NOTE

This online version of the thesis may have different page formatting and pagination from the paper copy held in the University of Wollongong Library.

UNIVERSITY OF WOLLONGONG

COPYRIGHT WARNING

You may print or download ONE copy of this document for the purpose of your own research or study. The University does not authorise you to copy, communicate or otherwise make available electronically to any other person any copyright material contained on this site. You are reminded of the following:

Copyright owners are entitled to take legal action against persons who infringe their copyright. A reproduction of material that is protected by copyright may be a copyright infringement. A court may impose penalties and award damages in relation to offences and infringements relating to copyright material. Higher penalties may apply, and higher damages may be awarded, for offences and infringements involving the conversion of material into digital or electronic form.
Fat Flat Feet: Footwear for the Obese Child

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

Doctor of Philosophy

from the

University of Wollongong

by

Annaliese Dowling M. Sc. (Hons)

School of Health Sciences

2006
I, Annaliese M. Dowling, declare that this thesis, submitted in partial 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.

_____________________
Annaliese M. Dowling

02/09/2006
Dedication

To Mum, Dad, Edwina, Dave and Kate,
who have been involved from the beginning.
Thank you for all for your love, support and encouragement.

To Tim, who has been my pillar of strength and kept me sane throughout
this long journey called a thesis.
Acknowledgments

I would like to express my gratitude to the following people without whose assistance this thesis would not have been possible. Sincere thanks to:

- The Australian Research Council for funding this PhD through the Strategic Partnerships with Industry – Research and Training (SPIRT) scheme (C00106578). The Industry Partner for this project was ASICS Tiger Oceania Pty Ltd.
- Professor Julie Steele, my supervisor, who helped to shape me as a researcher.
- Professor Louise Baur, my co-supervisor, who allowed me to gain great insight into the area of childhood obesity.
- All members of the Biomechanics Research Laboratory who, with their support, friendship and knowledge of research, helped me to get through this thesis with as few dramas as possible.
- My research team, whom without their assistance during data collection, the test days would have taken so much longer. Thanks to Sally Davidson, Elizabeth Cowling and Suzi Edwards who assisted in Experimental Section 1. Thanks to Katrina Simpson, Renate List, Kai Henrichs, and Karen Mickle who assisted in Experimental Section 2.
- Gary Slater for his technical support and expertise.
- The staff and students of all the schools that participated in Experimental Section 1.
- The children who participated as subjects for Experimental Section 2 and who endured testing with no air-conditioning in the middle of summer.
- Renate List [RL] and Kai Henrichs for their computer programming and video analysis skills.
- Dr John Simpson for his technical support.
- Karen Mickle and Jessica Steele who helped pilot my protocols for the study.
- Patrick McLaughlin from Ezup Ltd for his support with Novel hardware and software.
- Mark Doherty from ASICS Tiger Oceania Pty Ltd, who provided invaluable assistance and expertise throughout this thesis.
- Professor Caroline Finch and the staff at the NSW Injury Risk Management Research Centre (UNSW) for their support during the writing up process.
List of Presentations

The presentations listed below have arisen directly from the research conducted for this thesis. Other related publications completed by the author are included in the reference list.

Publications in Conference Proceedings


Dowling AM, Steele JR & Baur LA. Sex, age and plantar pressure: How are they affected by obesity? 2003 Australian Conference of Science and Medicine in Sport, Canberra, Australia, October 2003. *Journal of Science and Medicine in Sport* December 2003, 6(4) Supplement, 47.


Dowling AM, Steele JR & Baur LA. Obesity and prepubertal plantar pressures: what is the problem? Ninth International Congress on Obesity, Sao Paulo, Brazil, August, 2002. *International Journal of Obesity and Related Metabolic Disorders* August 2002, 26(S1), S123.

Abstract

Obesity is a global public health problem that affects both children and adults. The consequences and complications of bearing additional mass place an enormous amount of stress on the human body. Musculoskeletally, the feet must endure this excessive mass throughout the tasks of daily living as the feet are the terminus of the body for both stance and gait. Previous studies have reported that obese children display different foot structural characteristics and generate higher plantar pressures, particularly under the midfoot and forefoot, compared to non-obese children. It has been speculated that these higher plantar pressures may potentially place the feet of obese children at risk of injury, although this notion has not been confirmed. Therefore, the aim of this thesis was to develop a shoe to cater for the unique structural and functional characteristics of the obese child and to examine whether the experimental shoe improved the level of shoe fit, comfort and decreased the high forefoot plantar pressures experienced by obese children when walking. To achieve this aim, the thesis was divided into two Experimental Sections, incorporating the development and assessment of the experimental footwear.

In Experimental Section 1 foot shape, foot structure and function were evaluated in 437 children (aged 7-12 years) attending 27 primary schools in New South Wales to form a database of information regarding the feet of Australian children. Gender and age were found to affect the foot measurements obtained for these children, confirming that children’s feet develop at different rates and proportions. The boys displayed larger foot dimensions compared to the girls and, as anticipated, the older children displayed larger foot dimensions compared to the younger children. When these data were compared to adult foot dimension values they highlighted differences in proportion between adult and children’s feet, indicating the need to develop a children’s shoe last, as shoes manufactured as scaled-down versions of adult shoes will not correctly fit the foot shape of children’s feet.

From this normative database the foot dimensions, plantar shape and plantar pressure variables for 45 obese children and 45 age and gender–matched controls were compared to establish the effect of obesity and gender on foot structure and function. The obese children displayed significantly greater values for 17 out of the 26 foot/leg dimensions, as well as an increased plantar contact area compared to their matched non-obese counterparts. As no interaction was identified between gender and obesity, it was
confirmed that the effects of obesity were not moderated by gender. In comparison to
the non-obese children, the obese children generated higher forces, force-time integrals,
peak pressures, pressure-time integrals and increased plantar contact area when walking
compared to the non-obese children. Based on these results it was recommended that a
shoe should be designed to cater for the larger foot dimensions characteristic of obese
children and to cushion the larger plantar pressure distributions generated when these
children walk.

A survey was also undertaken to identify factors that influence the purchasing of
children’s shoes. Parents indicated that fit and comfort were important factors
influencing their footwear purchases for their child, even though few parents regularly
had their child professionally fitted for shoes. It was anticipated that shoes would need
to be replaced because the child had outgrown them, although there was also a high
proportion of shoes being replaced because they had been worn out.

An experimental shoe was designed to cater for obese children based on the foot
structure, function and survey data. The two main design parameters included in the
shoes were an increase in forefoot width to cater for the large foot dimensions of obese
children and variations in midsole hardness to cushion the high plantar pressures. Six
experimental shoes were evaluated by 14 children who were classified as either
overweight and obese children or non-overweight children. Experimental Section 2
investigated how variations in shoe width and midsole hardness affected the fit,
comfort, plantar pressures and gait in the two subject groups.

A shoe fit assessment revealed no noticeable differences between the
experimental shoes by the children. The shoe comfort and fit parameters, which were
assessed via a visual analog scale, demonstrated that these parameters, when used in the
evaluation of footwear, relied on individual perceptions of the wearer. The
overweight/obese children did report slightly higher shoe fit and comfort values when
wearing the wide shoe compared to the narrow shoe although this difference was not
significant. However, the non-overweight children reported higher fit and comfort
values than the overweight/obese children when wearing the wide shoes.

In general, the plantar pressure distributions at the foot/shoe interface were
lower than the previous barefoot values, indicating that footwear moderated the plantar
pressure distributions generated during walking. Changes in shoe width and midsole
density were found to have negligible affect on the in-shoe plantar pressure variables
and spatio-temporal gait parameters, which may be attributable to the small differences
reported in shoe fit assessment. The soft shoes resulted in lower peak pressures being generated under the forefoot but higher peak pressures for the heel and midfoot. The overweight/obese children, regardless of footwear condition, altered their gait to cope with the stresses placed on their feet during walking. Clearly, further research is required to develop shoes to cater for the unique feet of obese children and to better dissipate loading during gait.

It was concluded that a shoe based on the unique foot structure, shape and function of obese children is required by these children. However, the difficulty in designing such a shoe that is universally suitable for obese children because of differential foot development, are acknowledged. Further, perceptions of shoe fit and shoe comfort are highly subjective variables, compounding appropriate shoe design. This thesis highlighted that without good levels of shoe fit, it is difficult to achieve optimal shoe comfort. Although a shoe was developed based on the unique features of obese children’s feet, more modifications are required to the experimental shoes, especially in shoe width, in order to improve shoe fit.
# Table of Contents

| Declaration ................................................................................................................. | ii |
| Dedication ................................................................................................................ | iii |
| Acknowledgments ...................................................................................................... | iv |
| List of Presentations ............................................................................................... | v |
| Abstract .................................................................................................................. | vi |
| Table of Contents .................................................................................................... | ix |
| List of Tables .......................................................................................................... | xvi |
| List of Figures ......................................................................................................... | xxii |

## Chapter 1: The Problem

1.1 Introduction ......................................................................................................... 1
1.2 Statement of the Problem .................................................................................... 3
1.3 Significance of the Study .................................................................................... 4

## Chapter 2: Literature Review

2.1 Introduction ......................................................................................................... 5
2.2 Child Development .............................................................................................. 5
2.3 Childhood Obesity ............................................................................................... 7
2.4 The Foot ................................................................................................................ 11
2.5 Foot Shape ........................................................................................................... 16
2.6 Childhood Obesity, Foot Structure and Function ............................................... 18
2.7 Childhood Obesity and Plantar Pressure Measurement ...................................... 21
2.8 Shoe Design ........................................................................................................ 25
2.9 Shoe Fit ............................................................................................................... 26
2.10 Summary ............................................................................................................ 30

## Experimental Section 1

## Chapter 3: How do gender and age affect foot shape in children?  
Implications for shoe design.

3.1 Introduction ......................................................................................................... 32

3.1.1 Hypotheses .................................................................................................... 33
Chapter 5: What factors do parents consider important when purchasing shoes for their children?

5.1 Introduction .................................................................85
  5.1.1 Hypotheses ............................................................85
5.2 Methods .................................................................86
  5.2.1 Survey Instrument ................................................86
  5.2.2 Survey Instrument Validity ...................................87
  5.2.3 Survey Instrument Reliability ..............................88
  5.2.4 Survey Distribution .............................................88
  5.2.5 Response Rate ....................................................90
  5.2.6 Data Analysis ......................................................90
5.3 Statistical Analyses ..................................................91
5.4 Results .................................................................91
  5.4.1 Demographic and Foot Pathology Data ...............91
5.4.2 Shoe Fit .....................................................................................................92
5.4.3 Athletic Footwear ......................................................................................94
5.5 Discussion ......................................................................................................98
5.6 Summary .........................................................................................................101
5.7 Conclusions .....................................................................................................102

Chapter 6: Summary and Implications for an Experimental Shoe

6.1 Summary .........................................................................................................103
6.2 Design of the Experimental Shoe ..................................................................105
  6.2.1 Shoe Fit ...................................................................................................105
  6.2.2 Shoe Cushioning ......................................................................................106
  6.2.3 Summary of the Fit and Midsole Features ..............................................108
  6.2.4 Other Footwear Features .........................................................................109
6.3 Summary of the Experimental Shoe ............................................................112

Experimental Section 2

Chapter 7: How do variations in shoe width and midsole hardness affect shoe fit, comfort, plantar pressures and gait in overweight/obese and non-overweight children?

7.1 Introduction .....................................................................................................114
  7.1.1 Hypotheses .............................................................................................114
7.2 Methods ..........................................................................................................115
  7.2.1 Subjects ...................................................................................................115
  7.2.2 Foot Anthropometry ..............................................................................116
  7.2.3 Assessing Shoe Fit ..................................................................................116
  7.2.4 The Experimental Footwear Movement .................................................117
  7.2.5 Subjective Ratings of Shoe Fit and Comfort ..........................................117
  7.2.6 In-Shoe Plantar Pressure Distributions .................................................119
  7.2.7 Spatio-Temporal Characteristics of Gait ................................................122
7.3 Statistical Analyses ........................................................................................124
7.4 Results ............................................................................................................125
  7.4.1 Anthropometry .......................................................................................125
  7.4.2 Shoe Fit .................................................................................................126
Chapter 8: Conclusions and Recommendations for Future Research

8.1 Synopsis ..................................................................................................................168
8.2 Conclusions .............................................................................................................170
8.3 Recommendations for Future Research .................................................................170

References ..................................................................................................................172

Appendices ..................................................................................................................193
1. List of Schools Contacted ........................................................................................194
2. Experimental Section 1 Parent Information Package ........................................196
3. Experimental Section 1 Child Information Sheet .................................................197
4. Experimental Section 1 Consent Form ................................................................198
5. Experimental Section 1 University of Wollongong Ethics Approval 2001 ....199
6. Experimental Section 1 University of Wollongong Ethics Renewal 2002 ......200
7. Experimental Section 1 NSW Department of Education and Training
   Ethics Approval ......................................................................................................201
8. Classification of Body Mass Index ........................................................................202
9. Height and Mass of Children Worldwide ............................................................203
10. Experimental Section 1 Survey ..............................................................................204
11. Experimental Section 1 Flow Chart of Data Collection ......................................208
12. Experimental Section 1 Certificate of Participation ...........................................209
13. Shoe sizes of the Obese and Non-obese Children ..............................................210
14. Experimental 2 Media Release ..........................................................................212
15. Experimental Section 2 Parent Information Package ........................................213
16. Experimental Section 2 Child Information Sheet ...............................................214
17. Experimental Section 2 Consent Form ...............................................................215
18. Experimental Section 2 University of Wollongong Ethics Approval 2004 ......216
19. Experimental Section 2 Shoe Fit Assessment ......................................................217
20. Experimental Section 2 Flow Chart of Data Collection ....................................218
21. Experimental Section 2 Fit Scale Information Sheet .........................................219
22. Experimental Section 2 Fit Scale Form ..............................................................220
23. Experimental Section 2 Comfort Scale Information Sheet ..............................221
List of Tables

Table | Page
--- | ---
2.1 The rate in increase per decade between 1899 and 1999 in height and mass for Australian boys and girls aged 7 years and 12 years (Olds & Harten, 2001) | 6
2.2 A summary of foot and lower limb dimensions that have been reported for children (M = males, F = females; means and standard deviations). Only data for children aged 7 to 12 years are presented in this table | 17
2.3 The effect of obesity on the foot shape in children (obese (n = 10) and non-obese (n = 10) children; Dowling & Steele, 2001) | 20
3.1 Means (standard deviations) for the height, mass and body mass index (BMI) values for the 437 children according to age and gender. These data indicated that the children were representative of a wide range of body types | 41
3.2 Means (standard deviations) for the 26 foot structure dimensions (mm) according to age and gender | 42
3.3 The effect of age on the foot dimensions, when the data were pooled across genders, and where the significant differences for each foot structure dimension were located | 43
3.4 Age x gender interactions for ankle height, diagonal ball of foot breadth, ball length, foot length, horizontal ball of foot breadth, and 1st to 3rd toe breadth. Significant between-age group differences were found at $p < 0.0013$ for the boys (M) and for the girls (F). Significant between-gender differences were found at $p < 0.0013$ for certain ages | 46
3.5 Means, (standard deviations) and $p$-values for foot structure dimensions normalised to foot length for the girls (n = 234) and the boys (n = 203). Means for adult foot structure dimensions normalised to foot length data obtained from Wunderlich & Cavanagh (2001) | 49
<table>
<thead>
<tr>
<th>Table</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.6</td>
<td>Foot length and diagonal foot breadth normalised to standing height and estimates of these values for boys and girls with a standing height of 1.4 m (1.4 m represented the mean height of this sample of children; see Table 3.1). Values for men and women were obtained from Wunderlich &amp; Cavanagh (2001) and estimates of these values for men and women with a standing height of 1.4 m</td>
</tr>
<tr>
<td>3.7</td>
<td>Means (standard deviations) for Arch Index values calculated for the girls (n = 234) and the boys (n= 203)</td>
</tr>
<tr>
<td>3.8</td>
<td>F-ratios and $p$-values derived for each source of variance for the Arch Index data obtained for the girls (n = 234) and the boys (n = 203)</td>
</tr>
<tr>
<td>4.1</td>
<td>Means (standard deviations) and statistics comparing the age, height, mass and body mass index (BMI) for the obese children (n = 45) and the non-obese children (n = 45)</td>
</tr>
<tr>
<td>4.2</td>
<td>Means (standard deviations) for the foot dimensions of the obese (n = 45; girls n = 30; boys = 15) and non-obese (n = 45; girls n = 30; boys = 15) children grouped by gender (bof = ball of foot)</td>
</tr>
<tr>
<td>4.3</td>
<td>F-ratios and $p$-values derived for each source of variance for the foot dimensions data obtained for the obese (n = 45) and non-obese (n = 45) children and for the girls (n = 60) and boys (n = 30)</td>
</tr>
<tr>
<td>4.4</td>
<td>Means (standard deviations) for Arch Index values for the obese (n = 45) and the non-obese (n = 45) children</td>
</tr>
<tr>
<td>4.5</td>
<td>F-ratios and $p$-values derived for each source of variance for the Arch Index data obtained for the obese (n = 45) and non-obese (n = 45) children</td>
</tr>
<tr>
<td>4.6A</td>
<td>Means (standard deviations) for the area and force data for the obese (n = 45; girls n = 30; boys = 15) and non-obese (n = 45; girls n = 30; boys = 15) children grouped by gender</td>
</tr>
<tr>
<td>4.6B</td>
<td>Means (standard deviations) for pressure and force-time integrals (FTI) for the obese (n = 45; girls n = 30; boys = 15) and non-obese (n = 45; girls n = 30; boys = 15) children by gender</td>
</tr>
<tr>
<td>4.6C</td>
<td>Means (standard deviations) for the pressure-time integrals (PTI) for the obese (n = 45; girls n = 30; boys = 15) and non-obese (n = 45; girls n = 30; boys = 15) children by gender</td>
</tr>
</tbody>
</table>
Table

4.7A F-ratios and $p$-values derived for each source of variance for the contact area data obtained for the obese (n = 45) and non-obese (n = 45) children .................................................................70

4.7B F-ratios and $p$-values derived for each source of variance for the force and pressure data obtained for the obese (n = 45) and non-obese (n = 45) children .................................................................71

4.7C F-ratios and $p$-values derived for each source of variance for the force-time (FTI) and pressure-time integral (PTI) data obtained for the obese (n = 45) and non-obese (n = 45) children ..............................................72

5.1 The age and sex of the respondent’s child for whom the survey was completed ....................................................................................................................................................90

5.2 The distribution of observed responses according to socio-economic status (SES) index tertile related to when each child was most recently fitted for shoes by a professional .................................................................93

5.3 The responses that parents and children reported to be important factors to incorporate into an ideal athletic shoe ........................................................................................................................................99

6.1 Descriptive information about the fit, midsole density and mass of the experimental shoes .......................................................................................................................109

7.1 The technical specifications of the pedar® insoles (novelgmbh, 2003) ...............120

7.2 Descriptive statistics for the overweight/obese (n = 8) and non-overweight (n = 6) children for the anthropometric variables. .................................................126

7.3A The distribution of observed responses from the overweight/obese (O; n = 8) children and non-overweight (N; n = 6) children in each of the shoe width and midsole hardness footwear combinations for the fit variables ‘length of shoe’ and ‘toe width’ reported by the children (mode is in bold; see Appendix 19 for the ratings) ........................................................................127

7.3B The distribution of observed responses from the overweight/obese (O; n = 8) children and non-overweight (N; n = 6) children in each of the shoe width and midsole hardness footwear combinations for the fit variables ‘forefoot girth’ and ‘midfoot girth’ reported by the children (mode is in bold; see Appendix 19 for the ratings) .................................................................128
7.3C The distribution of observed responses from the overweight/obese (O; n = 8) children and non-overweight (N; n = 6) children in each of the shoe width and midsole hardness footwear combinations for the fit variables ‘heel width’, ‘toe height’ and ‘heel slip’ reported by the children (mode is in bold; see Appendix 19 for the ratings)............................129

7.3D The distribution of observed responses from the overweight/obese (O; n = 8) children and non-overweight (N; n = 6) children in each of the shoe width and midsole hardness combinations for the fit variables ‘length of shoe’, ‘toe width’, ‘forefoot girth’ and ‘midfoot girth’ reported by the chief investigator (mode is in bold; see Appendix 19 for the ratings) ..................................................................................................130

7.3E The distribution of observed responses from the overweight/obese (O; n = 8) children and non-overweight (N; n = 6) children in each of the shoe width and midsole hardness footwear combinations for the fit variables ‘heel width’, ‘toe height’ and ‘heel slip’ reported by the chief investigator (mode is in bold; see Appendix 19 for the ratings)......................131

7.4 Means and standard deviations (SD) pertaining to the fit values reported by the overweight/obese (n = 8) and non-overweight (n = 6) children, for each of the shoe width and midsole hardness footwear combinations.....................................................................................................133

7.5 Means and standard deviations (SD) pertaining to the comfort values reported by the overweight/obese (n = 8) and non-overweight (n = 6) children, for each of the shoe width and midsole hardness footwear combinations.....................................................................................................134

7.6 F-ratios and p-values derived for each source of variance for the subjective parameter data obtained for the overweight/obese (n = 8) and the non-overweight (n= 6) children .................................................................................................................135

7.7A Means and standard deviations (SD) for the contact areas (cm²) displayed by the overweight/obese (n = 8) and non-overweight (n = 6) children for the masked regions of the foot, in each of the shoe width and midsole hardness footwear combinations ..................................................................................137
<table>
<thead>
<tr>
<th>Table</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.7B</td>
<td>Means and standard deviations (SD) for the maximum forces (N) generated by the overweight/obese (n = 8) and non-overweight (n = 6) children for the masked regions of the foot, in each of the shoe width and midsole hardness footwear combinations ..................................................138</td>
</tr>
<tr>
<td>7.7C</td>
<td>Means and standard deviations (SD) for the peak pressures (N/cm²) generated by the overweight/obese (n = 8) and non-overweight (n = 6) children for the masked regions of the foot, in each of the shoe width and midsole hardness footwear combinations ..................................................139</td>
</tr>
<tr>
<td>7.7D</td>
<td>Means and standard deviations (SD) for the force-time integrals (N/s) generated by the overweight/obese (n = 8) and non-overweight (n = 6) children for the masked regions of the foot, in each of the shoe width and midsole hardness footwear combinations.........................................................140</td>
</tr>
<tr>
<td>7.7E</td>
<td>Means and standard deviations (SD) for the pressure-time integrals (Ns/cm²) generated by the overweight/obese (n = 8) and non-overweight (n = 6) children for the masked regions of the foot, in each of the shoe width and midsole hardness footwear combinations........................................141</td>
</tr>
<tr>
<td>7.8A</td>
<td>F-ratios and p-values derived for each source of variance for the in-shoe plantar pressure distribution data obtained for the overweight/obese (n = 8) and the non-overweight (n= 6) children ....................142</td>
</tr>
<tr>
<td>7.8B</td>
<td>F-ratios and p-values derived for each source of variance for the in-shoe plantar pressure distribution data obtained for the overweight/obese (n = 8) and the non-overweight (n= 6) children ....................143</td>
</tr>
<tr>
<td>7.9A</td>
<td>Means and standard deviations (SD) pertaining to the left step length, stride length, stride time and steps values for the overweight/obese (n =8) and non-overweight (n = 6) children, in each of the shoe width and midsole hardness footwear combinations ........................................150</td>
</tr>
<tr>
<td>7.9B</td>
<td>Means and standard deviations (SD) pertaining to the time spent in and percentage of stride for initial double support, left single support and terminal double support phases of the gait cycle values for the overweight/obese (n =8) and non-overweight (n = 6) children, in each of the shoe width and midsole hardness footwear combinations .......................151</td>
</tr>
</tbody>
</table>
7.10 F-ratios and $p$-values derived for each source of variance for the gait parameter data obtained for the overweight/obese ($n = 8$) and non-overweight ($n = 6$) children.
# List of Figures

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>The bones incorporated in the foot complex (Primal Pictures©, 2000)</td>
<td>11</td>
</tr>
<tr>
<td>2.2</td>
<td>The main ligaments of the foot, excluding the plantar aponeurosis (Primal Pictures©, 2000)</td>
<td>12</td>
</tr>
<tr>
<td>2.3</td>
<td>The truss and tie-bar mechanism as described by Hicks (adapted from Stainsby, 1997, p 60)</td>
<td>13</td>
</tr>
<tr>
<td>2.4</td>
<td>Design of a capacitive sensor (adapted from Kalpen, 1998)</td>
<td>22</td>
</tr>
<tr>
<td>3.1</td>
<td>Map of Australia with enlarged map of New South Wales, divided into the Census regions showing the number of children sampled in each region (Discover Australia, 2006; The area of New South Wales is approximately 800,000 km². Driving distance from the north to the south of the state is about 1,800 km or 19 hours driving time)</td>
<td>35</td>
</tr>
<tr>
<td>3.2</td>
<td>The foot anthropometric variables (adapted from Parham et al., 1992, p 32-3 and Wunderlich &amp; Cavanagh, 2001)</td>
<td>37</td>
</tr>
<tr>
<td>3.3</td>
<td>The procedure for calculating Arch Index (adapted from Cavanagh &amp; Rodgers, 1987, p 548)</td>
<td>39</td>
</tr>
<tr>
<td>3.4</td>
<td>Effect of gender when the foot dimension data were pooled for age (means and standard error bars; * denotes a significant between-gender difference at $p \leq 0.05$; see Figure 3.2 for corresponding definitions of the numbered variables)</td>
<td>44</td>
</tr>
<tr>
<td>3.5</td>
<td>Age x gender interactions for the (A) ankle height; (B) diagonal ball of foot breadth; (C) ball of foot length; (D) foot length; (E) horizontal ball of foot breadth; (F) 1st to 3rd toe breadth data (* denotes significant between-age differences for the girls $p &lt; 0.0013$; * denotes significant between-age difference for the boys $p &lt; 0.0013$; * denotes significant between-gender differences $p &lt; 0.0013$)</td>
<td>45</td>
</tr>
<tr>
<td>4.1</td>
<td>The masked regions of the foot. M01-medial heel, M02-lateral heel, M03-medial midfoot, M04-lateral midfoot, M05-metatarsal head 1, M06-metatarsal head 2, M07-metatarsal heads 3-5, M08-hallux, M09-2nd toe and M10-toes 3-5</td>
<td>60</td>
</tr>
<tr>
<td>Figure</td>
<td>Page</td>
<td></td>
</tr>
<tr>
<td>-------</td>
<td>------</td>
<td></td>
</tr>
<tr>
<td>4.2</td>
<td>Effect of obesity on the foot structure data (means and standard error bars; * indicates a significant between-subject group difference $p \leq 0.05$; see Table 4.3 for definitions of the numbered variables)</td>
<td>64</td>
</tr>
<tr>
<td>4.3</td>
<td>Effect of gender on the foot structure data (means and standard error bars; * indicates a significant between-gender difference $p \leq 0.05$; see Table 4.3 for definitions of the numbered variables)</td>
<td>65</td>
</tr>
<tr>
<td>4.4</td>
<td>The number of obese and non-obese subjects whose Arch Index value placed them in the following categories: flat, normal and high arch (see Section 3.2.3 for a definition of these categories)</td>
<td>66</td>
</tr>
<tr>
<td>4.5</td>
<td>Effect of obesity on contact area and force data (means and standard error bars; * indicates a significant between-subject group difference $p \leq 0.05$; see Figure 4.1 for locations of masked regions)</td>
<td>73</td>
</tr>
<tr>
<td>4.6</td>
<td>Effect of obesity on the pressure and force-time integral (means and standard error bars; * indicates a significant between-subject group difference $p \leq 0.05$; see Figure 4.1 for locations of masked regions)</td>
<td>74</td>
</tr>
<tr>
<td>4.7</td>
<td>Effect of obesity on the pressure-time integrals (means and standard error bars; * indicates a significant between-subject group difference $p \leq 0.05$; see Figure 4.1 for locations of masked regions)</td>
<td>75</td>
</tr>
<tr>
<td>4.8</td>
<td>Effect of gender on the contact area and force data (means and standard error bars; * indicates a significant main effect of gender $p \leq 0.05$; see Figure 4.1 for locations of masked regions)</td>
<td>76</td>
</tr>
<tr>
<td>5.1</td>
<td>The map of New South Wales containing the number of parents who completed the survey in each region (n = 474)</td>
<td>89</td>
</tr>
<tr>
<td>5.2</td>
<td>The time since each child had been professionally fitted for shoes (n = 474)</td>
<td>92</td>
</tr>
<tr>
<td>5.3</td>
<td>The main types of footwear (including ‘barefoot’) worn at school or at home during both summer and winter (multiple responses recorded; n = 562)</td>
<td>94</td>
</tr>
<tr>
<td>5.4</td>
<td>The main material components comprising the upper of athletic shoes (multiple responses recorded; n = 543)</td>
<td>95</td>
</tr>
</tbody>
</table>
5.5 How often worn out footwear was replaced by parents (multiple responses recorded; n = 532) ............................................................................96
5.6 The components of the child’s shoe that wore out (multiple responses recorded; n = 943).............................................................................................96
5.7 The most and least important factors considered by parents when purchasing children’s shoes (n = 474)..............................................................97
5.8 The distribution of prices parents would be willing to pay for the ideal athletic shoe (multiple responses recorded; n = 682) .........................98
6.1 The regions in the shoe where the upper was expanded in the wide shoe.
A: Ball of foot and B: Posterior to the ball of the foot across the laces ..........107
6.2 The experimental shoe displaying some of the design features of the shoe...................................................................................................................111
7.1 Schematic diagram of the setup used to collect the spatio-temporal kinematic data during each walking trial..........................................................118
7.2 The masked regions of the insoles (heel, midfoot and forefoot).......................121
7.3 The walking gait cycle (adapted from Norkin & Levangie, 1992).................123
7.4 Effect of shoe width for peak pressure generated in the masked regions of the foot during walking (means and standard error bars; * denotes a significant between-shoe width difference at $p \leq 0.05$)................136
7.5 Effect of shoe width for force-time integrals generated in the masked regions during walking (means and standard error bars; * denotes a significant between-shoe width difference at $p \leq 0.05$).............144
7.6 Effect of midsole hardness for contact area in the masked regions during walking (means and standard error bars; * denotes a significant between-midsole hardness difference at $p \leq 0.05$) ..................145
7.7 Effect of body type generated for maximum force in the masked regions during walking (means and standard error bars; * denotes a significant between-subject group difference at $p \leq 0.05$) .......................146
7.8 Effect of body type for force-time integrals in the masked regions during walking (means and standard error bars; * denotes a significant between-subject group difference at $p \leq 0.05$) ..................147
Figure

7.9 Effect of body type for pressure-time integrals generated in the masked regions during walking (means and standard error bars; * denotes a significant between-subject group difference at $p \leq 0.05$)...........................................................................................................148

7.10 Effect of midsole hardness on the left step length data (means and standard error bars; * denotes a significant between-midsole hardness difference at $p \leq 0.05$). .........................................153

7.11 Effect of midsole hardness on the velocity data (means and standard error bars; * denotes a significant between-midsole hardness difference at $p \leq 0.05$).......................................................................153

7.12 Effect of body type on the percentage of the stride in initial double support data (means and standard error bars; * denotes a significant between-subject group difference at $p \leq 0.05$).............................154

7.13 Effect of body type on the percentage of the stride in terminal double support data (means and standard error bars; * denotes a significant between-subject group difference at $p \leq 0.05$) ........................................155

7.14 The significant interaction between body type and shoe width (* denotes a significant between-subject group difference at $p \leq 0.008$)........................................................................................................156