilk p:	0,00025
Mean:	0,129
Std.Dev.:	0,0937
Variance:	0,00878
Std.Err.Mean	0,0168
Skewness:	1,233
Valid N:	31,00
Minimum:	0,0290
Lower Quartile	0,0652
Median:	0,0855
Upper Quartile	0,182
Maximum:	0,363
95% Confidence for Std Dev	
Lower	0,0749
Upper	0,125
95% Confidence for Mean	
Lower	0,0943
Upper	0,163
95% Prediction for Observation	
Lower	-0,0657
Upper	0,323

Figure 47: Shapiro-Wilks test and Box & whisker plots for average EMG amplitude during concentric 0% of MVE.

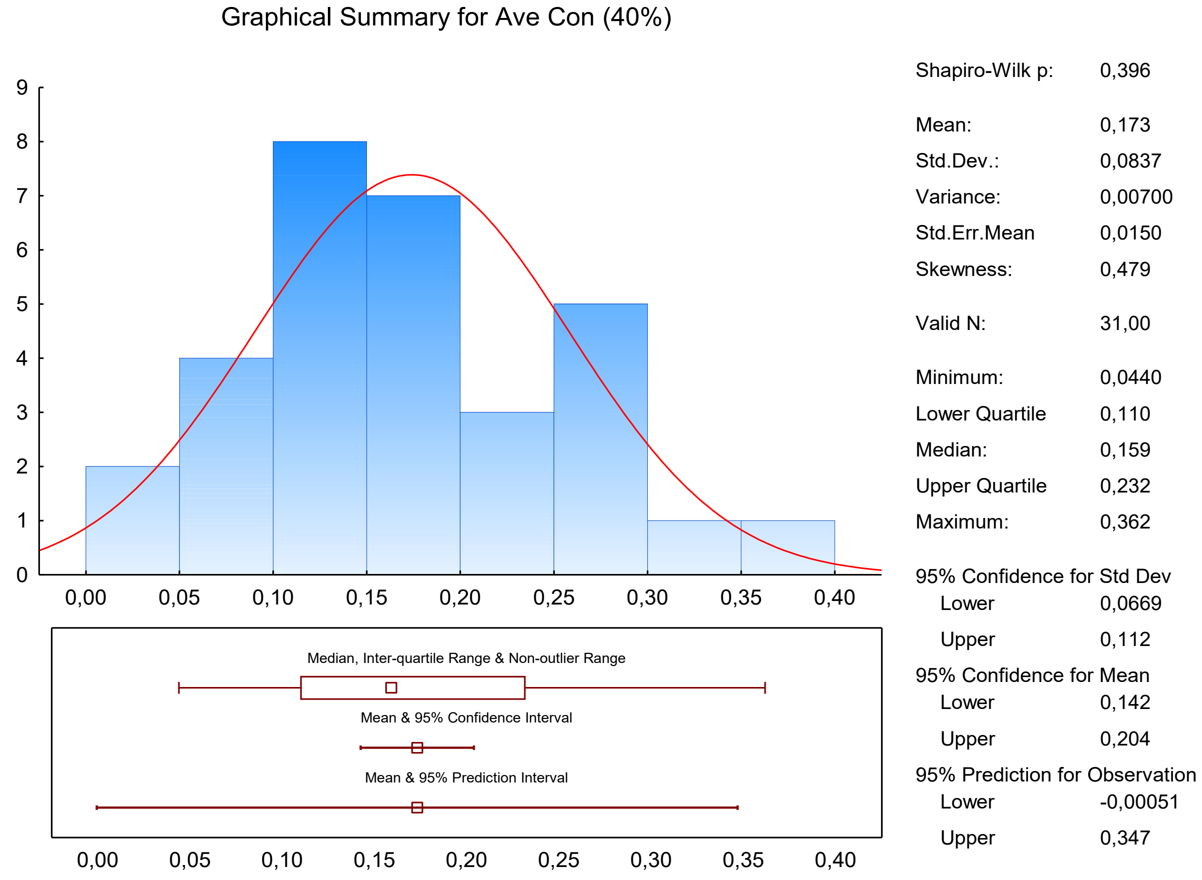
Concentric 20%



Shapiro-Wilk p:	< 0,00001
Mean:	0,170
Std.Dev.:	0,131
Variance:	0,0170
Std.Err.Mean	0,0234
Skewness:	3,173
Valid N:	31,00
Minimum:	0,0267
Lower Quartile	0,0992
Median:	0,146
Upper Quartile	0,205
Maximum:	0,757
95% Confidence for Std Dev	
Lower	0,104
Upper	0,174
95% Confidence for Mean	
Lower	0,122
Upper	0,218
95% Prediction for Observation	
Lower	-0,101
Upper	0,441

Figure 48: Shapiro-Wilks test and Box & whisker plots for average EMG amplitude during concentric 20% of MVE.

Concentric 40%

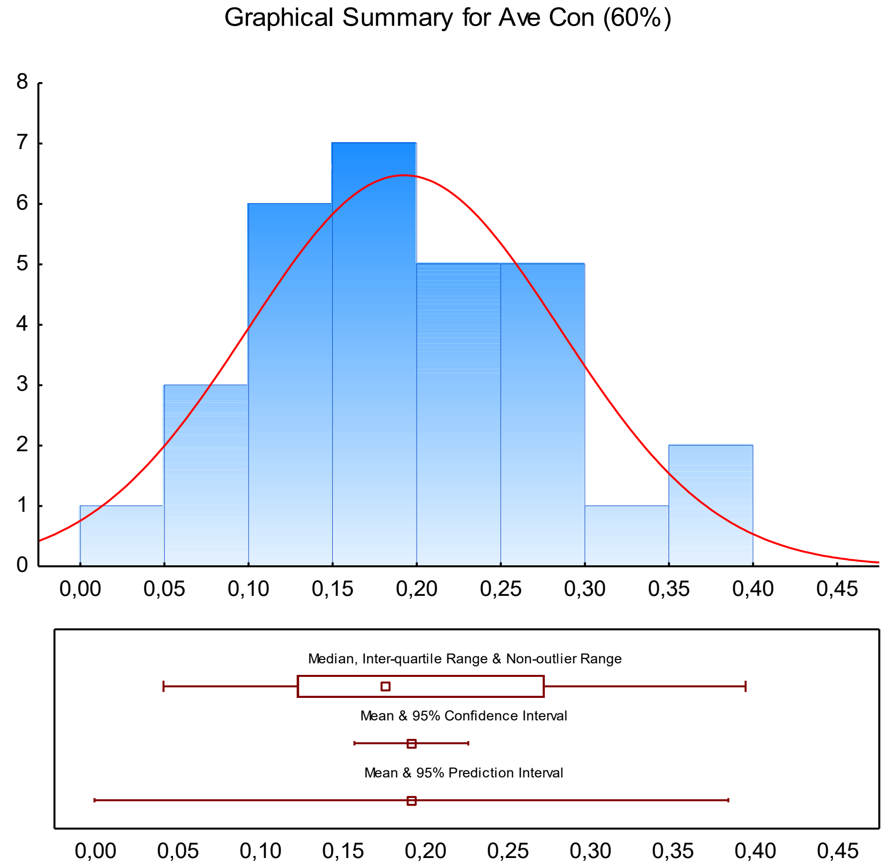


Shapiro-Wilk p:	0,396
Mean:	0,173
Std.Dev.:	0,0837
Variance:	0,00700
Std.Err.Mean	0,0150
Skewness:	0,479
Valid N:	31,00
Minimum:	0,0440
Lower Quartile	0,110
Median:	0,159
Upper Quartile	0,232
Maximum:	0,362
95% Confidence for Std Dev	
Lower	0,0669
Upper	0,112
95% Confidence for Mean	
Lower	0,142
Upper	0,204
95% Prediction for Observation	
Lower	-0,00051
Upper	0,347

Figure 49: Shapiro-Wilks test and Box & whisker plots for average EMG amplitude during concentric 40% of MVE.

.

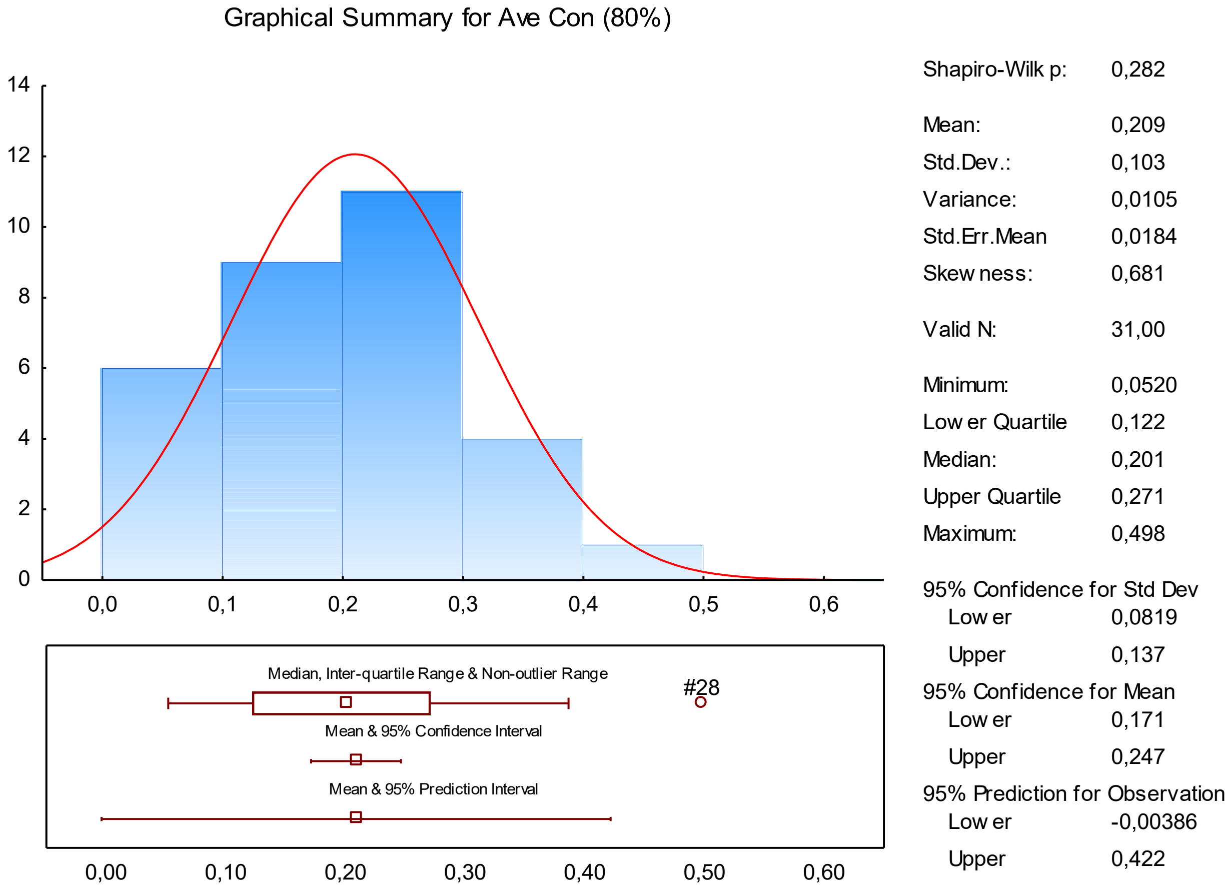
Concentric 60%



Shapiro-Wilk p:	0,269
Mean:	0,191
Std.Dev.:	0,0924
Variance:	0,00854
Std.Err.Mean	0,0169
Skewness:	0,571
Valid N:	30,00
Minimum:	0,0411
Lower Quartile	0,122
Median:	0,175
Upper Quartile	0,272
Maximum:	0,394
95% Confidence for Std Dev	
Lower	0,0736
Upper	0,124
95% Confidence for Mean	
Lower	0,157
Upper	0,226
95% Prediction for Observation	
Lower	-0,00073
Upper	0,384

Figure 50: Shapiro-Wilks test and Box & whisker plots for average EMG amplitude during concentric 60% of MVE.

Concentric 80%

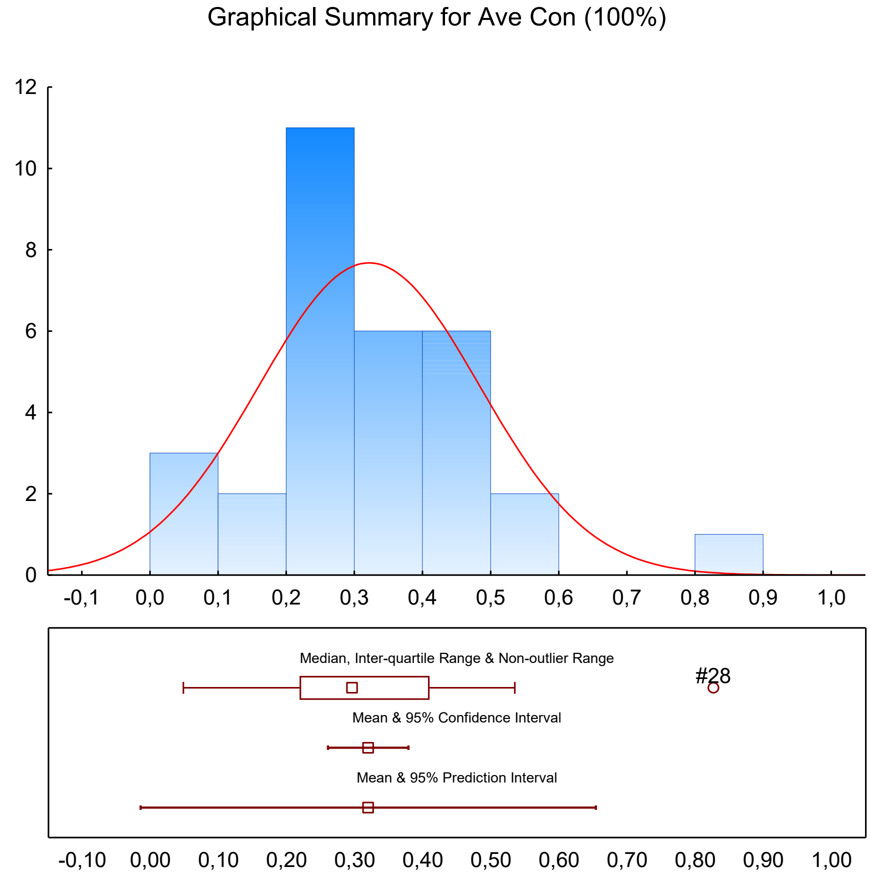


Shapiro-Wilk p:	0,282
Mean:	0,209
Std.Dev.:	0,103
Variance:	0,0105
Std.Err.Mean	0,0184
Skewness:	0,681
Valid N:	31,00
Minimum:	0,0520
Lower Quartile	0,122
Median:	0,201
Upper Quartile	0,271
Maximum:	0,498
95% Confidence for Std Dev	
Lower	0,0819
Upper	0,137
95% Confidence for Mean	
Lower	0,171
Upper	0,247
95% Prediction for Observation	
Lower	-0,00386
Upper	0,422

Figure 51: Shapiro-Wilks test and Box & whisker plots for average EMG amplitude during concentric 80% of MVE.

.

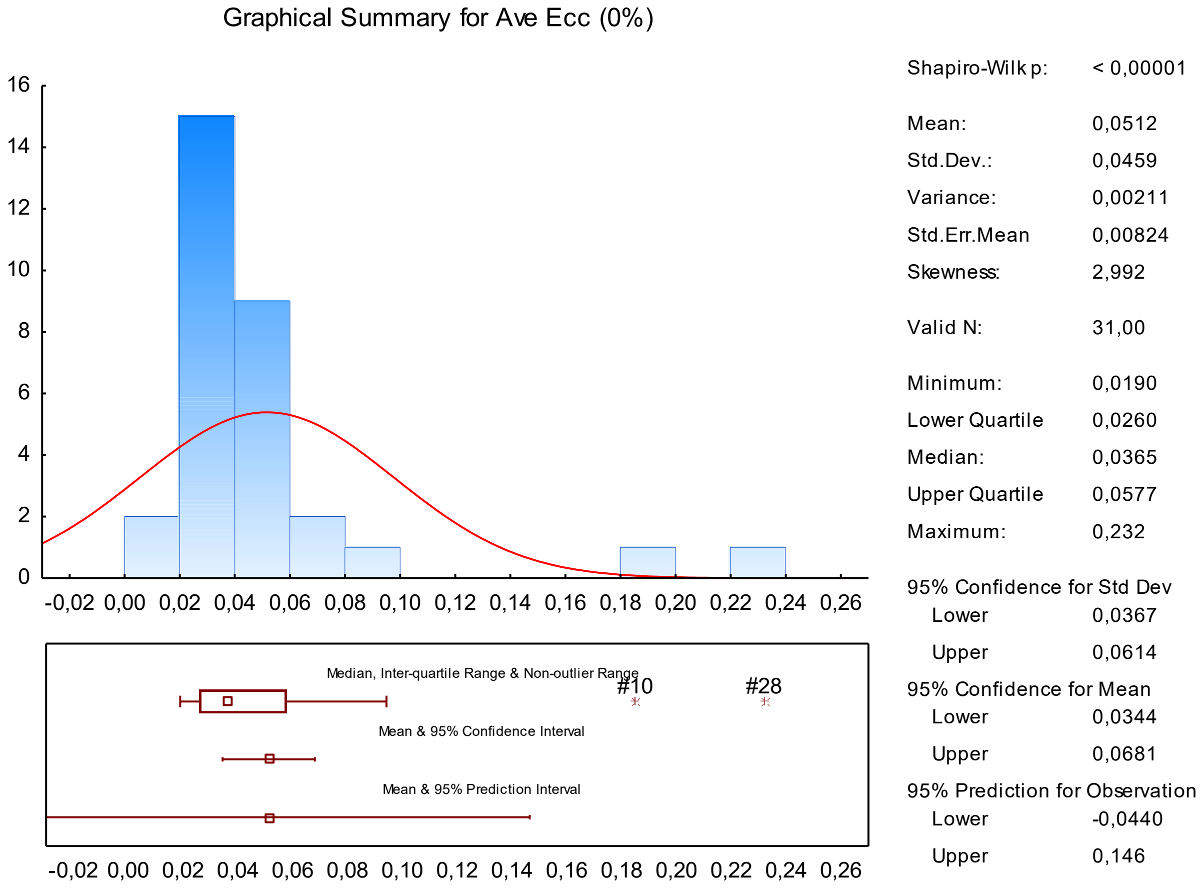
Concentric 100%



Shapiro-Wilk p:	0,144
Mean:	0,320
Std.Dev.:	0,161
Variance:	0,0259
Std.Err.Mean	0,0289
Skewness:	0,800
Valid N:	31,00
Minimum:	0,0482
Lower Quartile	0,219
Median:	0,295
Upper Quartile	0,409
Maximum:	0,826
95% Confidence for Std Dev	
Lower	0,129
Upper	0,215
95% Confidence for Mean	
Lower	0,260
Upper	0,379
95% Prediction for Observation	
Lower	-0,0147
Upper	0,654

Figure 52: Shapiro-Wilks test and Box & whisker plots for average EMG amplitude during concentric 100% of MVE.

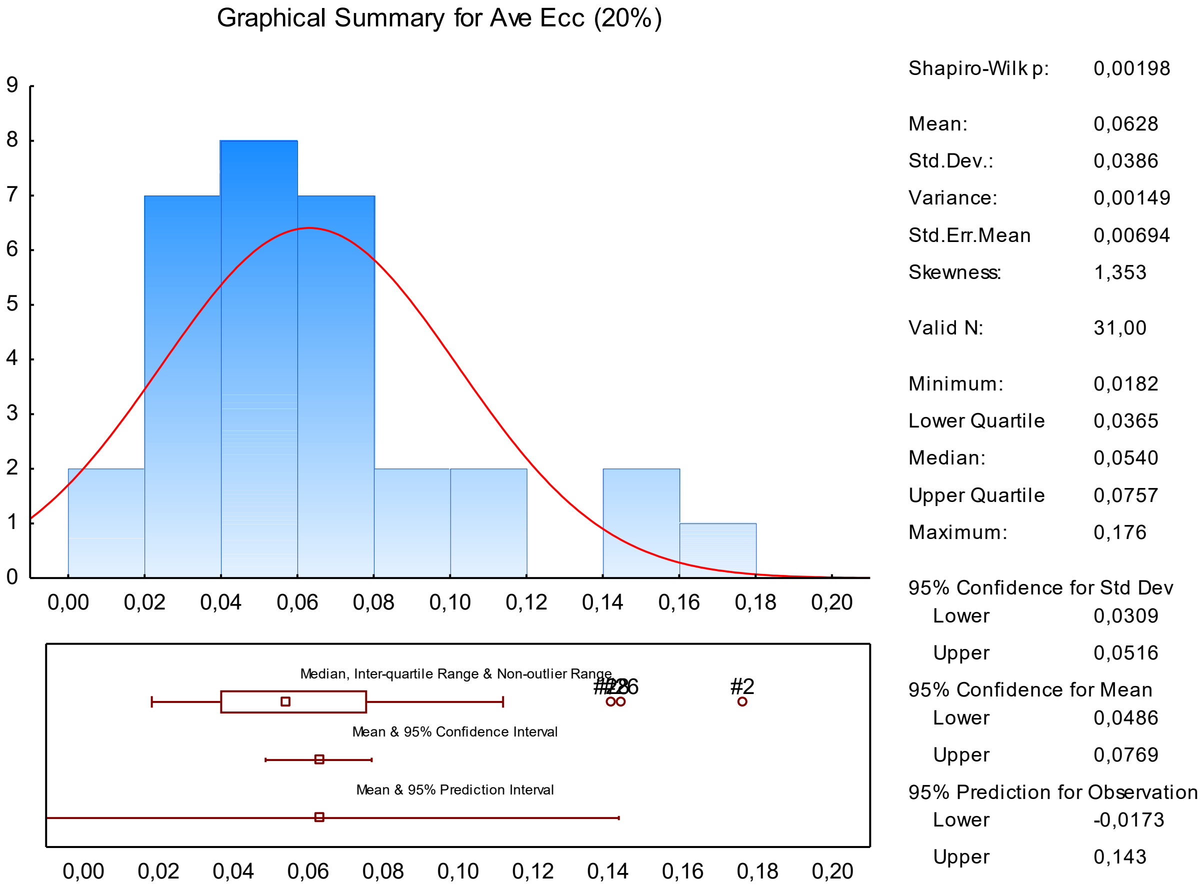
Eccentric 0%



Shapiro-Wilk p:	< 0,00001
Mean:	0,0512
Std.Dev.:	0,0459
Variance:	0,00211
Std.Err.Mean	0,00824
Skewness:	2,992
Valid N:	31,00
Minimum:	0,0190
Lower Quartile	0,0260
Median:	0,0365
Upper Quartile	0,0577
Maximum:	0,232
95% Confidence for Std Dev	
Lower	0,0367
Upper	0,0614
95% Confidence for Mean	
Lower	0,0344
Upper	0,0681
95% Prediction for Observation	
Lower	-0,0440
Upper	0,146

Figure 53: Shapiro-Wilks test and Box & whisker plots for average EMG amplitude during eccentric 0% of MVE.

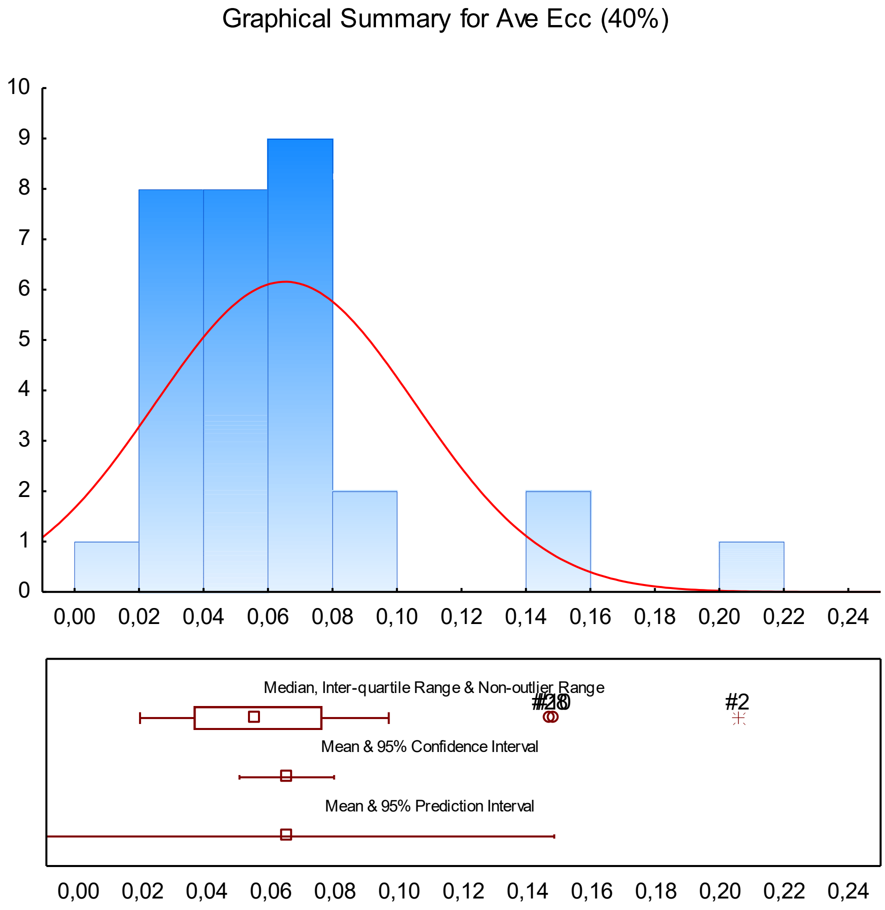
Eccentric 20%



Shapiro-Wilk p:	0,00198
Mean:	0,0628
Std.Dev.:	0,0386
Variance:	0,00149
Std.Err.Mean	0,00694
Skewness:	1,353
Valid N:	31,00
Minimum:	0,0182
Lower Quartile	0,0365
Median:	0,0540
Upper Quartile	0,0757
Maximum:	0,176
95% Confidence for Std Dev	
Lower	0,0309
Upper	0,0516
95% Confidence for Mean	
Lower	0,0486
Upper	0,0769
95% Prediction for Observation	
Lower	-0,0173
Upper	0,143

Figure 54: Shapiro-Wilks test and Box & whisker plots for average EMG amplitude during eccentric 20% of MVE.

Eccentric 40%

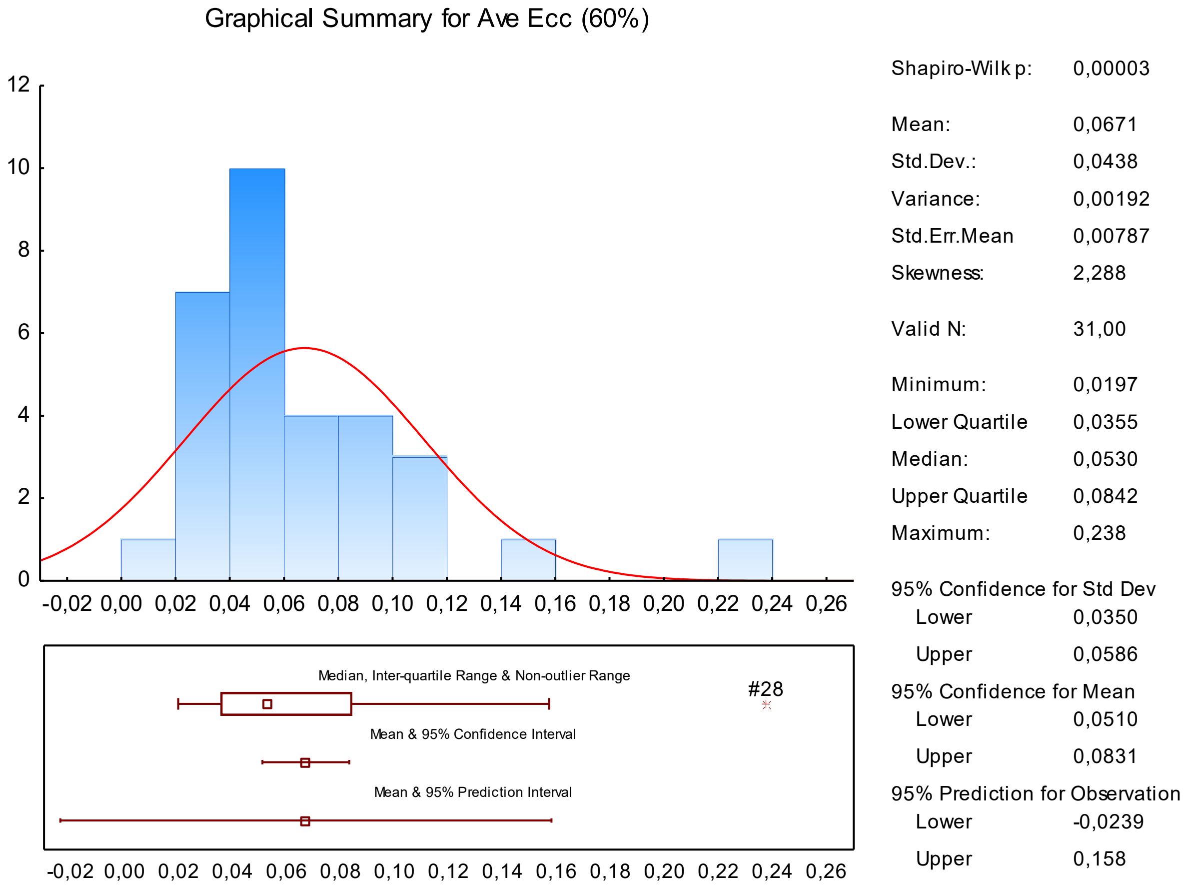


Shapiro-Wilk p:	0,00008
Mean:	0,0650
Std.Dev.:	0,0402
Variance:	0,00161
Std.Err.Mean	0,00722
Skewness:	1,936
Valid N:	31,00
Minimum:	0,0192
Lower Quartile	0,0360
Median:	0,0550
Upper Quartile	0,0760
Maximum:	0,205
95% Confidence for Std Dev	
Lower	0,0321
Upper	0,0537
95% Confidence for Mean	
Lower	0,0502
Upper	0,0797
95% Prediction for Observation	
Lower	-0,0184
Upper	0,148

Figure 55: Shapiro-Wilks test and Box & whisker plots for average EMG amplitude during eccentric 40% of MVE.

.

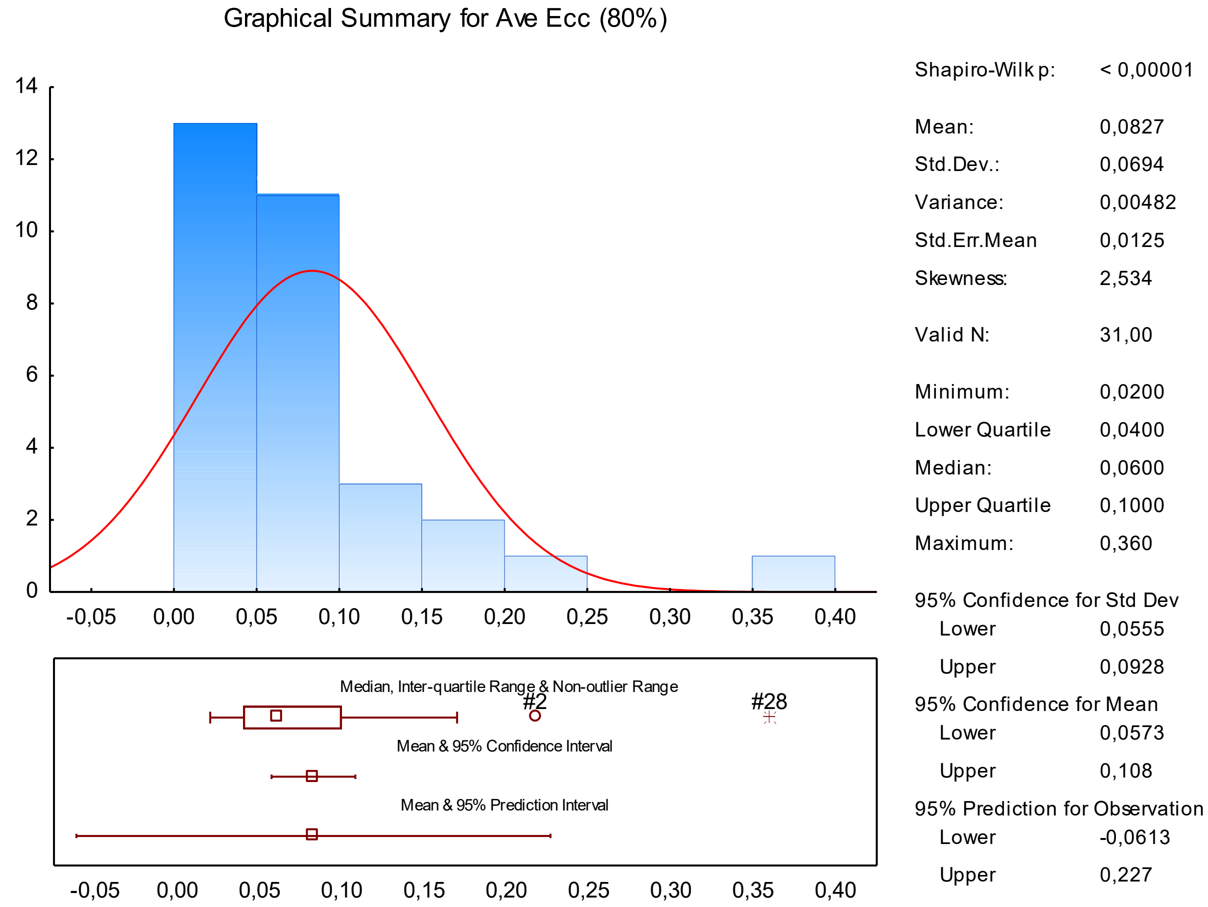
Eccentric 60%



Shapiro-Wilk p:	0,00003
Mean:	0,0671
Std.Dev.:	0,0438
Variance:	0,00192
Std.Err.Mean	0,00787
Skewness:	2,288
Valid N:	31,00
Minimum:	0,0197
Lower Quartile	0,0355
Median:	0,0530
Upper Quartile	0,0842
Maximum:	0,238
95% Confidence for Std Dev	
Lower	0,0350
Upper	0,0586
95% Confidence for Mean	
Lower	0,0510
Upper	0,0831
95% Prediction for Observation	
Lower	-0,0239
Upper	0,158

Figure 56: Shapiro-Wilks test and Box & whisker plots for average EMG amplitude during eccentric 60% of MVE.

Eccentric 80%

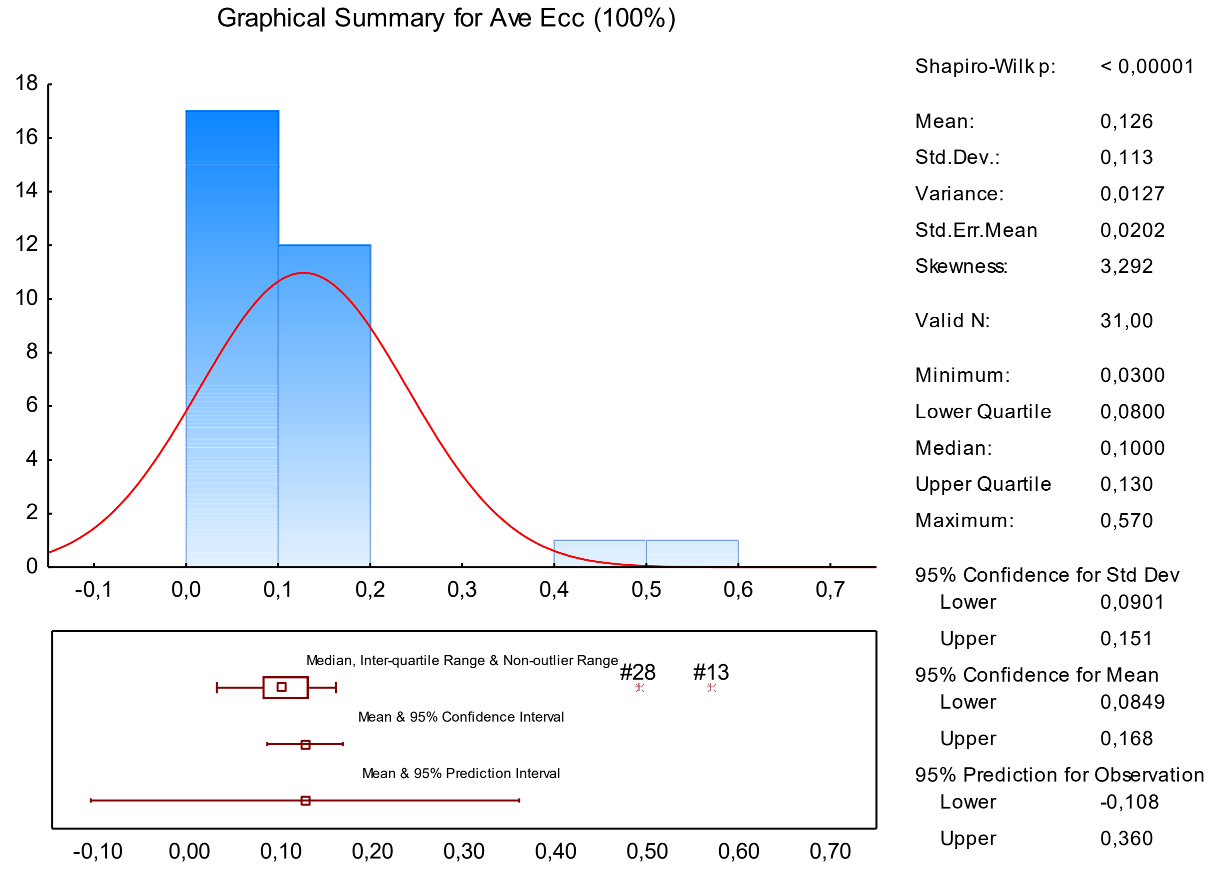

Graphical Summary for Ave Ecc (80%)

Shapiro-Wilk p:	< 0,00001
Mean:	0,0827
Std.Dev.:	0,0694
Variance:	0,00482
Std.Err.Mean	0,0125
Skewness:	2,534
Valid N:	31,00
Minimum:	0,0200
Lower Quartile	0,0400
Median:	0,0600
Upper Quartile	0,1000
Maximum:	0,360
95% Confidence for Std Dev	
Lower	0,0555
Upper	0,0928
95% Confidence for Mean	
Lower	0,0573
Upper	0,108
95% Prediction for Observation	
Lower	-0,0613
Upper	0,227

Figure 57: Shapiro-Wilks test and Box & whisker plots for average EMG amplitude during eccentric 80% of MVE.

.

Eccentric 100%



Shapiro-Wilk p:	< 0,00001
Mean:	0,126
Std.Dev.:	0,113
Variance:	0,0127
Std.Err.Mean	0,0202
Skewness:	3,292
Valid N:	31,00
Minimum:	0,0300
Lower Quartile	0,0800
Median:	0,1000
Upper Quartile	0,130
Maximum:	0,570
95% Confidence for Std Dev	
Lower	0,0901
Upper	0,151
95% Confidence for Mean	
Lower	0,0849
Upper	0,168
95% Prediction for Observation	
Lower	-0,108
Upper	0,360

Figure 58: Shapiro-Wilks test and Box & whisker plots for average EMG amplitude during concentric 100% of MVE.

Isometric 0%

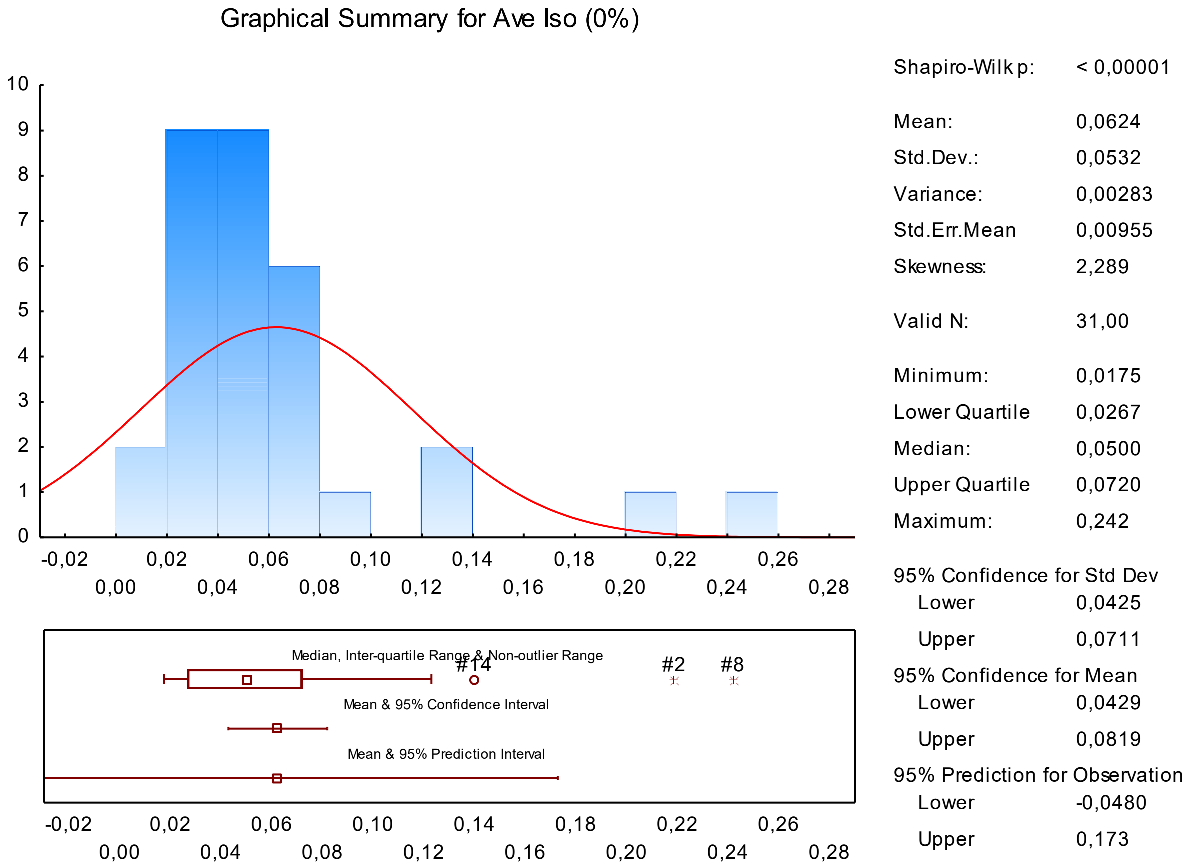
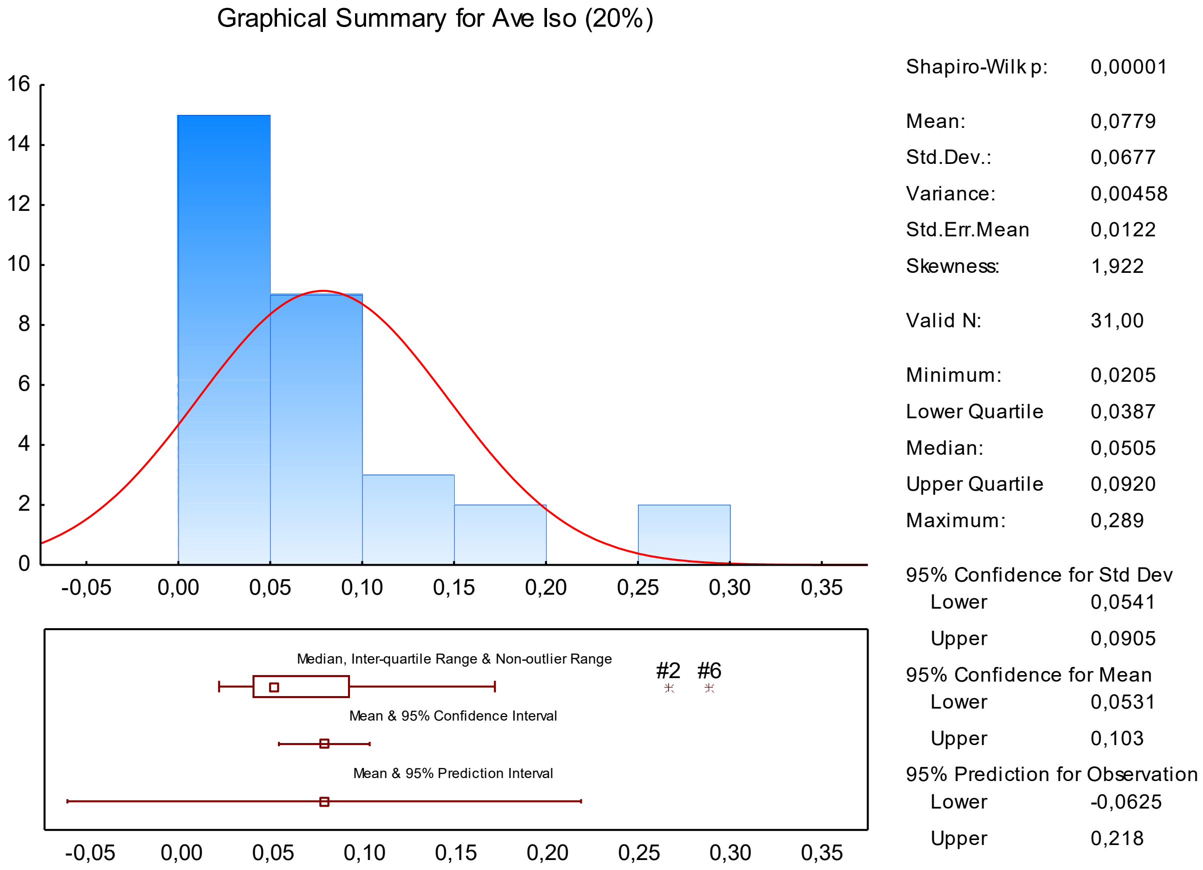


Figure 59: Shapiro-Wilks test and Box & whisker plots for average EMG amplitude during isometric 0% of MVE.

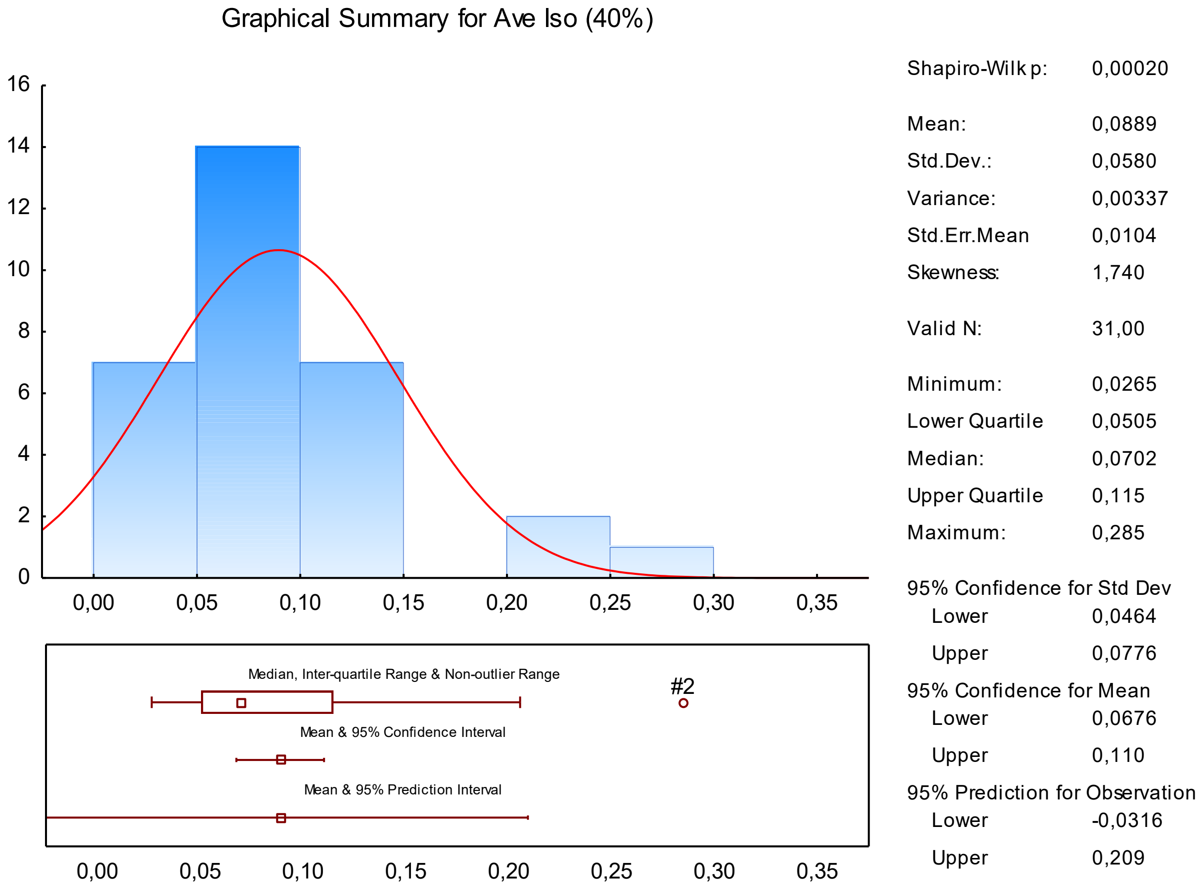
Isometric 20%



Shapiro-Wilk p:	0,00001
Mean:	0,0779
Std.Dev.:	0,0677
Variance:	0,00458
Std.Err.Mean	0,0122
Skewness:	1,922
Valid N:	31,00
Minimum:	0,0205
Lower Quartile	0,0387
Median:	0,0505
Upper Quartile	0,0920
Maximum:	0,289
95% Confidence for Std Dev	
Lower	0,0541
Upper	0,0905
95% Confidence for Mean	
Lower	0,0531
Upper	0,103
95% Prediction for Observation	
Lower	-0,0625
Upper	0,218

Figure 60: Shapiro-Wilks test and Box & whisker plots for average EMG amplitude during isometric 20% of MVE.

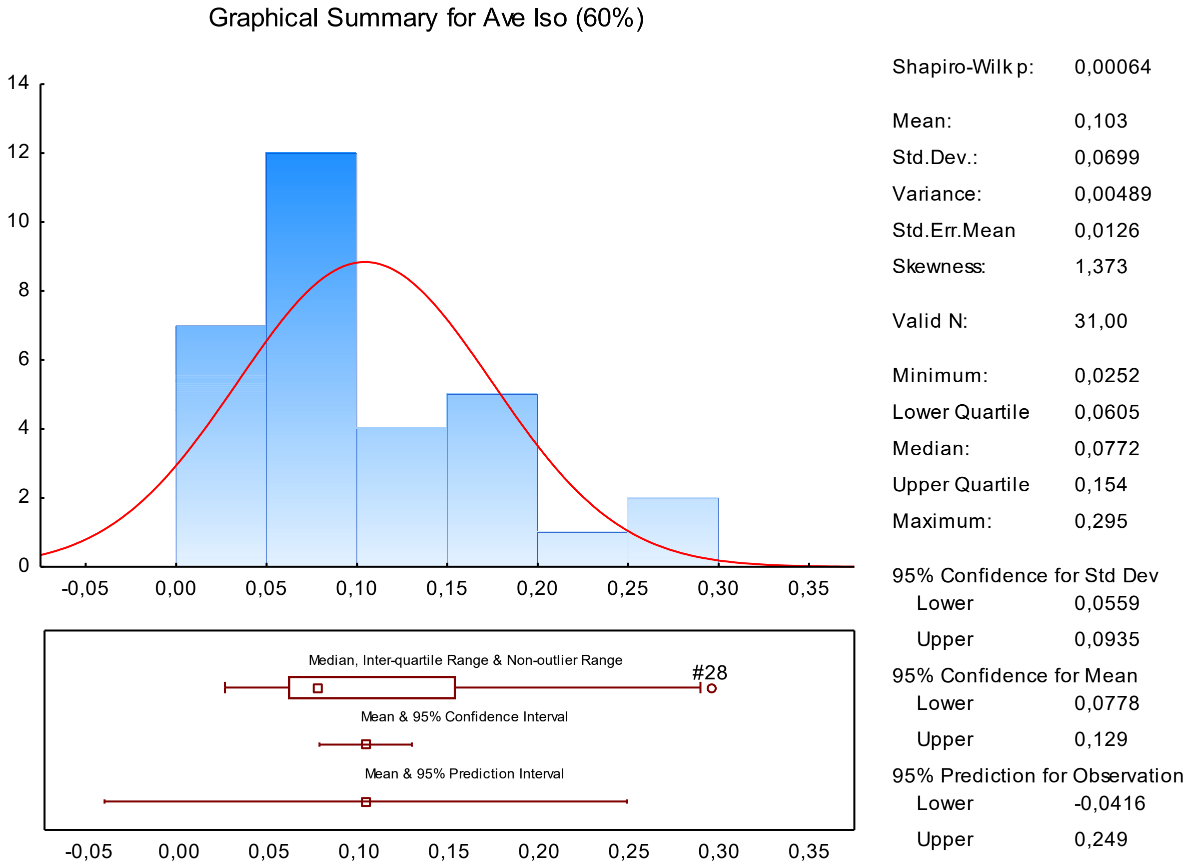
Isometric 40%



Shapiro-Wilk p:	0,00020
Mean:	0,0889
Std.Dev.:	0,0580
Variance:	0,00337
Std.Err.Mean	0,0104
Skewness:	1,740
Valid N:	31,00
Minimum:	0,0265
Lower Quartile	0,0505
Median:	0,0702
Upper Quartile	0,115
Maximum:	0,285
95% Confidence for Std Dev	
Lower	0,0464
Upper	0,0776
95% Confidence for Mean	
Lower	0,0676
Upper	0,110
95% Prediction for Observation	
Lower	-0,0316
Upper	0,209

Figure 61: Shapiro-Wilks test and Box & whisker plots for average EMG amplitude during isometric 40% of MVE.

Isometric 60%

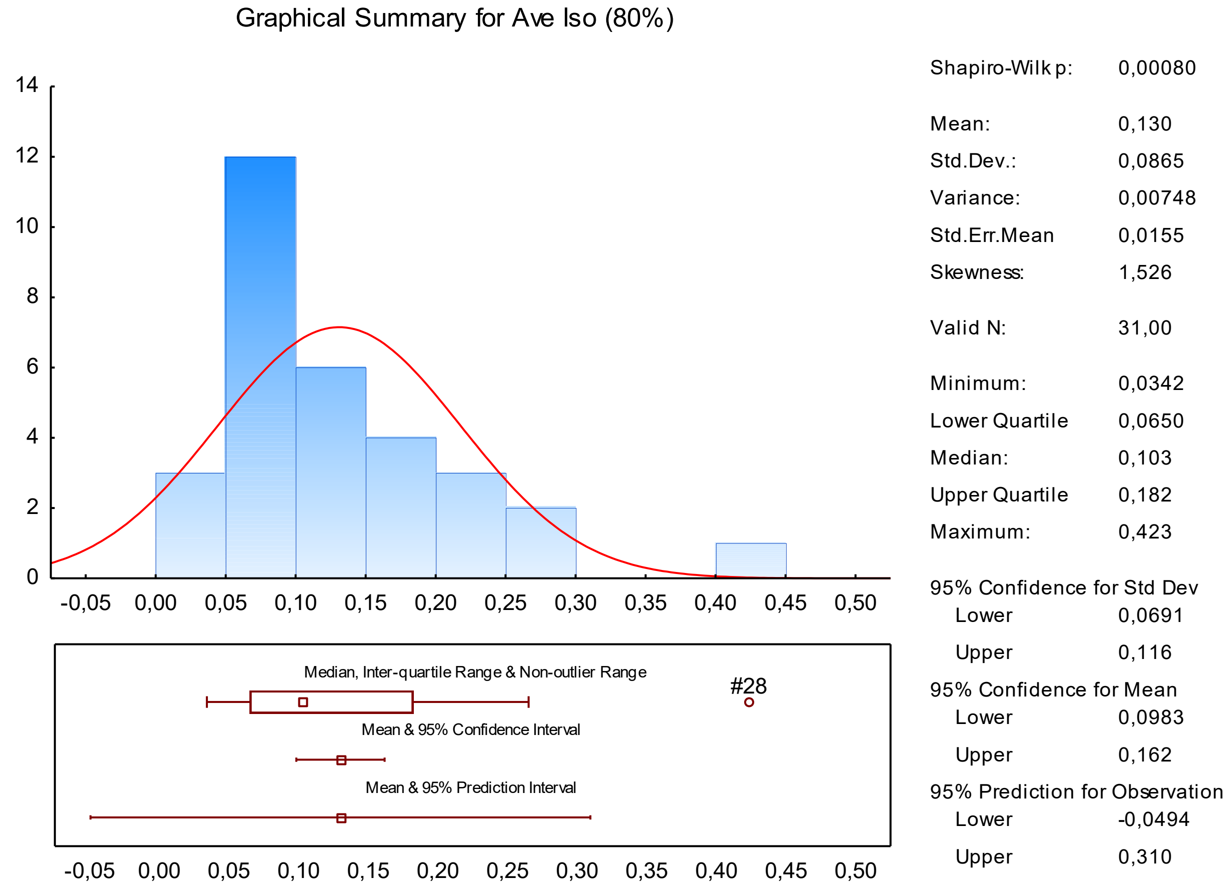


Graphical Summary for Ave Iso (60%)

Shapiro-Wilk p:	0,00064
Mean:	0,103
Std.Dev.:	0,0699
Variance:	0,00489
Std.Err.Mean	0,0126
Skewness:	1,373
Valid N:	31,00
Minimum:	0,0252
Lower Quartile	0,0605
Median:	0,0772
Upper Quartile	0,154
Maximum:	0,295
95% Confidence for Std Dev	
Lower	0,0559
Upper	0,0935
95% Confidence for Mean	
Lower	0,0778
Upper	0,129
95% Prediction for Observation	
Lower	-0,0416
Upper	0,249

Figure 62: Shapiro-Wilks test and Box & whisker plots for average EMG amplitude during isometric 60% of MVE.

Isometric 80%

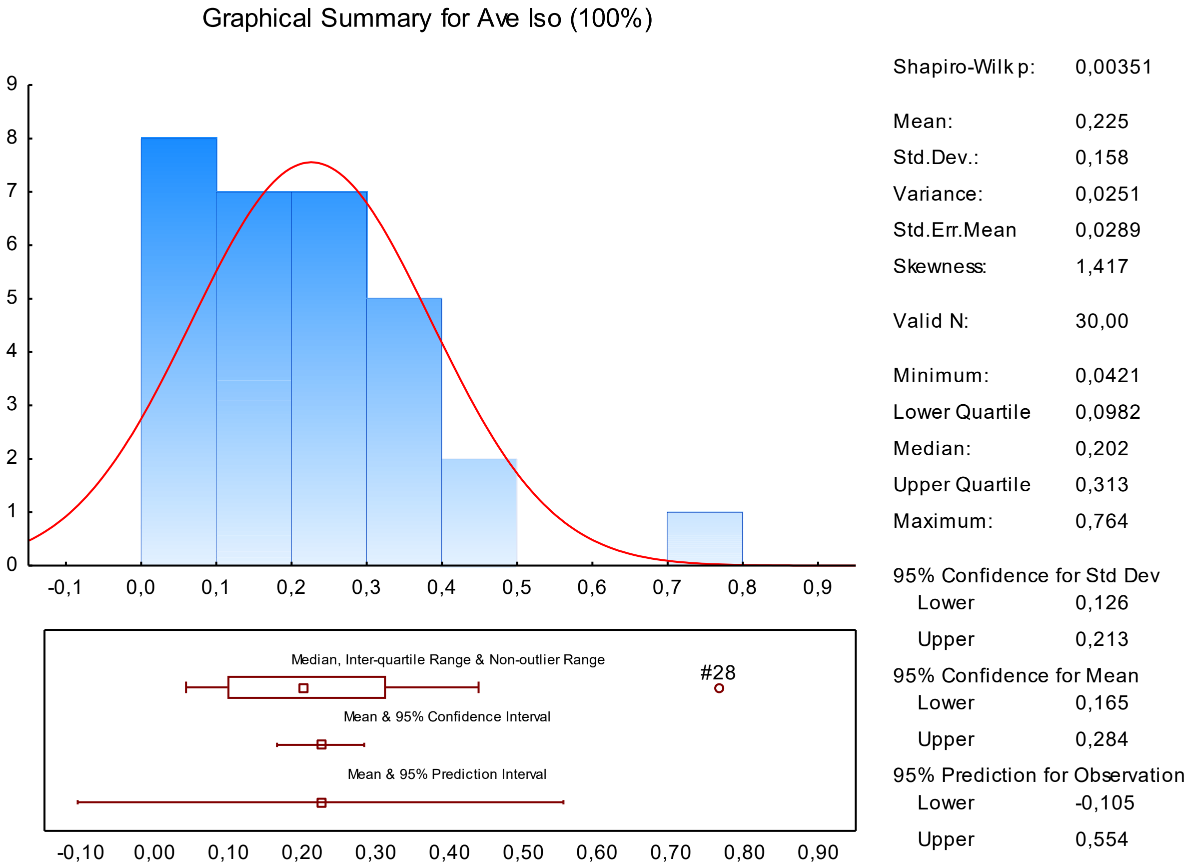


Shapiro-Wilk p:	0,00080
Mean:	0,130
Std.Dev.:	0,0865
Variance:	0,00748
Std.Err.Mean	0,0155
Skewness:	1,526
Valid N:	31,00
Minimum:	0,0342
Lower Quartile	0,0650
Median:	0,103
Upper Quartile	0,182
Maximum:	0,423
95% Confidence for Std Dev	
Lower	0,0691
Upper	0,116
95% Confidence for Mean	
Lower	0,0983
Upper	0,162
95% Prediction for Observation	
Lower	-0,0494
Upper	0,310

Figure 63: Shapiro-Wilks test and Box & whisker plots for average EMG amplitude during isometric 80% of MVE.

.

Isometric 100%

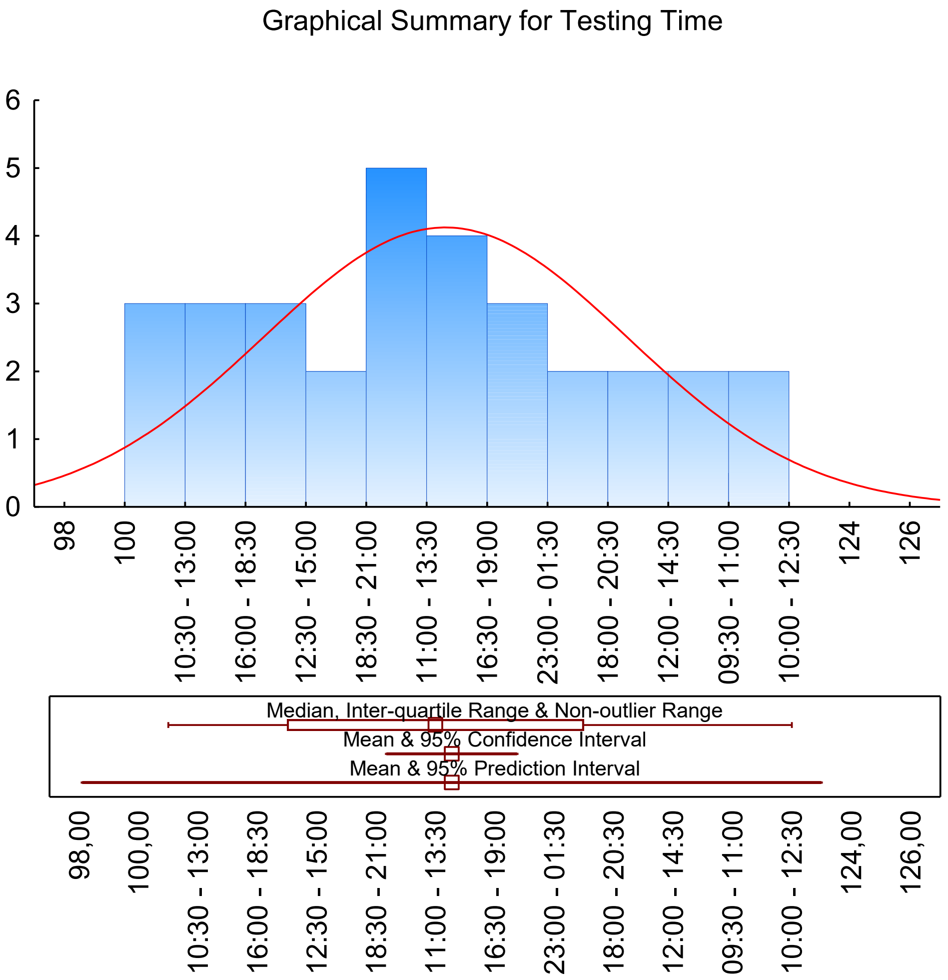


Shapiro-Wilk p:	0,00351
Mean:	0,225
Std.Dev.:	0,158
Variance:	0,0251
Std.Err.Mean	0,0289
Skewness:	1,417
Valid N:	30,00
Minimum:	0,0421
Lower Quartile	0,0982
Median:	0,202
Upper Quartile	0,313
Maximum:	0,764
95% Confidence for Std Dev	
Lower	0,126
Upper	0,213
95% Confidence for Mean	
Lower	0,165
Upper	0,284
95% Prediction for Observation	
Lower	-0,105
Upper	0,554

Figure 64: Shapiro-Wilks test and Box & whisker plots for average EMG amplitude during isometric 100% of MVE.

D.1.4. Time of day (ToD)

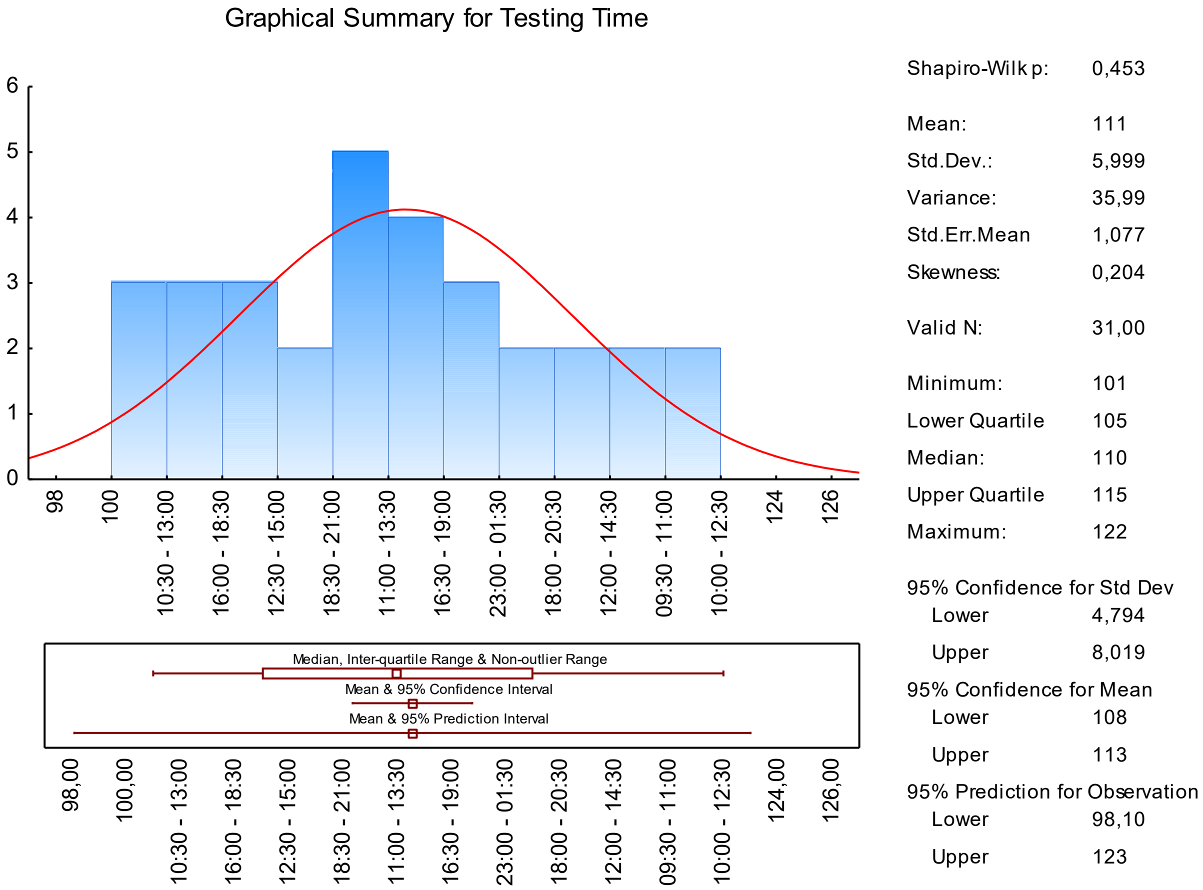
D.1.4.1. Self-selected testing sessions.



Shapiro-Wilk p:	0,453
Mean:	111
Std.Dev.:	5,999
Variance:	35,99
Std.Err.Mean	1,077
Skewness:	0,204
Valid N:	31,00
Minimum:	101
Lower Quartile	105
Median:	110
Upper Quartile	115
Maximum:	122
95% Confidence for Std Dev	
Lower	4,794
Upper	8,019
95% Confidence for Mean	
Lower	108
Upper	113
95% Prediction for Observation	
Lower	98,10
Upper	123

Figure 65: Shapiro-Wilks test and Box & whisker plots for self-selected testing sessions..

D.1.4.2. Grouped testing sessions.



Shapiro-Wilk p:	0,453
Mean:	111
Std.Dev.:	5,999
Variance:	35,99
Std.Err.Mean	1,077
Skewness:	0,204
Valid N:	31,00
Minimum:	101
Lower Quartile	105
Median:	110
Upper Quartile	115
Maximum:	122
95% Confidence for Std Dev	
Lower	4,794
Upper	8,019
95% Confidence for Mean	
Lower	108
Upper	113
95% Prediction for Observation	
Lower	98,10
Upper	123

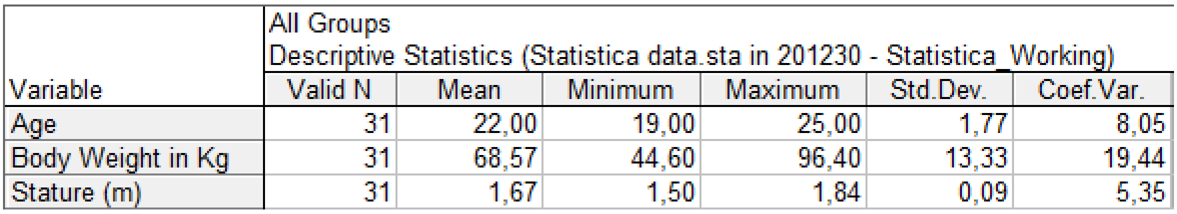
Figure 66: Shapiro-Wilks test and Box & whisker plots for grouped testing sessions.

D.2. Descriptive Statistics

D.2.1. Basic Anthropometric and Demographic Data

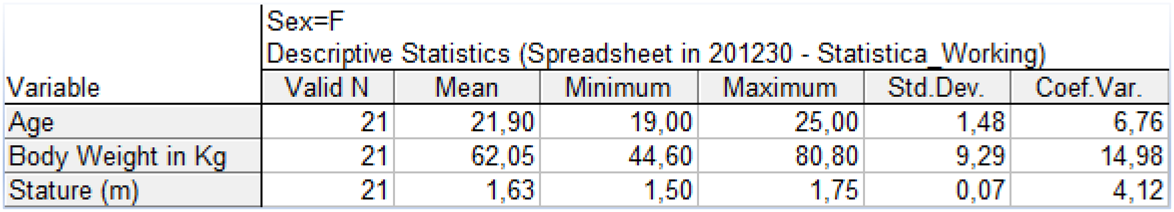
D.2.1.1. *Anthropometric* data

Table xiii: Descriptive stats for age, sex and stature of all participants.



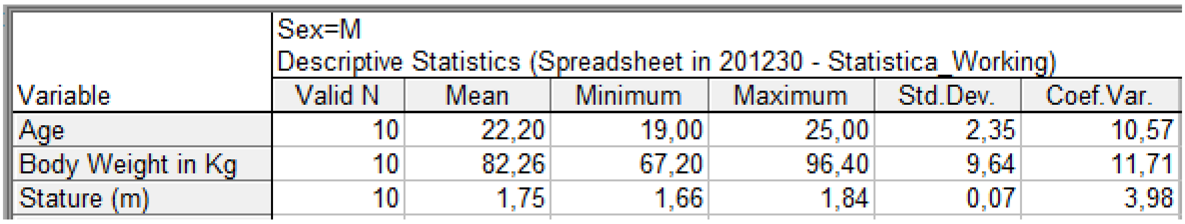
	All Groups Descriptive Statistics (Statistica data.sta in 201230 - Statistica_Working)					
Variable	Valid N	Mean	Minimum	Maximum	Std.Dev.	Coef.Var.
Age	31	22,00	19,00	25,00	1,77	8,05
Body Weight in Kg	31	68,57	44,60	96,40	13,33	19,44
Stature (m)	31	1,67	1,50	1,84	0,09	5,35

Table xiv: Descriptive stats for age, sex and stature of females.



	Sex=F Descriptive Statistics (Spreadsheet in 201230 - Statistica_Working)					
Variable	Valid N	Mean	Minimum	Maximum	Std.Dev.	Coef.Var.
Age	21	21,90	19,00	25,00	1,48	6,76
Body Weight in Kg	21	62,05	44,60	80,80	9,29	14,98
Stature (m)	21	1,63	1,50	1,75	0,07	4,12

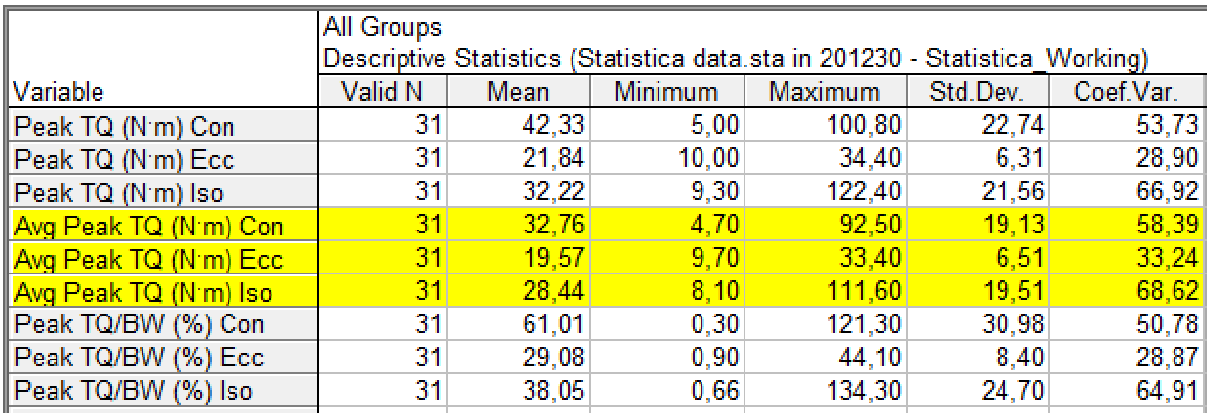
Table xv: Descriptive stats for age, sex and stature of males.



	Sex=M Descriptive Statistics (Spreadsheet in 201230 - Statistica_Working)					
Variable	Valid N	Mean	Minimum	Maximum	Std.Dev.	Coef.Var.
Age	10	22,20	19,00	25,00	2,35	10,57
Body Weight in Kg	10	82,26	67,20	96,40	9,64	11,71
Stature (m)	10	1,75	1,66	1,84	0,07	3,98

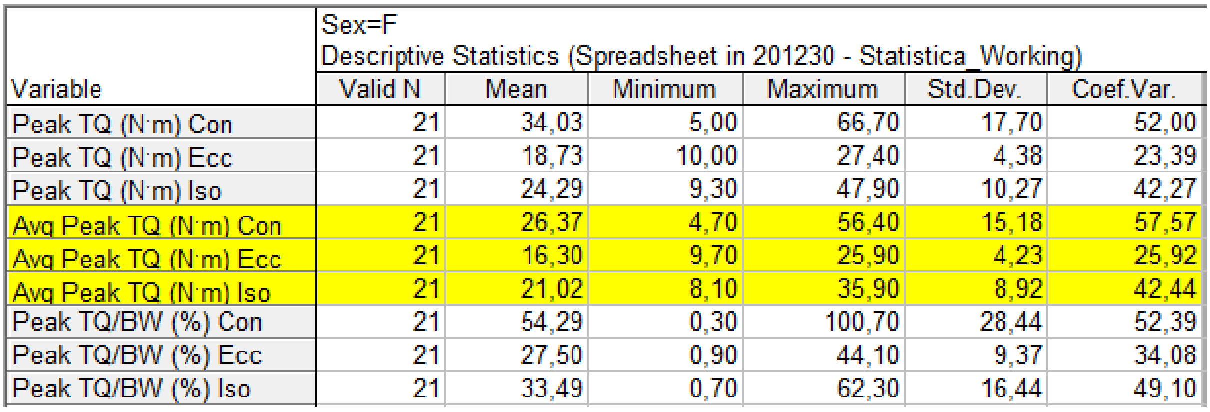
Torque data

Table xvi: Descriptive stats for torque of all participants.



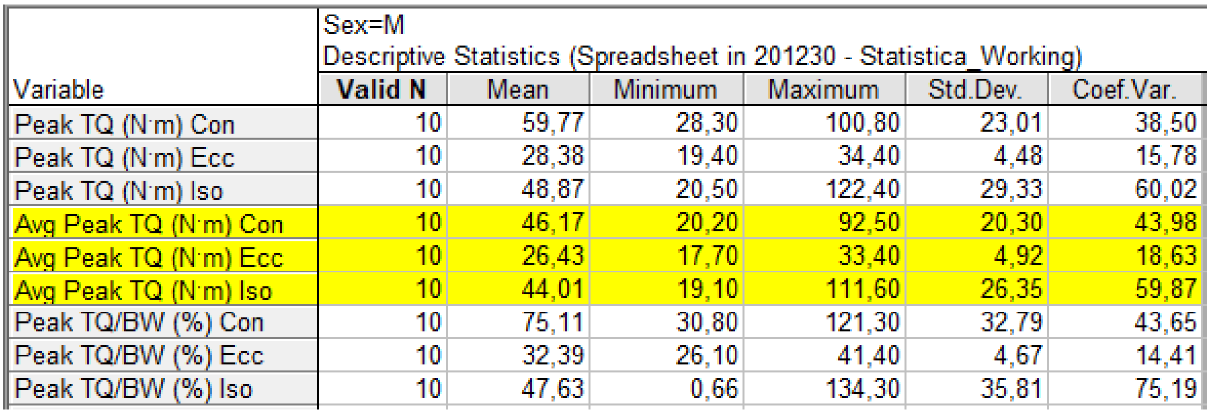
	All Groups Descriptive Statistics (Statistica data.sta in 201230 - Statistica_Working)					
Variable	Valid N	Mean	Minimum	Maximum	Std.Dev.	Coef.Var.
Peak TQ (N·m) Con	31	42,33	5,00	100,80	22,74	53,73
Peak TQ (N·m) Ecc	31	21,84	10,00	34,40	6,31	28,90
Peak TQ (N·m) Iso	31	32,22	9,30	122,40	21,56	66,92
Avg Peak TQ (N·m) Con	31	32,76	4,70	92,50	19,13	58,39
Avg Peak TQ (N·m) Ecc	31	19,57	9,70	33,40	6,51	33,24
Avg Peak TQ (N·m) Iso	31	28,44	8,10	111,60	19,51	68,62
Peak TQ/BW (%) Con	31	61,01	0,30	121,30	30,98	50,78
Peak TQ/BW (%) Ecc	31	29,08	0,90	44,10	8,40	28,87
Peak TQ/BW (%) Iso	31	38,05	0,66	134,30	24,70	64,91

Table xvii: Descriptive stats for torque of female participants.



	Sex=F Descriptive Statistics (Spreadsheet in 201230 - Statistica_Working)					
Variable	Valid N	Mean	Minimum	Maximum	Std.Dev.	Coef.Var.
Peak TQ (N·m) Con	21	34,03	5,00	66,70	17,70	52,00
Peak TQ (N·m) Ecc	21	18,73	10,00	27,40	4,38	23,39
Peak TQ (N·m) Iso	21	24,29	9,30	47,90	10,27	42,27
Avg Peak TQ (N·m) Con	21	26,37	4,70	56,40	15,18	57,57
Avg Peak TQ (N·m) Ecc	21	16,30	9,70	25,90	4,23	25,92
Avg Peak TQ (N·m) Iso	21	21,02	8,10	35,90	8,92	42,44
Peak TQ/BW (%) Con	21	54,29	0,30	100,70	28,44	52,39
Peak TQ/BW (%) Ecc	21	27,50	0,90	44,10	9,37	34,08
Peak TQ/BW (%) Iso	21	33,49	0,70	62,30	16,44	49,10

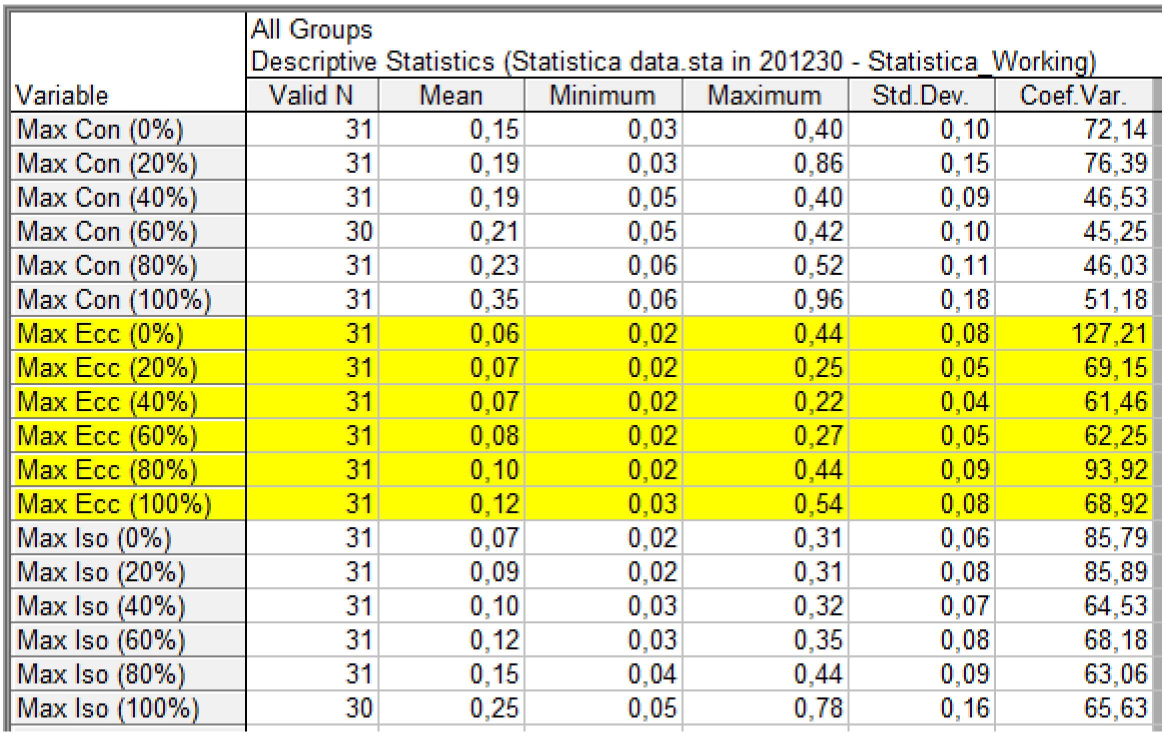
Table xviii: Descriptive stats for torque of male participants.



	Sex=M Descriptive Statistics (Spreadsheet in 201230 - Statistica_Working)					
Variable	**Valid N**	Mean	Minimum	Maximum	Std.Dev.	Coef.Var.
Peak TQ (N·m) Con	10	59,77	28,30	100,80	23,01	38,50
Peak TQ (N·m) Ecc	10	28,38	19,40	34,40	4,48	15,78
Peak TQ (N·m) Iso	10	48,87	20,50	122,40	29,33	60,02
Avg Peak TQ (N·m) Con	10	46,17	20,20	92,50	20,30	43,98
Avg Peak TQ (N·m) Ecc	10	26,43	17,70	33,40	4,92	18,63
Avg Peak TQ (N·m) Iso	10	44,01	19,10	111,60	26,35	59,87
Peak TQ/BW (%) Con	10	75,11	30,80	121,30	32,79	43,65
Peak TQ/BW (%) Ecc	10	32,39	26,10	41,40	4,67	14,41
Peak TQ/BW (%) Iso	10	47,63	0,66	134,30	35,81	75,19

EMG Responses

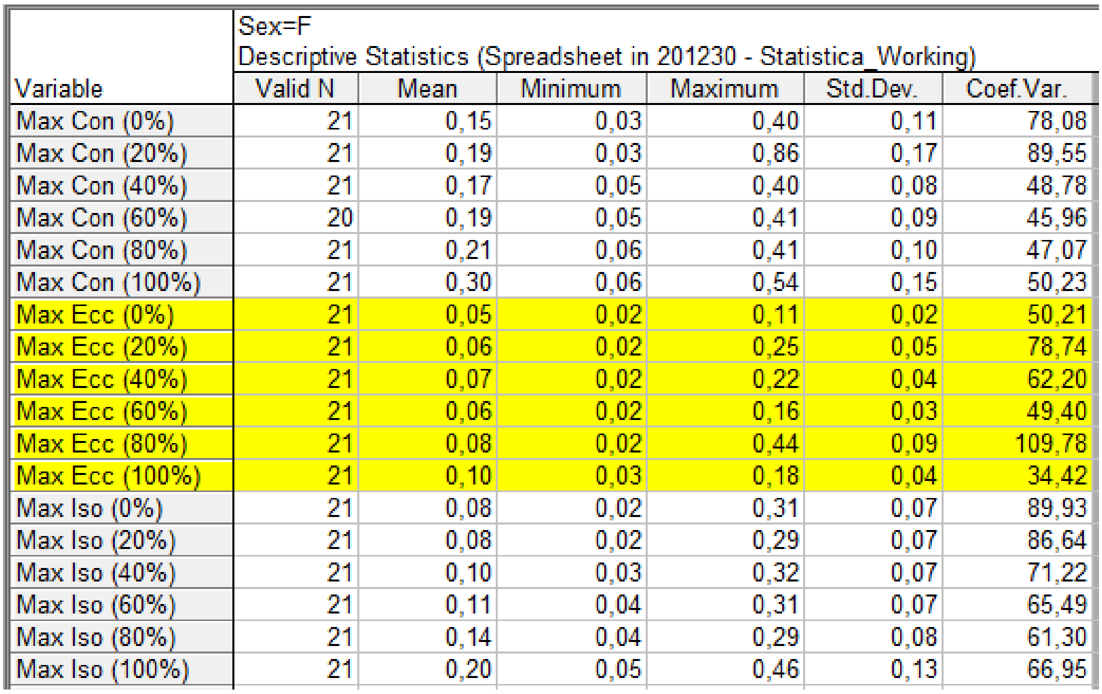
Table xix: Descriptive stats for EMG responses for all experimental conditions.



All Groups
Descriptive Statistics (Statistica data.sta in 201230 - Statistica_Working)

Variable	Valid N	Mean	Minimum	Maximum	Std.Dev.	Coef.Var.
Max Con (0%)	31	0,15	0,03	0,40	0,10	72,14
Max Con (20%)	31	0,19	0,03	0,86	0,15	76,39
Max Con (40%)	31	0,19	0,05	0,40	0,09	46,53
Max Con (60%)	30	0,21	0,05	0,42	0,10	45,25
Max Con (80%)	31	0,23	0,06	0,52	0,11	46,03
Max Con (100%)	31	0,35	0,06	0,96	0,18	51,18
Max Ecc (0%)	31	0,06	0,02	0,44	0,08	127,21
Max Ecc (20%)	31	0,07	0,02	0,25	0,05	69,15
Max Ecc (40%)	31	0,07	0,02	0,22	0,04	61,46
Max Ecc (60%)	31	0,08	0,02	0,27	0,05	62,25
Max Ecc (80%)	31	0,10	0,02	0,44	0,09	93,92
Max Ecc (100%)	31	0,12	0,03	0,54	0,08	68,92
Max Iso (0%)	31	0,07	0,02	0,31	0,06	85,79
Max Iso (20%)	31	0,09	0,02	0,31	0,08	85,89
Max Iso (40%)	31	0,10	0,03	0,32	0,07	64,53
Max Iso (60%)	31	0,12	0,03	0,35	0,08	68,18
Max Iso (80%)	31	0,15	0,04	0,44	0,09	63,06
Max Iso (100%)	30	0,25	0,05	0,78	0,16	65,63

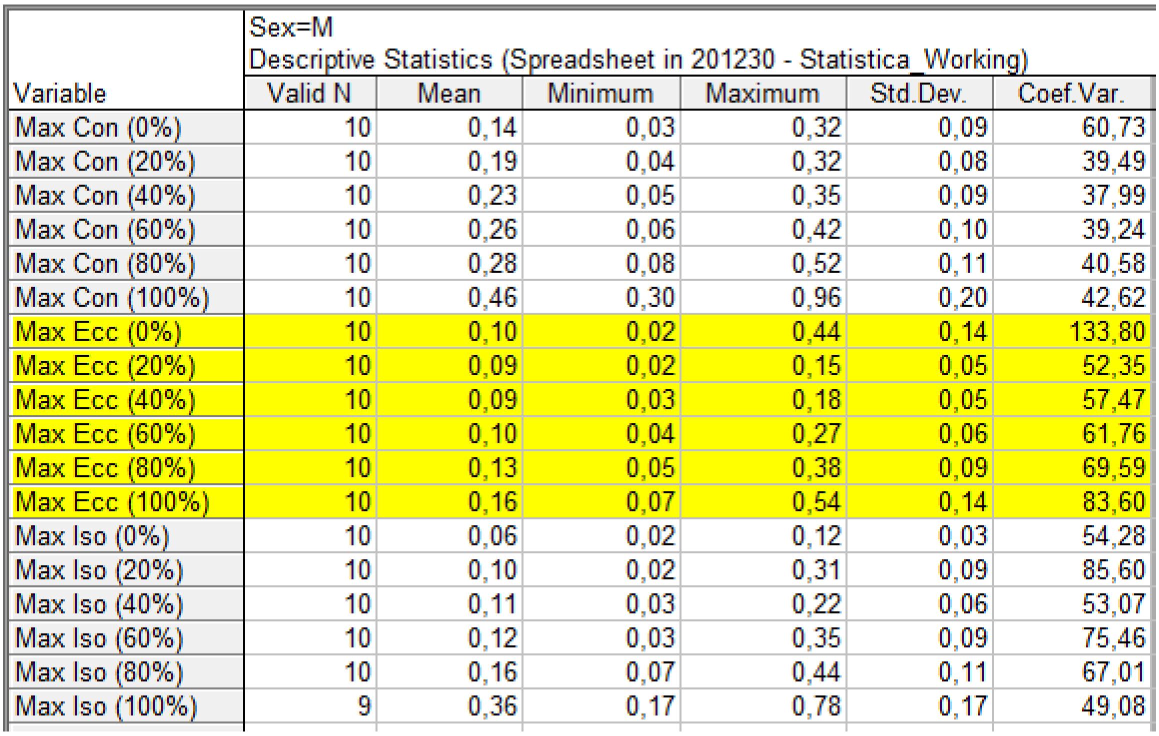
Table xx: Descriptive stats for EMG responses of female participants.



Sex=F
Descriptive Statistics (Spreadsheet in 201230 - Statistica_Working)

Variable	Valid N	Mean	Minimum	Maximum	Std.Dev.	Coef.Var.
Max Con (0%)	21	0,15	0,03	0,40	0,11	78,08
Max Con (20%)	21	0,19	0,03	0,86	0,17	89,55
Max Con (40%)	21	0,17	0,05	0,40	0,08	48,78
Max Con (60%)	20	0,19	0,05	0,41	0,09	45,96
Max Con (80%)	21	0,21	0,06	0,41	0,10	47,07
Max Con (100%)	21	0,30	0,06	0,54	0,15	50,23
Max Ecc (0%)	21	0,05	0,02	0,11	0,02	50,21
Max Ecc (20%)	21	0,06	0,02	0,25	0,05	78,74
Max Ecc (40%)	21	0,07	0,02	0,22	0,04	62,20
Max Ecc (60%)	21	0,06	0,02	0,16	0,03	49,40
Max Ecc (80%)	21	0,08	0,02	0,44	0,09	109,78
Max Ecc (100%)	21	0,10	0,03	0,18	0,04	34,42
Max Iso (0%)	21	0,08	0,02	0,31	0,07	89,93
Max Iso (20%)	21	0,08	0,02	0,29	0,07	86,64
Max Iso (40%)	21	0,10	0,03	0,32	0,07	71,22
Max Iso (60%)	21	0,11	0,04	0,31	0,07	65,49
Max Iso (80%)	21	0,14	0,04	0,29	0,08	61,30
Max Iso (100%)	21	0,20	0,05	0,46	0,13	66,95

Table xxi: Descriptive stats for EMG responses of male participants.

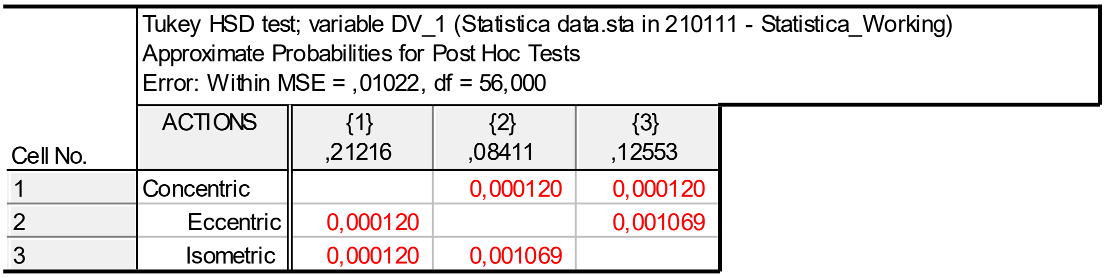


Variable	Sex=M Descriptive Statistics (Spreadsheet in 201230 - Statistica_Working) Valid N	Mean	Minimum	Maximum	Std.Dev.	Coef.Var.
Max Con (0%)	10	0,14	0,03	0,32	0,09	60,73
Max Con (20%)	10	0,19	0,04	0,32	0,08	39,49
Max Con (40%)	10	0,23	0,05	0,35	0,09	37,99
Max Con (60%)	10	0,26	0,06	0,42	0,10	39,24
Max Con (80%)	10	0,28	0,08	0,52	0,11	40,58
Max Con (100%)	10	0,46	0,30	0,96	0,20	42,62
Max Ecc (0%)	10	0,10	0,02	0,44	0,14	133,80
Max Ecc (20%)	10	0,09	0,02	0,15	0,05	52,35
Max Ecc (40%)	10	0,09	0,03	0,18	0,05	57,47
Max Ecc (60%)	10	0,10	0,04	0,27	0,06	61,76
Max Ecc (80%)	10	0,13	0,05	0,38	0,09	69,59
Max Ecc (100%)	10	0,16	0,07	0,54	0,14	83,60
Max Iso (0%)	10	0,06	0,02	0,12	0,03	54,28
Max Iso (20%)	10	0,10	0,02	0,31	0,09	85,60
Max Iso (40%)	10	0,11	0,03	0,22	0,06	53,07
Max Iso (60%)	10	0,12	0,03	0,35	0,09	75,46
Max Iso (80%)	10	0,16	0,07	0,44	0,11	67,01
Max Iso (100%)	9	0,36	0,17	0,78	0,17	49,08

D.3 Inferential Statistics

D.3.1 Muscle actions

Table xxii: Post-Hoc Tukey test for differences between concentric, eccentric, and isometric muscle actions.

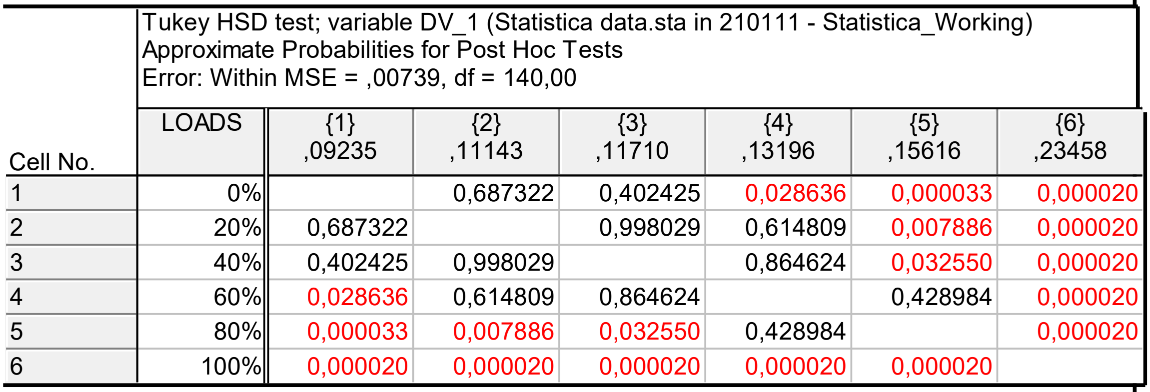


Tukey HSD test; variable DV_1 (Statistica data.sta in 210111 - Statistica_Working)
Approximate Probabilities for Post Hoc Tests
Error: Within MSE = ,01022, df = 56,000

Cell No.	ACTIONS	{1} ,21216	{2} ,08411	{3} ,12553
1	Concentric		0,000120	0,000120
2	Eccentric	0,000120		0,001069
3	Isometric	0,000120	0,001069	

D.3.2 Load levels

Table xxiii: Post-Hoc Tukey test for differences between all load levels.



Tukey HSD test; variable DV_1 (Statistica data.sta in 210111 - Statistica_Working)
Approximate Probabilities for Post Hoc Tests
Error: Within MSE = ,00739, df = 140,00

Cell No.	LOADS	{1} ,09235	{2} ,11143	{3} ,11710	{4} ,13196	{5} ,15616	{6} ,23458
1	0%		0,687322	0,402425	0,028636	0,000033	0,000020
2	20%	0,687322		0,998029	0,614809	0,007886	0,000020
3	40%	0,402425	0,998029		0,864624	0,032550	0,000020
4	60%	0,028636	0,614809	0,864624		0,428984	0,000020
5	80%	0,000033	0,007886	0,032550	0,428984		0,000020
6	100%	0,000020	0,000020	0,000020	0,000020	0,000020	

D.3.3 Interaction effect on sEMG between muscle actions X load levels

Table xxiv: Post-Hoc Tukey test for differences between muscle actions at each load level.

Tukey HSD test; variable DV_1 (Statistica data.sta in 201230 - Statistica_Working)
Approximate Probabilities for Post Hoc Tests
Error: Within MSE = ,00356, df = 280,00

Cell No.	MUSCLEA	LOAD%	Con 0% ,13942	Con 20%	Con 40%	Con 60%	Con 80%	Con 100%	Ecc 0% ,06387	Ecc 20% ,07173	Ecc 40% ,07133	Ecc 60% ,07512	Ecc 80% ,10004	Ecc 100% ,12258	Iso 0% ,07376	Iso 20% ,07736	Iso 40% ,10068	Iso 60% ,11281	Iso 80% ,14408	Iso 100%
1	Con	0%		0,24	0,49	0,00	0,00	0,00	0,00	0,00	0,00	0,01	0,52	1,00	0,00	0,01	0,55	0,97	1,00	0,00
2	Con	20%	0,24		1,00	0,99	0,53	0,00	0,00	0,00	0,00	0,00	0,00	0,01	0,00	0,00	0,00	0,00	0,43	0,02
3	Con	40%	0,49	1,00		0,94	0,26	0,00	0,00	0,00	0,00	0,00	0,00	0,03	0,00	0,00	0,00	0,00	0,72	0,00
4	Con	60%	0,00	0,99	0,94		1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,01	0,66
5	Con	80%	0,00	0,53	0,26	1,00		0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	1,00
6	Con	100%	0,00	0,00	0,00	0,00	0,00		0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
7	Ecc	0%	0,00	0,00	0,00	0,00	0,00	0,00		1,00	1,00	1,00	0,68	0,02	1,00	1,00	0,65	0,15	0,00	0,00
8	Ecc	20%	0,00	0,00	0,00	0,00	0,00	0,00	1,00		1,00	1,00	0,94	0,10	1,00	1,00	0,93	0,44	0,00	0,00
9	Ecc	40%	0,00	0,00	0,00	0,00	0,00	0,00	1,00	1,00		1,00	0,93	0,10	1,00	1,00	0,92	0,42	0,00	0,00
10	Ecc	60%	0,01	0,00	0,00	0,00	0,00	0,00	1,00	1,00	1,00		0,98	0,19	1,00	1,00	0,98	0,60	0,00	0,00
11	Ecc	80%	0,52	0,00	0,00	0,00	0,00	0,00	0,68	0,94	0,93	0,98		0,99	0,97	0,99	1,00	1,00	0,30	0,00
12	Ecc	100%	1,00	0,01	0,03	0,00	0,00	0,00	0,02	0,10	0,10	0,19	0,99		0,15	0,26	1,00	1,00	1,00	0,00
13	Iso	0%	0,00	0,00	0,00	0,00	0,00	0,00	1,00	1,00	1,00	1,00	0,97	0,15		1,00	0,96	0,54	0,00	0,00
14	Iso	20%	0,01	0,00	0,00	0,00	0,00	0,00	1,00	1,00	1,00	1,00	0,99	0,26	1,00		0,99	0,71	0,00	0,00
15	Iso	40%	0,55	0,00	0,00	0,00	0,00	0,00	0,65	0,93	0,92	0,98	1,00	1,00	0,96	0,99		1,00	0,33	0,00
16	Iso	60%	0,97	0,00	0,00	0,00	0,00	0,00	0,15	0,44	0,42	0,60	1,00	1,00	0,54	0,71	1,00		0,87	0,00
17	Iso	80%	1,00	0,43	0,72	0,01	0,00	0,00	0,00	0,00	0,00	0,00	0,30	1,00	0,00	0,00	0,33	0,87		0,00
18	Iso	100%	0,00	0,02	0,00	0,66	1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	

D.3.4 Variables affecting Torque

D.3.4.1 Effects of sex on SEMG

Table xxv: Maximum sEMG in (mV) recorded during muscle actions at various loads.

Muscle Action	Loads	All (n=31)	Female (n=21)	Male (n=10)	Load X Sex
Concentric	0%	0,15 ± 0,10 (72,14%)	0,15 ± 0,11 (78,08%)	0,14 ± 0.09 (60,73%)	p=1,000
	20%	0,19 ± 0,15 (76,39%)	0,19 ± 0,17 (89,55%)	0,19 ± 0,08 (39,49%)	p=1,000
	40%	0,19 ± 0,09 (46,53%)	0,17 ± 0,08 (48,78%)	0,23 ± 0,09 (37,99%)	p=0,999
	60%	0,21 ± 0,10 (45,25%)	0,19 ± 0,09 (45,96%)	0,26 ± 0,10 (39,24%)	p=1,000
	80%	0,23 ± 0,11 (46,03%)	0,21 ± 0,10 (47,07%)	0,28 ± 0,11 (40,58%)	p=0,991
	100%	0,35 ± 0,18 (51,18%)	0,30 ± 0,15 (50,23%)	0,46 ± 0,20 (42,62%)	p=0,085
Eccentric	0%	0,06 ± 0,08 (127,21%)	0,05 ± 0,02 (50,21%)	0,10 ± 0.14 (133,80%)	p=0,999
	20%	0,07 ± 0,05 (69,15%)	0,06 ± 0,05 (78,74%)	0,09 ± 0,05 (52,35%)	p=1,000
	40%	0,07 ± 0,04 (61,46%)	0,07 ± 0,04 (62,20%)	0,09 ± 0,05 (57,47%)	p=1,000
	60%	0,08 ± 0,05 (62,25%)	0,06 ± 0,03 (49,40%)	0,10 ± 0,06 (61,76%)	p=1,000
	80%	0,10 ± 0,09 (93,92%)	0,08 ± 0,09 (109,78%)	0,13 ± 0,09 (69,59%)	p=1,000
	100%	0,12 ± 0,08 (68,92%)	0,10 ± 0,04 (34,42%)	0,16 ± 0,14 (83,60%)	p=0,999
Isometric	0%	0,07 ± 0,06 (85,79%)	0,08 ± 0,07 (89,93%)	0,06 ± 0.03 (54,28%)	p=1,000
	20%	0,09 ± 0,08 (85,89%)	0,08 ± 0,07 (86,64%)	0,10 ± 0,09 (85,60%)	p=1,000

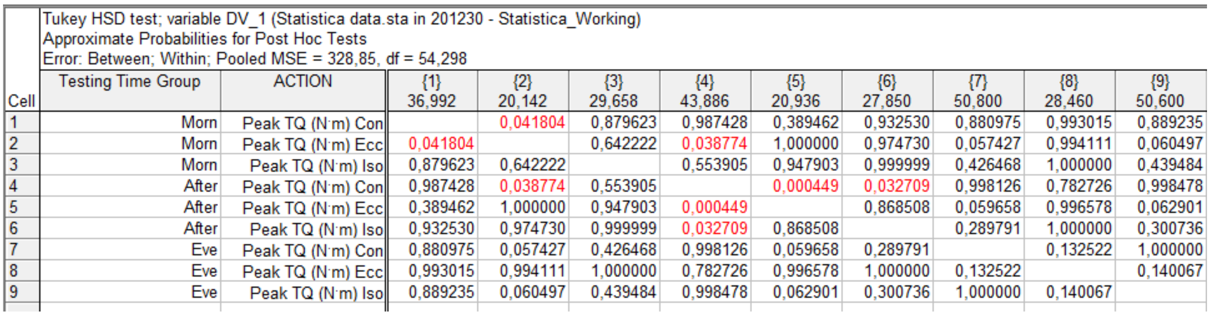
	40%	0,10 ± 0,07 (64,53%)	0,10 ± 0,07 (71,22%)	0,11 ± 0,06 (53,07%)	p=1,000
	60%	0,12 ± 0,08 (68,18%)	0,11 ± 0,07 (65,49%)	0,12 ± 0,09 (75,46%)	p=1,000
	80%	0,15 ± 0,09 (63,06%)	0,14 ± 0,08 (61,30%)	0,16 ± 0,11 (67,01%)	p=1,000
	100%	0,25 ± 0,16 (65,63%)	0,20 ± 0,13 (66,95%)	0,36 ± 0,17 (49,08%)	p=0,058

* indicates significant difference (p<0.05) between male and female participants.

D.3.4.2. Time of day (ToD)

Time of day effects on peak torque

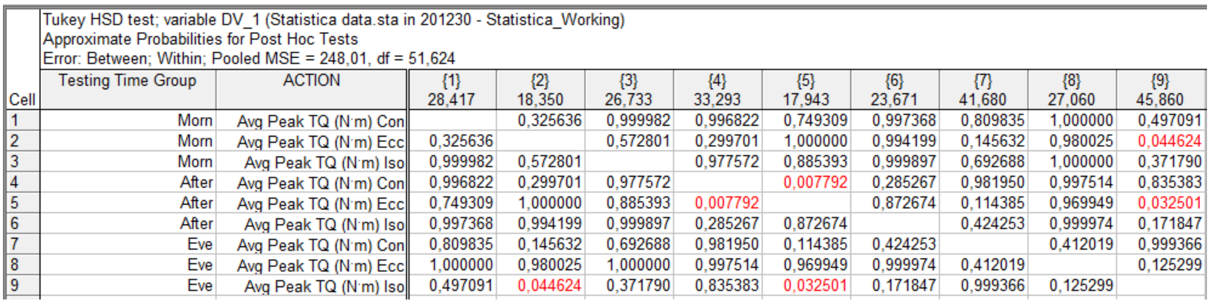
Table xxvi: Post-Hoc Tukey test for differences between time of day and peak torque.



Tukey HSD test; variable DV_1 (Statistica data.sta in 201230 - Statistica_Working)
Approximate Probabilities for Post Hoc Tests
Error: Between; Within; Pooled MSE = 328,85, df = 54,298

Cell	Testing Time Group	ACTION	{1} 36,992	{2} 20,142	{3} 29,658	{4} 43,886	{5} 20,936	{6} 27,850	{7} 50,800	{8} 28,460	{9} 50,600
1	Morn	Peak TQ (N·m) Con		0,041804	0,879623	0,987428	0,389462	0,932530	0,880975	0,993015	0,889235
2	Morn	Peak TQ (N·m) Ecc	0,041804		0,642222	0,038774	1,000000	0,974730	0,057427	0,994111	0,060497
3	Morn	Peak TQ (N·m) Iso	0,879623	0,642222		0,553905	0,947903	0,999999	0,426468	1,000000	0,439484
4	After	Peak TQ (N·m) Con	0,987428	0,038774	0,553905		0,000449	0,032709	0,998126	0,782726	0,998478
5	After	Peak TQ (N·m) Ecc	0,389462	1,000000	0,947903	0,000449		0,868508	0,059658	0,996578	0,062901
6	After	Peak TQ (N·m) Iso	0,932530	0,974730	0,999999	0,032709	0,868508		0,289791	1,000000	0,300736
7	Eve	Peak TQ (N·m) Con	0,880975	0,057427	0,426468	0,998126	0,059658	0,289791		0,132522	1,000000
8	Eve	Peak TQ (N·m) Ecc	0,993015	0,994111	1,000000	0,782726	0,996578	1,000000	0,132522		0,140067
9	Eve	Peak TQ (N·m) Iso	0,889235	0,060497	0,439484	0,998478	0,062901	0,300736	1,000000	0,140067	

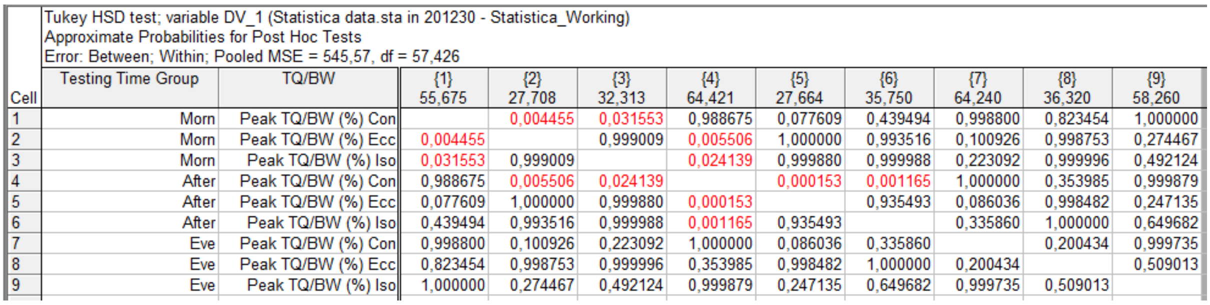
Table xxvii: Post-Hoc Tukey test for differences between time of day and average torque.



Tukey HSD test; variable DV_1 (Statistica data.sta in 201230 - Statistica_Working)
Approximate Probabilities for Post Hoc Tests
Error: Between; Within; Pooled MSE = 248,01, df = 51,624

Cell	Testing Time Group	ACTION	{1} 28,417	{2} 18,350	{3} 26,733	{4} 33,293	{5} 17,943	{6} 23,671	{7} 41,680	{8} 27,060	{9} 45,860
1	Morn	Avg Peak TQ (N·m) Con		0,325636	0,999982	0,996822	0,749309	0,997368	0,809835	1,000000	0,497091
2	Morn	Avg Peak TQ (N·m) Ecc	0,325636		0,572801	0,299701	1,000000	0,994199	0,145632	0,980025	0,044624
3	Morn	Avg Peak TQ (N·m) Iso	0,999982	0,572801		0,977572	0,885393	0,999897	0,692688	1,000000	0,371790
4	After	Avg Peak TQ (N·m) Con	0,996822	0,299701	0,977572		0,007792	0,285267	0,981950	0,997514	0,835383
5	After	Avg Peak TQ (N·m) Ecc	0,749309	1,000000	0,885393	0,007792		0,872674	0,114385	0,969949	0,032501
6	After	Avg Peak TQ (N·m) Iso	0,997368	0,994199	0,999897	0,285267	0,872674		0,424253	0,999974	0,171847
7	Eve	Avg Peak TQ (N·m) Con	0,809835	0,145632	0,692688	0,981950	0,114385	0,424253		0,412019	0,999366
8	Eve	Avg Peak TQ (N·m) Ecc	1,000000	0,980025	1,000000	0,997514	0,969949	0,999974	0,412019		0,125299
9	Eve	Avg Peak TQ (N·m) Iso	0,497091	0,044624	0,371790	0,835383	0,032501	0,171847	0,999366	0,125299	

Table xxviii: Post-Hoc Tukey test for differences between time of day and average torque.



Tukey HSD test; variable DV_1 (Statistica data.sta in 201230 - Statistica_Working)
Approximate Probabilities for Post Hoc Tests
Error: Between; Within; Pooled MSE = 545,57, df = 57,426

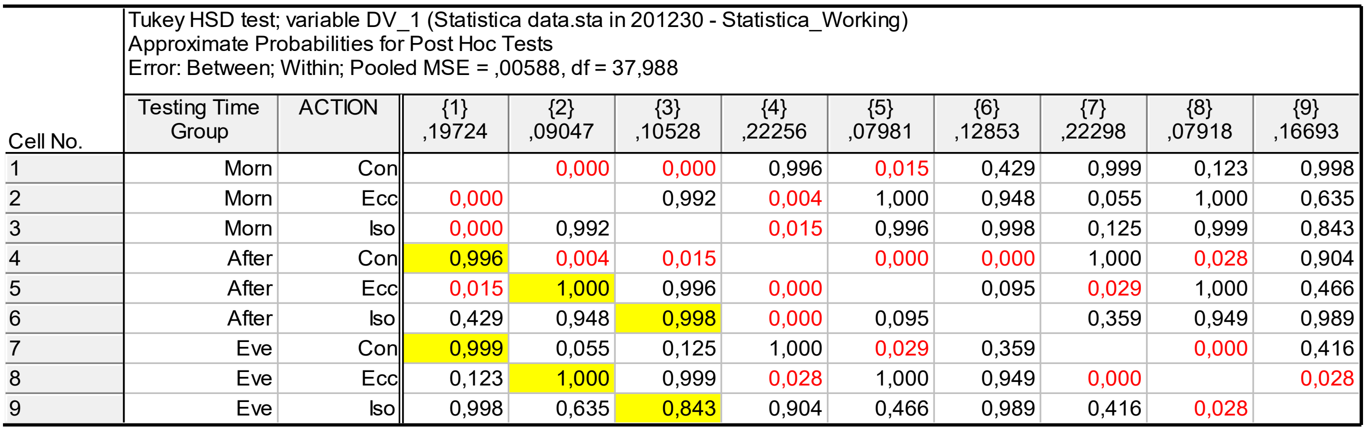
Cell	Testing Time Group	TQ/BW	{1} 55,675	{2} 27,708	{3} 32,313	{4} 64,421	{5} 27,664	{6} 35,750	{7} 64,240	{8} 36,320	{9} 58,260
1	Morn	Peak TQ/BW (%) Con		0,004455	0,031553	0,988675	0,077609	0,439494	0,998800	0,823454	1,000000
2	Morn	Peak TQ/BW (%) Ecc	0,004455		0,999009	0,005506	1,000000	0,993516	0,100926	0,998753	0,274467
3	Morn	Peak TQ/BW (%) Iso	0,031553	0,999009		0,024139	0,999880	0,999988	0,223092	0,999996	0,492124
4	After	Peak TQ/BW (%) Con	0,988675	0,005506	0,024139		0,000153	0,001165	1,000000	0,353985	0,999879
5	After	Peak TQ/BW (%) Ecc	0,077609	1,000000	0,999880	0,000153		0,935493	0,086036	0,998482	0,247135
6	After	Peak TQ/BW (%) Iso	0,439494	0,993516	0,999988	0,001165	0,935493		0,335860	1,000000	0,649682
7	Eve	Peak TQ/BW (%) Con	0,998800	0,100926	0,223092	1,000000	0,086036	0,335860		0,200434	0,999735
8	Eve	Peak TQ/BW (%) Ecc	0,823454	0,998753	0,999996	0,353985	0,998482	1,000000	0,200434		0,509013
9	Eve	Peak TQ/BW (%) Iso	1,000000	0,274467	0,492124	0,999879	0,247135	0,649682	0,999735	0,509013	

Table xxix: Post-Hoc Tukey test for differences between time of day and load levels.

Tukey HSD test; variable DV_1 (Statistica data.sta in 201230 - Statistica_Working)
Approximate Probabilities for Post Hoc Tests
Error: Between; Within; Pooled MSE = ,00690, df = 51,743

Cell N	Testing Time Group	LOAD	{1} ,08594	{2} ,10545	{3} ,11768	{4} ,12476	{5} ,14689	{6} ,20525	{7} ,08735	{8} ,11018	{9} ,11718	{10} ,13363	{11} ,16750	{12} ,24596	{13} ,11972	{14} ,12878	{15} ,11553	{16} ,14524	{17} ,15122	{18} ,27769
1	Morn	0%		1,000	0,987	0,915	0,213	0,000	1,000	1,000	1,000	0,993	0,608	0,002	1,000	1,000	1,000	0,996	0,989	0,007
2	Morn	20%	1,000		1,000	1,000	0,859	0,000	1,000	1,000	1,000	1,000	0,924	0,013	1,000	1,000	1,000	1,000	1,000	0,027
3	Morn	40%	0,987	1,000		1,000	0,995	0,003	1,000	1,000	1,000	1,000	0,989	0,037	1,000	1,000	1,000	1,000	1,000	0,057
4	Morn	60%	0,915	1,000	1,000		1,000	0,011	1,000	1,000	1,000	1,000	0,998	0,064	1,000	1,000	1,000	1,000	1,000	0,086
5	Morn	80%	0,213	0,859	0,995	1,000		0,283	0,945	1,000	1,000	1,000	1,000	0,277	1,000	1,000	1,000	1,000	1,000	0,258
6	Morn	100%	0,000	0,000	0,003	0,011	0,283		0,082	0,342	0,474	0,797	1,000	0,999	0,885	0,951	0,841	0,995	0,999	0,970
7	After	0%	1,000	1,000	1,000	1,000	0,945	0,082		1,000	0,993	0,714	0,011	0,000	1,000	1,000	1,000	0,997	0,991	0,008
8	After	20%	1,000	1,000	1,000	1,000	1,000	0,342	1,000		1,000	1,000	0,315	0,000	1,000	1,000	1,000	1,000	1,000	0,036
9	After	40%	1,000	1,000	1,000	1,000	1,000	0,474	0,993	1,000		1,000	0,565	0,000	1,000	1,000	1,000	1,000	1,000	0,056
10	After	60%	0,993	1,000	1,000	1,000	1,000	0,797	0,714	1,000	1,000		0,975	0,000	1,000	1,000	1,000	1,000	1,000	0,138
11	After	80%	0,608	0,924	0,989	0,998	1,000	1,000	0,011	0,315	0,565	0,975		0,015	1,000	1,000	0,999	1,000	1,000	0,547
12	After	100%	0,002	0,013	0,037	0,064	0,277	0,999	0,000	0,000	0,000	0,000	0,015		0,313	0,439	0,262	0,694	0,780	1,000
13	Eve	0%	1,000	1,000	1,000	1,000	1,000	0,885	1,000	1,000	1,000	1,000	1,000	0,313		1,000	1,000	1,000	1,000	0,000
14	Eve	20%	1,000	1,000	1,000	1,000	1,000	0,951	1,000	1,000	1,000	1,000	1,000	0,439	1,000		1,000	1,000	1,000	0,000
15	Eve	40%	1,000	1,000	1,000	1,000	1,000	0,841	1,000	1,000	1,000	1,000	0,999	0,262	1,000	1,000		1,000	1,000	0,000
16	Eve	60%	0,996	1,000	1,000	1,000	1,000	0,995	0,997	1,000	1,000	1,000	1,000	0,694	1,000	1,000	1,000		1,000	0,004
17	Eve	80%	0,989	1,000	1,000	1,000	1,000	0,999	0,991	1,000	1,000	1,000	1,000	0,780	1,000	1,000	1,000	1,000		0,009
18	Eve	100%	0,007	0,027	0,057	0,086	0,258	0,970	0,008	0,036	0,056	0,138	0,547	1,000	0,000	0,000	0,000	0,004	0,009	

Table xxx: Post-Hoc Tukey test for differences between time of day and muscle actions.



Tukey HSD test; variable DV_1 (Statistica data.sta in 201230 - Statistica_Working)
Approximate Probabilities for Post Hoc Tests
Error: Between; Within; Pooled MSE = ,00588, df = 37,988

Cell No.	Testing Time Group	ACTION	{1} ,19724	{2} ,09047	{3} ,10528	{4} ,22256	{5} ,07981	{6} ,12853	{7} ,22298	{8} ,07918	{9} ,16693
1	Morn	Con		0,000	0,000	0,996	0,015	0,429	0,999	0,123	0,998
2	Morn	Ecc	0,000		0,992	0,004	1,000	0,948	0,055	1,000	0,635
3	Morn	Iso	0,000	0,992		0,015	0,996	0,998	0,125	0,999	0,843
4	After	Con	0,996	0,004	0,015		0,000	0,000	1,000	0,028	0,904
5	After	Ecc	0,015	1,000	0,996	0,000		0,095	0,029	1,000	0,466
6	After	Iso	0,429	0,948	0,998	0,000	0,095		0,359	0,949	0,989
7	Eve	Con	0,999	0,055	0,125	1,000	0,029	0,359		0,000	0,416
8	Eve	Ecc	0,123	1,000	0,999	0,028	1,000	0,949	0,000		0,028
9	Eve	Iso	0,998	0,635	0,843	0,904	0,466	0,989	0,416	0,028	