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2008

## A non-invasive analysis of the structure and function of human multi-segmental muscle

Darryl J. McAndrew  
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**A NON-INVASIVE ANALYSIS OF THE  
STRUCTURE AND FUNCTION OF HUMAN  
MULTI-SEGMENTAL MUSCLE**

**A thesis submitted in fulfilment of the  
requirements for the award of the degree**

**DOCTOR OF PHILOSOPHY**

from

**UNIVERSITY OF WOLLONGONG**

By

**DARRYL JOHN MCANDREW *B.Sc. (UoW)***

**SCHOOL OF HEALTH SCIENCES**

2008

## **Certification**

I, Darryl John McAndrew, declare that this thesis, submitted in fulfilment of the requirements for the award of Doctor of Philosophy, in the School of Health Sciences, University of Wollongong, is wholly my own work unless otherwise referenced or acknowledged. The document has not been submitted for qualifications at any other academic institution.

Darryl John McAndrew

15 December 2008

## **Acknowledgments**

I would like to acknowledge the help given by all those in the former Department of Biomedical Science (now School of Health Sciences) and Graduate School of Medicine. In particular I would like to thank my primary supervisor Dr. Mark Brown, and my secondary supervisor Associate Professor Peter McLennan for their supervision and guidance, both in the production of this thesis and in my professional development throughout my employment with the University. I also wish to thank Mr. Mario Solitro and Mr Mark Andrews, who without their technical support this research would not have been possible. Thanks also to my fellow postgraduate students Dr. James Wickham, Dr. Mark Gorelick, Mr. Nick Rosser, Ms. Katherine Phillips and Ms. Laurel Snelson for their valued input and assistance during the data collection and to all persons who acted as the subjects involved in this thesis.

To Mum and Dad, I thank you for your never ending support, encouragement and belief, not only through my university years but through my entire upbringing. Without your support I may not have taken the education path and ended up where I am today.

Finally, and without doubt most importantly, I would like to thank my beautiful wife Susan, whose endless love and commitment has kept me sane during this project. For her patience during the long hours spent on this endeavour and for putting up with my frequent fits of despair, I shall be forever grateful. To Cooper and Miles, my children, thank you for providing the urge that was greatly needed to get the manuscript finished.

## **Thesis Organisation**

*Chapter 1* provides a general introduction to the thesis and specifically states the research objectives.

*Chapter 2* reviews the relevant literature, including an overview of muscle fibre types, spatial distribution and contractile physiology, evidence for functional differentiation and research that specifically investigated non-invasive measurements of contractile properties.

*Chapter 3* details the techniques used to determine the Tensiometric, Mechanomyographic and Myoelectric measures of muscle performance.

*Chapter 4* describes experiments that validated the Laser-MMG technique for the detection of changes in muscle contractile properties induced by physiological modulators of muscle performance (temperature and fatigue). Confirmation of the Laser-MMG technique to detect the contractile properties of multiple muscle segments contained within a single animal muscle is also contained within.

*Chapter 5* describes two experiments that examined the contractile properties of muscle segments within human multi-segmental muscles, for the purpose of matching contractile properties to functional roles. This chapter has been published in the Journal of Musculoskeletal Research.

*Chapter 6* describes an experiment that examined the neuromotor control of 14 superficial muscle segments surrounding the shoulder during movements at different speeds.

*Chapter 7* provides a summary and synthesis of the results from the three experimental chapters and draws conclusions regarding the spatial distribution of muscle fibres within multi-segmental muscle and their neuromotor control based on the objectives outlined in Chapter 1. Recommendations for future research and acknowledgment of experimental limitations are also made.

# Table of Contents

Certification.....	i
Acknowledgments .....	ii
Thesis Organisation.....	iii
Table of Contents .....	iv
List of Figures .....	ix
List of Tables.....	xiii
Abbreviations .....	xiv
List of Publications.....	xv
Abstract .....	xvi
<b>CHAPTER 1 INTRODUCTION .....</b>	<b>19</b>
<b>CHAPTER 2 LITERATURE REVIEW .....</b>	<b>27</b>
2.1 Muscle fibre types and contractile physiology.....	28
2.2 Distribution of muscle fibre types.....	30
2.3 Activation of muscle .....	31
2.4 Control of muscle activation .....	32
2.5 Effect of movement speed on muscle activation patterns .....	35
2.6 Evidence for functional differentiation within skeletal muscle .....	36
2.7 Functional role of muscle segments .....	37
2.8 Muscle coordination / synergy .....	39



2.9	Non-invasive measurement of muscle contractile properties – Mechanomyography (MMG) .....	40
2.10	Electromyography (EMG) .....	44
2.11	Musculoskeletal functional anatomy .....	45
2.12	Justification of research direction .....	50

## **CHAPTER 3 GENERAL METHODS ..... 51**

3.1	Introduction .....	52
3.2	Mechanomyography (MMG) .....	52
3.2.1	MMG laser sensor .....	53
3.2.2	Neuromuscular Stimulation .....	53
3.2.3	Animal muscle preparation .....	53
3.2.4	Simultaneous measurement of Laser-MMG & Tensiometry (Animal studies) .....	54
3.2.3	Laser-MMG waveform analysis .....	56
3.3	Tensiometry .....	58
3.3.1	Force transducer .....	58
3.3.2	DC Amplifier .....	59
3.3.3	Tension waveform analysis .....	59
3.4	Electromyography (EMG) .....	60
3.4.1	Surface Electrodes .....	60
3.4.2	Myoelectric Amplifiers .....	62
3.4.3	Myoelectric signal analysis .....	62

<b>CHAPTER 4 VALIDATION OF MECHANOMYOGRAPHY I: SENSITIVITY TO</b>	
<b>PHYSIOLOGICAL MODULATORS OF MUSCLE CONTRACTILE</b>	
<b>PROPERTIES ..... 65</b>	
4.1	Introduction ..... 66
4.1	Introduction ..... 66
4.2	Aims and Hypotheses..... 68
4.3	Methods..... 70
4.3.1	Study A: Laser-MMG response to a change in muscle temperature ..... 70
4.3.2	Study B: Laser-MMG response to a change in muscle fatigue ..... 72
4.3.3	Study C: Laser-MMG response to a change in muscle segment fibre type ..... 74
4.4	Results ..... 78
4.4.1	Study A: Laser-MMG response to a change in muscle temperature ..... 78
4.4.2	Study B: Laser-MMG response to a change in muscle fatigue ..... 86
4.4.3	Study C: Laser-MMG response to a change in muscle segment fibre type ..... 93
4.5	Discussion ..... 100
4.5.1	Study A - Temperature..... 100
4.5.2	Study B – Fatigue..... 102
4.5.3	Study C – Fibre Type ..... 105

<b>CHAPTER 5 VALIDATION OF MECHANOMYOGRAPHY II:</b>	
<b>QUANTIFICATION OF HUMAN MUSCLE SEGMENT</b>	
<b>CONTRACTILE PROPERTIES ..... 109</b>	
5.1	Introduction ..... 110
5.2	Aims and Hypotheses..... 112
5.3	Study D: Contractile properties of segments within gluteus maximus ..... 113

5.3.1	Methods – Gluteus Maximus .....	113
5.3.1.1	Experimental design .....	113
5.3.1.2	Subjects .....	113
5.3.1.3	Muscle segment identification .....	113
5.3.1.4	Equipment .....	115
5.3.1.5	Experimental set-up .....	115
5.3.1.6	Percutaneous neuromuscular stimulation .....	116
5.3.1.7	Laser-MMG data analysis .....	117
5.3.1.8	Statistical analysis .....	117
5.3.1.9	Ethics .....	118
5.3.2	Results – Gluteus Maximus .....	119
5.3.2.1	General muscle description and summary of results .....	119
5.3.2.2	Within muscle segment analysis: (medial to lateral portions) .....	119
5.3.2.3	Between muscle segment analysis: (superior to inferior segments) .....	120
5.4	Study E: Contractile properties of multi-segmental shoulder muscles .....	124
5.4.1	Methods – Multi-segmental Muscle .....	124
5.4.1.1	Experimental design .....	124
5.4.1.2	Subjects .....	124
5.4.1.3	Muscle segment identification .....	124
5.4.1.3	Equipment .....	129
5.4.1.4	Experimental set-up .....	129
5.4.1.5	Percutaneous neuromuscular stimulation .....	129
5.4.1.6	Laser-MMG data analysis .....	130
5.4.1.7	Statistical analysis .....	130
5.3.2.9	Ethics .....	130
5.4.2	Results – Multi-segmental Muscle .....	131
5.4.2.1	General muscle description and summary of results .....	131
5.4.2.2	Between segment analysis of contractile properties .....	136
5.5	Discussion .....	144

## **CHAPTER 6 THE INFLUENCE OF FIBER-TYPE ON THE NEUROMOTOR**

### **CONTROL OF HUMAN SHOULDER MUSCLE SEGMENTS..... 149**

6.1	Introduction .....	150
6.2	Aims and Hypotheses.....	152
6.3	Methods – Study F .....	153
6.4	Results .....	159
6.5	Discussion .....	172
6.5	Discussion .....	173

## **CHAPTER 7 GENERAL DISCUSSION, LIMITATIONS AND CONCLUSION ... 185**

General Discussion.....	186
Limitations.....	199
Conclusion.....	201
REFERENCES .....	202
APPENDIX A .....	221
MMG laser site and Microelectrode site identification .....	221

## List of Figures

Figure 3.1	Gastrocnemius muscle of the toad attached to the test rig.....	54
Figure 3.2	Neuromuscular stimulation .....	56
Figure 3.3	Quantification of the Laser-MMG waveform .....	58
Figure 3.4	Quantification of the Tension waveform .....	60
Figure 3.5	Bipolar microelectrode.....	61
Figure 3.6	Myoelectric and Force variables .....	64
Figure 4.1	Diagram of the medial gastrocnemius attached to rat lower limb. ....	75
Figure 4.2	Parabolic waveforms representing A: Laser-MMG and B: tension in response to electrical stimulation at different thermal states .....	78
Figure 4.3	Laser-MMG and Tensiometric waveforms A: 15°C, B: 20°C, and C: 25°C	79
Figure 4.4	Changes in max. displacement and tension due to effect of temperature. ...	81
Figure 4.5	Normalised contraction time, relaxation time and sustain time measures for each muscle temperature .....	82
Figure 4.6	A: Correlation between Laser-MMG Dmax and Tensiometric Tmax for the medial gastrocnemius.....	84
Figure 4.7	Correlation between Laser-MMG tcN and Tensiometric tcN for the medial gastrocnemius.....	84
Figure 4.8	Correlation between Laser-MMG trN and Tensiometric trN for the medial gastrocnemius.....	85
Figure 4.9	Correlation between Laser-MMG tsN and Tensiometric tsN for the medial gastrocnemius.....	85
Figure 4.10	Parabolic waveform output from A: Laser-MMG and B: Tensiometry technique pre- and post-fatigue task .....	86
Figure 4.11	Laser-MMG and Tensiometric waveform output at A: Pre- fatigue and B: Post- fatigue .....	87
Figure 4.12	Changes in A: maximal displacement and B: maximal tension due to the repetitive stimulation task. ....	88
Figure 4.13	tcN, trN and tsN values for the pre- and post-stimulation task A: Laser-MMG and B: Tensiometry.....	89

Figure 4.14	Maximal rate of contraction and relaxation for the pre and post stimulation task, measured by A: Laser-MMG and B: Tensiometry.....	89
Figure 4.15	Relationship between Dmax and Tmax for the medial gastrocnemius.....	90
Figure 4.16	The relationship between Tensiometry and Laser-MMG for A: tcN B: trN	91
Figure 4.17	The correlation between Tensiometry and Laser-MMG for A: maximal rate of contraction B: maximal rate of relaxation .....	92
Figure 4.18	Pictures taken through Image Pro software of proximal and distal muscle segments.....	93
Figure 4.19	Muscle fibre types.....	94
Figure 4.20	Waveforms from the distal and proximal muscle segments of the medial gastrocnemius when measured by the A: Laser-MMG. B: Tensiometry....	94
Figure 4.21	Laser-MMG and Tensiometric waveform output from A: distal muscle segment. B: proximal muscle segment .....	95
Figure 4.22	Differences in A: Dmax and B: Tmax for the distal & proximal segments.	96
Figure 4.23	tcN, trN and tsN of the distal and proximal segments normalised for the degree of A: displacement and B: tension.....	97
Figure 4.25	Relationship between Dmax and Tmax for the medial gastrocnemius.....	98
Figure 4.26	Relationship for A: tcN; B: trN and C: tsN when measured by the Laser-MMG and the Tensiometer for the medial gastrocnemius.....	99
Figure 5.1	Posterior view of the left hip, identifying the location of superficial cranial-, middle- and caudal- muscle segments of the gluteus maximus muscle.....	114
Figure 5.2	The Laser-MMG technique.....	116
Figure 5.3	Representative MMG waveforms from the three segments of the gluteus maximus (medial portions). .....	121
Figure 5.4	Maximal displacement (Dmax) values for each segment (all subjects).....	121
Figure 5.5	Normalised contraction time (tcN), relaxation time (trN), and sustain time (tsN) of the cranial, middle and caudal segments. ....	122
Figure 5.6	Illustration of lateral view of the shoulder musculature showing the muscle segments within the three superficial shoulder muscles. ....	125
Figure 5.7	Schematic representation of the pectoralis major muscle showing the Laser-MMG recording sites .....	126

Figure 5.8	Schematic representation of the deltoid muscle showing the Laser-MMG recording sites .....	127
Figure 5.10	Dmax values for each muscle segment. ....	133
Figure 5.11	Normalised contraction time ( $tcN$ ) for each muscle segment. ....	134
Figure 5.12	Normalised relaxation time ( $trN$ ) and sustain time ( $tsN$ ) for each muscle segment. ....	135
Figure 5.13	Dmax values for all muscle segments.....	136
Figure 5.14	$tcN$ values for all muscle segments .....	137
Figure 5.15	$trN$ values for all muscle segments.....	138
Figure 5.16	$tsN$ values for all muscle segments .....	138
Figure 5.17	Maximal rates of contraction for all muscle segments.....	139
Figure 5.18	Maximal rates of relaxation for all muscle segments.....	139
Figure 5.19	The average maximal displacement (Dmax) of each pectoralis major segment (all subjects).....	141
Figure 5.20	The average maximal displacement (Dmax) of each segment of the deltoid (all subjects). ....	142
Figure 5.21	The average maximal displacement (Dmax) of each segment of the latissimus dorsi (all subjects). ....	143
Figure 6.1	PVC arm cast .....	154
Figure 6.2	The force/time program display .....	155
Figure 6.3	View of the pectoralis major, deltoid and latissimus dorsi muscles showing the electromyographic microelectrodes attached to a subject.....	156
Figure 6.4	Experimental set-up .....	156
Figure 6.5	Muscle segment $OnN$ at all MT .....	162
Figure 6.6	Muscle segment $OnN\%MT$ at all MT.....	163
Figure 6.7	Muscle segment $PkN$ at all MT .....	165
Figure 6.8	Muscle segment $DurN\%$ at all MT.....	165
Figure 6.9	Muscle segment $iEMGN\%$ at all MT.....	166
Figure 6.10	Electromyographic intensity ( $iEMGN\%$ ) of muscle segments averaged across all speeds of movement. ....	167

Figure 6.11	Muscle segment On, Pk, Dur and Off for the 700ms MT (medium speed of movement). ....	168
Figure 6.12	Onset (On $N$ ) time for all muscle segments during the 700ms MT condition (medium speed of movement).....	169
Figure 6.13	Segment onset, peak and duration compared to force onset, peak and duration for the 1500 ms MT (slow).....	174
Figure 6.14	Segment onset, peak and duration compared to force onset, peak and duration for the 300 ms MT (fast).....	175
Figure 6.15	Illustration showing a muscle segments contraction time (tc $N$ ) and order of electromyographic activation (Onset) during the 700ms MT condition....	181



## List of Tables

Table 2.1	A selection of studies from the literature reporting fibre-type composition of the medial gastrocnemius muscle of the rat. ....	46
Table 4.1	Summary table of results for each measurement technique and muscle temperature.....	80
Table 4.2	Summary table for each measurement technique and muscle condition .....	87
Table 4.3	Summary table of results from the Laser-MMG and Tensiometry methods for each muscle segment. ....	95
Table 5.1	Group mean data for Laser-MMG variables.....	119
Table 5.2	MMG variables for the three muscle segments.....	120
Table 5.3	Segment mean values for each MMG variable. ....	132
Table 6.1	Muscle segment mean values for each EMG variable at the slow (1500 ms), medium (700 ms) and fast (300 ms) MT. ....	160

## Abbreviations

Abbreviation	Term
Cm	centimetre
CNS	central nervous system
CSA	cross sectional area
°C	degrees Celsius
Dur	electromyographic duration
DurN%	normalised electromyographic duration
Dmax	maximum displacement
EMG	electromyography
Fall	maximal rate of relaxation
FcOn	force onset
FcOff	force offset
FcPk	force peak
FDT	force development time
FT	fibre type
iEMGN%	normalised integrated EMG
Int	electromyographic intensity
Kg	kilogram
kHz	kilohertz
MDL	muscle displacement laser
mm	millimetre
MMG	mechanomyography
ms	millisecond
MT	movement time
mv	millivolt
MVC	maximum voluntary contractions
On	electromyographic onset
OnN	normalised electromyographic onset
Pk	electromyographic peak
PkN	normalised electromyographic peak
Rise	maximal rate of contraction
Tc	contraction time
tcN	normalised contraction time
TEN	Tensiometry
Tmax	maximum Tension
Tr	relaxation time
trN	normalised relaxation time
Ts	sustain time
tsN	normalised sustain duration

## **List of Publications**

The publications listed below are associated with the research conducted as part of this thesis.

### **Published Articles**

McAndrew, D.J., Gorelick, M. and Brown, J.M.M. (2006). Muscles within muscles: A mechanomyographic analysis of muscle segment contractile properties within human gluteus maximus. *Journal of Musculoskeletal Research* **10**(1): 23-35.

McAndrew, D.J., Rosser, N. and Brown, J.M.M. (2006). Mechanomyographic measures of muscle contractile properties are influenced by the duration of the stimulatory pulse. *Journal of Applied Research*. **6**(2): pp 142-152

### **Conference Proceedings**

McAndrew, D.J. and Brown, J.M.M. (2004). Muscles within muscles, inter- and intra-muscle segment coordination. *Proceedings of the Australian Association of Exercise and Sports Science Inaugural Conference*, Brisbane, Australia.

McAndrew, D.J., Gorelick, M. and Brown, J.M.M. (2004). Muscle belly displacement as a measure of fatigue. *Proceedings of the Australian Association of Exercise and Sports Science Inaugural Conference*, Brisbane, Australia.

McAndrew, D.J., Rosser, N., Gorelick, M., Phillips, K. and Brown, J.M.M. (2005). Mechanomyography for non-invasive clinical diagnosis in musculoskeletal rehabilitation. *Proceedings of the 4th International Cyberspace Conference on Ergonomics*, Johannesburg, South Africa.

McAndrew, D.J., Gorelick, M. and Brown, J.M.M. (2006). Mechanomyography for clinical decision making in exercise physiology practice. *Proceedings of the Australian Association of Exercise and Sports Science Conference*, Sydney, Australia.

## **Abstract**

The Central Nervous System (CNS) exerts extensive control over muscle activation in order to produce accurate voluntary movement, such as the complex movements of the human shoulder joint. Muscles surrounding multi-planar joints are selectively activated depending upon the movement performed, and within the radiate musculature of the shoulder, individual muscle segments exist that are capable of exhibiting specific myoelectric intensity and temporal activation patterns. The aim of this thesis was to assess the influence of inter-segment variations in contractile properties on the strategies employed by the CNS when producing voluntary movements. Experiments were designed to test the hypothesis that muscle segment neuromotor coordination (as determined by electromyographic analysis) would be sensitive to the contractile properties of individual muscle segments. A key component was the variation in isometric contraction speed ranging from slow to ballistic.

Mechanomyography (MMG), which is the measure of a muscle's physical dimensional change during contraction, is founded on the premise that the temporal aspect of muscle displacement is reflective of motor unit contractile properties and consequently the muscle fibre type composition. A series of studies were completed to establish the validity of the new Laser-MMG technique for quantifying contractile properties. The results confirmed: 1) the sensitivity of the Laser-MMG technique to modulators of physiological performance (thermal state, fatigue state, and fibre type composition variation between segments); and 2) that the contractile properties of muscle fibres varied between the individual segments of the muscles following maximal percutaneous neuromuscular stimulation (PNS). Most notably, 'slow-twitch' contractile properties were found in muscle segments that have a greater role in producing movement in the coronal plane, while 'fast-twitch' contractile properties were associated with segments having more efficient moment arms to produce movement in the sagittal plane. Furthermore, each of the muscles investigated was associated with a distinctive anatomical distribution of muscle fibre types. Muscle segment contractile properties were heterogeneous and their arrangement appears to reflect the most common or important joint movements. Moreover, the muscle segments located at the

periphery of all three shoulder muscles exhibited faster contractile properties than those located in the middle of the muscle. It appears that this internal arrangement may be a consistent organisational characteristic of radiate muscles.

Muscle segments within the pectoralis major, deltoid and latissimus dorsi muscles were found to be independently controlled by the CNS through manipulation of the myoelectric activation patterns, in particular: onset time; and discharge rate. The lower segments of the pectoralis major and the latissimus dorsi were identified as prime mover segments, initiating the movement and contributing the greatest myoelectric intensity. The immediately superior segments were classified as assistant movers, activating after the prime movers and contributing less to the overall movement. Furthermore, similarities in neuromotor coordination were identified between adjacent segments of individual muscles. The sequential “wave of segment activation” identified within each whole muscle appeared to ignore the anatomical boundaries between muscles, suggesting that the CNS coordinates individual muscle segments rather than the whole muscle as one unit in order to complete a motor task. This further complicates the process of controlling motor tasks as there appear to be no defined limits of muscles to which discrete functions can be applied.

Coordination between prime mover segments of agonist muscles was identified, with the lower segments of pectoralis major and latissimus dorsi showing no significant difference in any of the temporal myoelectric measures. The similarity in neuromotor coordination between these segments may be the result of a common drive, suggesting that the CNS uses a simple strategy of combining the segments into one functional unit.

No gross disordering of the muscle segments’ onset was identified within any of the investigated muscles, with regard to movement speed. However, the pectoralis major exhibited altered relative timing between the segments. This was particularly evident during the fast movement. The sequential “wave of activation” present during the slow movements became disordered as muscle contraction speed was increased. During fast contraction, the assistant mover segments within pectoralis major were activated later than the prime mover segments changing the relative timing of their activation. This indicates

that the CNS may initially prioritise the activation of only the most essential muscle segments to commence the movement during ballistic movements, perhaps due to the imposed time constraints. This form of change in relative timing can be interpreted as a direct reflection of the differences in muscle segment fibre type composition and hence the neuromotor control of the muscle segments involved in producing the movement. Most notably, variation to the control of muscle segment excitation and contraction onset exist in the more centrally located muscle segments that exhibit slower segment contractile properties. This finding appears logical when coupled with the finding of homogeneous myoelectric peak activity. The CNS must manipulate the onset of these slower contracting segments, especially during fast movements, in order to allow enough time for all segments to achieve a uniform peak of muscle activity that occurs just prior to peak force.

The variations and coordination of contractile properties, myoelectric properties and electromyographic burst patterns between adjacent muscle segments within the same skeletal muscle confirms the notion that for CNS control, individual muscle segments are considered as sub-volumes of muscle tissue that require individual neuromotor control – that they are, in effect, muscles within muscles.