



Faculty of Manufacturing Engineering



**EFFECTS OF TORQUE DIRECTION, SHAPE, SIZE, SENSATION
AND TECHNIQUE ON PINCH FORCE**

اونيورسيتي تيكنيكل مليسيا ملاك
UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Ng PohKiat

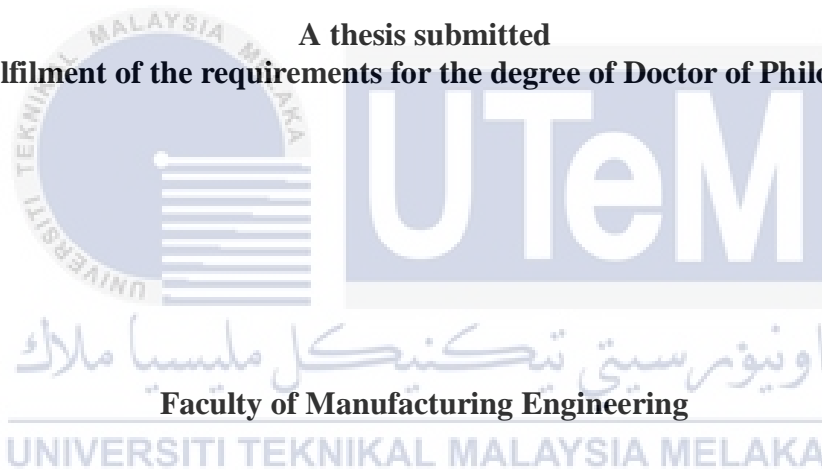
Doctor of Philosophy

2015

**EFFECTS OF TORQUE DIRECTION, SHAPE, SIZE, SENSATION AND
TECHNIQUE ON PINCH FORCE**

NG POH KIAT

**A thesis submitted
in fulfilment of the requirements for the degree of Doctor of Philosophy**




UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2015

DECLARATION

I declare that this thesis entitled “Effects of Torque Direction, Shape, Size, Sensation and Technique on Pinch Force” is the result of my own research except as cited in the references. The thesis has not been accepted for any other degree and is not concurrently submitted in candidature of any other degree.



Signature :

Name :

اونيورسيتي تيكنيكل مليسيا ملاك

Date :

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Doctor of Philosophy.

Signature	:
Supervisor Name	:
Date	:



اونيورسيتي تيكنيكل مليسيا ملاك

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

DEDICATION

To my beloved mother and father



ABSTRACT

In manual work, high pinch force exertions can be associated with the development of hand-related musculoskeletal disorders. Conversely, low pinch force exertions can cause slippages, which can lead to hand-related injuries. In association to this, researchers found that handgrip force is significantly affected by torque direction, size and sensation. However, there appear to be few related studies on the effects of different pinch parameters on pinch force. The novelty of this research lies in its aim which is to disclose the effects of pinch parameters such as the torque direction of pinches, shape and size of objects, sensation of fingers and technique of pinches on pinch force. The research uses a full factorial design of experiment with 5 variables. Three common types of screw knobs of 3 different shapes (spherical, cylindrical, 5-lobes) and sizes (large, medium, small) are identified and fabricated for the experiment, which involves approximately 30 participants. Participants are required to pinch the knobs with 3 commonly-used pinch techniques (lateral, 3-jaw chuck, pulp-2) while wearing pressure sensors that record the forces between the fingertips and knobs. The forces are recorded in Minitab 16. The analysis of variance is used to determine the effects of the main and combinatorial factors on pinch force while the response surface regression and response optimisation are used to determine the optimised pinch force response. It is found that pinch force is significantly affected by all the main parameters. For the two-way interactions, only interactions of sensation with pinch technique, sensation with size, pinch technique with torque direction, pinch technique with size, torque direction with size and shape with size are significant. A response surface regression model representing these effects is also generated. This is useful for the pinch force prediction using any of the parameter combinations. By defining the predicted maximum, minimum and average pinch force responses through the response optimisation, a total of 3 major factorial combinations were identified. The findings potentially aid the development of both safety and design guidelines for ergonomic precision designs. Although much research is required, it is hoped that this study can serve as a precursory guideline for researchers to further expound ideas related to pinch force capacity.

ABSTRAK

Dalam kerja manual, daya cubitan tinggi dikaitkan dengan punca penyakit muskuloskeletal tangan. Sebaliknya, daya cubitan rendah menyebabkan kegelinciran yang membawa kepada kecederaan tangan. Sehubungan itu, para penyelidik mendapati bahawa daya cengkaman tangan dipengaruhi oleh arah tork, bentuk, saiz, sensasi sentuhan dan teknik cubitan. Walau bagaimanapun, terdapat hanya beberapa kajian yang berkaitan dengan kesan-kesan arah tork, bentuk objek, saiz objek, sensasi sentuhan dan teknik cubitan kepada daya cubitan. Oleh itu, kajian ini bertujuan menentukan kesan-kesan arah tork, bentuk, saiz, sensasi dan teknik kepada daya cubitan. Kaedah penyelidikan ini melibatkan penggunaan reka bentuk faktorial eksperimen yang lengkap, yang mana 3 tombol skru dalam 3 bentuk (sfera, silinder, 5-cuping) dan 3 saiz (besar, sederhana, kecil) dikenalpasti dan direka bagi eksperimen ini. Sekitar 30 subjek ujian dikehendaki mencubit tombol-tombol yang direka dengan 3 teknik cubitan (lateral, chuck 3-rahang, pulpa-2) sambil memakai sensor-sensor tekanan yang merekodkan daya di antara hujung jari dan tombol. Daya direkodkan dalam Minitab 16. Analisis varians digunakan untuk menentukan kesan-kesan dari faktor-faktor utama dan kombinasi kepada daya cubitan, manakala regresi respons permukaan dan pengoptimuman respons digunakan untuk menentukan respons daya cubitan optimum. Keputusan kajian menunjukkan bahawa daya cubitan dipengaruhi oleh semua faktor-faktor utama dan kombinasi. Bagi interaksi dua arah, hanya interaksi sensasi dengan teknik cubitan, sensasi dengan saiz, teknik cubitan dengan arah tork, teknik cubitan dengan saiz, arah tork dengan saiz dan bentuk dengan saiz dikenalpasti sebagai interaksi-interaksi yang ketara. Model regresi respons permukaan yang mewakili kesan-kesan ini juga dihasilkan. Dengan pentakrifan jangkakan respons daya cubitan maksimum, minimum dan purata melalui pengoptimuman respons, sebanyak 3 kombinasi faktorial yang ketara dikenalpastikan. Penemuan ini berpotensi membantu penghasilan garis panduan keselamatan dan reka bentuk peralatan ergonomik persis. Walaupun banyak kajian perlu diterajui, adalah diharapkan bahawa kajian ini dapat menjadi garis panduan pendahuluan bagi para penyelidik supaya menyumbangkan lagi ide-ide berkaitan dengan kapasiti daya cubitan.

ACKNOWLEDGEMENTS

I would like to express my special appreciation and thanks to my supervisor, Professor Dr. Adi Saptari, who has shown the attitude and substance of an intellectual that continually and persuasively conveyed to me a spirit of adventure in regards to research. I would also like to thank Assoc. Prof. Dr. Rizal bin Salleh, for co-supervising me and enabling this doctoral journey to be an enjoyable one with his brilliant comments and suggestions.

I would especially like to thank my fellow colleagues and research peers, Mr. Jee Kian Siong and Ms. Yeow Jian Ai, who advised, motivated and encouraged me throughout my doctoral journey. A special thanks to my family as well. Words cannot express how grateful I am to my father, Dr. Ng Choon Liang, and my late mother, Mdm. Wong Siew Chin, and for all of the sacrifices that they have made on my behalf. Their prayers for me were what sustained me thus far.

I would like to thank all of my friends, especially those who supported me in my writing and inspired me to strive towards my goal. I would also like express appreciation to my beloved wife, Ms. Penny Ong Boon Peng, who supported me in moments when there was no one to answer my queries. Finally, a loving gratitude I give to my dear son and daughter, Jaymus Ng and Jeslyn Ng, whose laughter and smiles provided warmth to my heart and soul during this challenging and trying quest for the PhD.

TABLE OF CONTENTS

	PAGE
DECLARATION	
APPROVAL	
DEDICATION	
ABSTRACT	i
ABSTRAK	ii
ACKNOWLEDGEMENTS	iii
TABLE OF CONTENTS	iv
LIST OF TABLES	vii
LIST OF FIGURES	x
LIST OF APPENDICES	xiv
LIST OF PUBLICATIONS	xv
CHAPTER 1: INTRODUCTION	1
1.1 Background	1
1.2 Problem statement	3
1.3 Research objectives	4
1.4 Motivation of research	5
1.5 Contribution to knowledge	7
1.6 Scope and limitations of study	8
1.7 Structure of thesis	9
CHAPTER: LITERATURE REVIEW	11
2.1 Introduction	11
2.2 Background	11
2.3 Pinch grip	15
2.4 Pinch force	17
2.5 Pinch parameters	20
2.6 Pinch technique	20
2.6.1 Pulp/Pad pinch	23
2.6.2 Lateral pinch	29
2.6.3 Three-jaw chuck pinch	33
2.6.4 Tip pinch	36
2.6.5 Research on pinch techniques	37
2.7 Torque	41
2.7.1 Torque directions	47
2.8 Screw knobs	51
2.9 Object shape	52
2.10 Object size	56
2.11 Sensation	61
2.11.1 Research on sensation	62
2.11.2 Surface friction versus pinch force	65
2.11.3 Effects of glove usage on grip strength and three-point pinches	69
2.12 Research design	72

2.13	Regression modelling and validation	75
2.14	Summary of research gaps	76
CHAPTER 3: RESEARCH METHODOLOGY		80
3.1	Introduction	80
3.2	Development of hypotheses	80
3.3	Design of experiment	83
3.4	Equipment and materials	89
	3.4.1 Knob design	91
3.5	Participant selection	92
3.6	Ethical considerations	93
3.7	Experimental protocol and measurements	93
	3.7.1 Experimental protocol	94
	3.7.2 Data measurement	97
3.8	Analyses Used	100
	3.8.1 Analysis of variance (ANOVA)	101
	3.8.2 Response surface regression	104
	3.8.3 Response optimiser	107
3.9	Validation of experiment and model	112
3.10	Normality	113
3.11	Reliability	113
	3.11.1 Test-retest reliability	114
3.12	Pilot study	114
3.13	Results of pilot study	117
3.14	Constraints from pilot study	118
3.15	Proposed improvements	121
3.16	Estimation of sample size	125
3.17	Summary	127
CHAPTER 4: RESULTS AND DISCUSSION		129
4.1	Introduction	129
4.2	Results and discussion	129
	4.2.1 Summary of data collected	130
	4.2.2 Ryan-Joiner normality test	133
	4.2.3 Reliability analysis	133
	4.2.4 Summary of demographic details of participants	134
	4.2.5 Overall ANOVA analysis	136
	4.2.6 Results of main effects on pinch force	138
	4.2.7 Results of multiple combinatorial effects on pinch force	153
	4.2.8 Results of optimum pinch force response	183
	4.2.9 Validation of models	194
	4.2.9.1 Theoretical validation	194
	4.2.9.2 Generality validation	195
4.3	Summary of contributions	202
	4.3.1 Pinch parameters significantly affect pinch force	202
	4.3.2 Different pinch parameter combinations significantly affect pinch force	204
	4.3.3 Response surface regression models and optimum pinch force responses	206

4.4	Implications of study	207
CHAPTER 5: CONCLUSIONS AND FUTURE RESEARCH		210
5.1	Conclusions	210
5.1.1	The effects of the pinch parameters on pinch force	210
5.1.2	Relationship between pinch parameters and pinch force	211
5.1.3	Optimum pinch force response as a function of pinch parameters	212
5.2	Future research	213
REFERENCES		215
APPENDIX A		254
APPENDIX B		255
APPENDIX C		256
APPENDIX D		258
APPENDIX E		278
APPENDIX F		298
APPENDIX G		299



LIST OF TABLES

TABLE	TITLE	PAGE
2.1	Examples of pinches	22
2.2	Most common identification responses for pulp-2 pinch	24
2.3	Average force of pulp pinch with separate fingers	25
2.4	Average finger force	26
2.5	Most common identification responses for lateral pinch	30
2.6	Average force of lateral pinch by occupation	30
2.7	Most common identification responses for three-jaw chuck pinch	34
2.8	Average force of chuck pinch by occupation	34
2.9	Three-jaw chuck pinch difference among each glove type versus no gloves	35
2.10	Most common identification responses for tip pinch	36
2.11	The classification of knob shapes	55
2.12	The classification of knob sizes	60
2.13	Properties of leather, nitrile and vinyl gloves	70
2.14	Grip force differences of the means with each glove type versus no gloves	70
2.15	Summary of research gaps	78
3.1	DOE selection guideline	84
3.2	Design of experiment measurement layout	88

3.3	Sensor colour indicators and identifiers	96
3.4	Classification of indicators according to factor levels	103
3.5	Significance of the main effects on pinch force	117
3.6	Z-values for selected confidence levels	125
3.7	Summary of constraints and improvements	128
4.1	Description of indicators and respective levels	130
4.2	Data collected for 108 combinations (structure with loading)	131
4.3	Data collected for 108 combinations (structure without loading)	132
4.4	Test-retest reliability analysis results	134
4.5	Summary of demographic details	136
4.6	Overall ANOVA analysis (before screening)	137
4.7	Overall ANOVA analysis (after screening)	138
4.8	Significances of the main effects on pinch force	139
4.9	Outcomes of the hypotheses for the main effects	153
4.10	Summary of significances in higher and lower order interactions	181
4.11	Outcomes of the hypotheses for the multiple combinatorial effects	183
4.12	Response surface regression results (before screening)	184
4.13	Response surface regression results (after screening)	184
4.14	Minimum, mean and maximum pinch force	186
4.15	Optimisation for the predicted minimum response	187
4.16	Optimisation for the predicted maximum response	189
4.17	Optimisation for the predicted average response	191
4.18	Summary of response error validation results	195
4.19	Description and combination of categorised objects (with loading)	199

4.20	Description and combination of categorised objects (without loading)	200
4.21	Validation results for model with loading	201
4.22	Validation results for model without loading	201



LIST OF FIGURES

FIGURE	TITLE	PAGE
2.1	Pinch grip and power grip	12
2.2	A pinch grip position (right hand)	16
2.3	Number of phalanges in a hand	21
2.4	Pulp-2 pinch	24
2.5	Pulp-3 pinch	27
2.6	Pulp-4 pinch	28
2.7	Pulp-5 pinch	29
2.8	Distance between distal interphalangeal joint of the index finger and the interphalangeal joint of the thumb	32
2.9	The force exertion on a rod	41
2.10	The torque direction	42
2.11	The clockwise and counterclockwise torque direction	48
2.12	A schematic of the model that describes the DIP joint moment	49
2.13	The capacity of fingers to grip various diameters	58
2.14	Range of allowed forces determined by coefficient of friction	66
2.15	Measuring pinch forces for different surfaces	67
2.16	Maximum pinch force for the two grip surfaces	68
3.1	Summary table of randomised factorial combinations	89
3.2	Flexiforce sensors	90

3.3	Nitrile and cotton gloves for reduced and increased sensation	91
3.4	Large cylindrical, spherical and 5-lobes knobs	91
3.5	Medium cylindrical, spherical and 5-lobes knobs	92
3.6	Small cylindrical, spherical and 5-lobes knobs	92
3.7	Flow chart of entire experimental protocol	94
3.8	An example of a seated posture	95
3.9	Attachment of sensors to fingers	96
3.10	The 3 commonly used pinch techniques	97
3.11	Flow chart of entire data measurement process	98
3.12	Force distribution over a period of time	99
3.13	Saving the pinch force data as an ASCII file	99
3.14	List of forces in excel format	100
3.15	Flow chart for the ANOVA process	102
3.16	Flow chart of response surface regression process	105
3.17	Flow chart for response optimisation process	108
3.18	Setup for the response optimiser	109
3.19	Flow chart for entire experimentation process	115
3.20	Two wooden structures	116
3.21	Screw knobs wrapped with nitrile and cotton gloves	119
3.22	Sensors and handles attached to fingers and wrist	120
3.23	Wooden structure used for the pilot study	121
3.24	Small pieces of nitrile and cotton	122
3.25	Complete setup of the sensors	123
3.26	New wooden structure with knob adapter and indicators	124

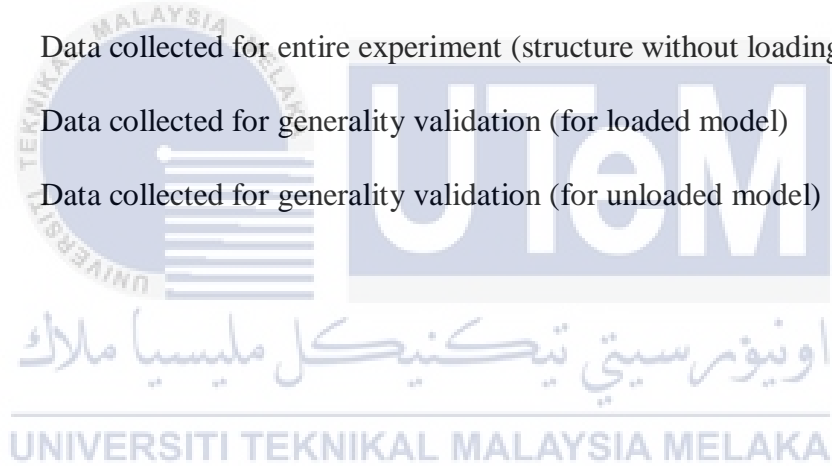
3.27	Results of sample size estimated	127
4.1	Ryan-Joiner normality test results	133
4.2	Factorial plot of torque direction	140
4.3	A schematic of the model that describes the DIP joint moment	142
4.4	Factorial plot of object shape	143
4.5	Surface areas of the three shapes	145
4.6	Factorial plot of object size	146
4.7	Contact area across different object sizes	147
4.8	Factorial plot of tactile sensation	149
4.9	Factorial plot of pinch technique	151
4.10	Interaction plot of sensation and pinch technique	155
4.11	Interaction plot of sensation and torque direction	158
4.12	Interaction plot of sensation and object shape	160
4.13	Interaction plot of sensation and object size	162
4.14	Interaction plot of pinch technique and torque direction	165
4.15	Interaction plot of pinch technique and object shape	167
4.16	Interaction plot of pinch technique and object size	169
4.17	Interaction plot of torque direction and object shape	172
4.18	Interaction plot of torque direction and object size	174
4.19	Interaction plot of object shape and object size	177
4.20	Summary of interaction plots of torque direction, shape, size, sensation and technique (with loading)	179
4.21	Summary of interaction plots of torque direction, shape, size, sensation and technique (without loading)	180

4.22	Selection of objects based on work classifications (loaded model)	197
4.23	Selection of objects based on work classifications (unloaded model)	197



LIST OF APPENDICES

APPENDIX	TITLE	PAGE
A	Consent form for the participant	254
B	Demographic details of participant	255
C	Design of experiment layout	256
D	Data collected for entire experiment (structure with loading)	258
E	Data collected for entire experiment (structure without loading)	278
F	Data collected for generality validation (for loaded model)	298
G	Data collected for generality validation (for unloaded model)	299



LIST OF PUBLICATIONS

NO. JOURNAL PAPERS (SCOPUS- AND ISI-INDEXED)

1. Tan, Y. H., Ng, P. K., Saptari, A. and Jee, K. S., 2015. Ergonomics Aspects of Knob Designs: A Literature Review. *Theoretical Issues in Ergonomics Science*, 16 (1), pp. 86-98.
2. Tan, Y. H., Ng, P. K., Saptari, A. and Jee, K. S., 2015. Roles of Pinch Grips in Different Knob Selections among Malaysian Manufacturing Workers. *Applied Mechanics and Materials*, 761, pp. 688-692.
3. Ng, P. K., Bee, M. C., Saptari, A. and Mohamad, N. A., 2014. A Review of Different Pinch Techniques. *Theoretical Issues in Ergonomics Science*, 15 (5), pp. 517-533.
4. Ng, P. K., Boon, Q. H., Chai, K. X., Leh, S. L., Bee, M. C. and Saptari, A., 2014. The Roles of Shape and Size in the Pinch Effort of Screw Knobs. *Applied Mechanics and Materials*, 465-466 (11), pp. 1202-1206.
5. Ng, P. K., Chai, K. X., Leh, S. L., Bee, M. C., Boon, Q. H. and Saptari, A., 2014. Applying Clockwise and Counterclockwise Torque Directions in Pinch Grips: A Descriptive Study. *Applied Mechanics and Materials*, 465-466 (11), pp. 1170-1174.
6. Ng, P. K., Leh, S. L., Bee, M. C., Boon, Q. H., Chai, K. X. and Jee, K. S., 2014. The Effects of Different Tactile Sensations on Pinch Effort. *Applied Mechanics and Materials*, 465-466 (11), pp. 1175-1179.

7. Ng, P. K., Bee, M. C., Boon, Q. H., Chai, K. X., Leh, S. L. and Jee, K. S., 2014. Pinch Techniques and Their Effects on Pinch Effort: A Pilot Study. *Applied Mechanics and Materials*, 465-466 (11), pp. 1165-1169.
8. Ng, P. K., Saptari, A., Boon, Q. H., Bee, M. C., Chai, K. X. and Leh, S. L., 2014. Pinch Effort Variations with Torque, Shape, Size, Sensation and Technique. *Journal of Applied Sciences*, 14 (5), pp. 401-414.
9. Ng, P. K., Saptari, A. and Yeow, J. A., 2014. Synthesising the Roles of Torque and Sensation in Pinch Force: A Framework. *Theoretical Issues in Ergonomics Science*, 15 (2), pp. 193-204.
10. Ng, P. K. and Saptari, A., 2014. A Review of Shape and Size Considerations in Pinch Grips. *Theoretical Issues in Ergonomics Science*, 15 (3), pp. 305-317.

NO. CONFERENCE PAPERS

1. Tan, Y. H., Ng, P. K., Saptari, A. and Jee, K. S. (2014). Roles of Pinch Grips in Different Knob Selections among Malaysian Manufacturing Workers. 3rd International Conference on Design and Concurrent Engineering, Melaka, Malaysia.
2. Ng, P. K., Bee, M. C., Boon, Q. H., Chai, K. X., Leh, S. L. and Jee, K. S. 2013. Pinch Techniques and Their Effects on Pinch Effort: A Pilot Study. 4th International Conference on Mechanical and Manufacturing Engineering. Bangi-Putrajaya, Malaysia.
3. Ng, P. K., Boon, Q. H., Chai, K. X., Leh, S. L., Bee, M. C. and Saptari, A. 2013. The Roles of Shape and Size in the Pinch Effort of Screw Knobs. 4th International Conference on Mechanical and Manufacturing Engineering. Bangi-Putrajaya, Malaysia.

4. Ng, P. K., Chai, K. X., Leh, S. L., Bee, M. C., Boon, Q. H. and Saptari, A. 2013. Applying Clockwise and Counterclockwise Torque Directions in Pinch Grips: A Descriptive Study. 4th International Conference on Mechanical and Manufacturing Engineering. Bangi-Putrajaya, Malaysia.
5. Ng, P. K., Leh, S. L., Bee, M. C., Boon, Q. H., Chai, K. X. and Jee, K. S. 2013. The Effects of Different Tactile Sensations on Pinch Effort. 4th International Conference on Mechanical and Manufacturing Engineering. Bangi-Putrajaya, Malaysia.



CHAPTER 1

INTRODUCTION

1.1 Background

In spite of the technological advancements in numerous manufacturing firms, hands and fingers are still primary tools for high precision manufacturing work and are often used to pinch, grip and manipulate objects such as fasteners, clips and electronic components. The use of hands and fingers are common in many manual activities such as twisting the handle of a screwdriver, turning a machine knob and pinching small threaded or unthreaded components (Seo and Armstrong, 2008; Seo et al., 2008b; Shivers et al., 2002). However, awkwardly positioned, high-force pinch grip exertions can lead to injuries and musculoskeletal disorders (Ellis et al., 2004). High-force pinch force exertions can cause fatigue, discomfort and injury to the hand in industrial populations (Shivers et al., 2002).

A pinch grip is defined as an act of gripping or squeezing an object between the thumb and the finger (Trew and Everett, 2005). For example, a pinch grip is used to hold a key in a position just before it is used to operate a lock. A pinch grip is considerably different from a hand grip which is used to grip an object between the palm of the hand with a force from the thumb opposing the combined forces from the other fingers (Kumar, 2008). For example, a hand grip is used to hold a hammer in a position just before it is used to deliver an impact to an object.