



# Strength Data

for design safety - Phase I

GOVERNMENT CONSUMER SAFETY RESEARCH

**dti**

Department of Trade and Industry

**SECTION 1**

Introduction and background	1
-----------------------------	---

**SECTION 2****DATASHEETS****5**

1. Finger push strength	5
2. Pinch-pull strength	9
3. Hand grip strength	13
4. Wrist-twisting strength	18
5. Opening strength	26
6. Push and pull strength	30

**APPENDIX 1 - Finger push strength****37****APPENDIX 2 - Pinch-pull strength****40****APPENDIX 3 - Handgrip strength****43****APPENDIX 4 - Wrist twisting strength****46****APPENDIX 5 - Opening strength****51****APPENDIX 6 - Push and pull strength****54****APPENDIX 7 - Correlation between measurements****61****REFERENCES****69**

## SECTION 1. INTRODUCTION AND BACKGROUND

This report summarises the results of research conducted by Nottingham University on behalf of the Consumer Affairs Directorate of the Department of Trade and Industry (DTI) to provide designers with ergonomics data for use in the design of safer products.

The University of Nottingham has recently worked with DTI to produce a series of publications containing ergonomics data. The three publications on children, adults and older adults ('Childata', 'Adultata' and 'Older Adultata') contain the most up-to-date anthropometric and physical strength data for countries around the world. However, their production has highlighted important 'gaps' in the data available for direct use in product design.

This report describes a two stage research programme which was undertaken to try to address some of these data 'gaps'. Potential needs for design-applicable data were identified and prioritised in Stage 1 of the project, and in Stage 2 new data were collected to meet some of those needs.

The report consists of three main sections:

1. Introduction and background
2. Data sheets
3. Appendices

In Section 1 of the report, the two stages of the research are introduced and the methodologies described. In Section 2, detailed descriptions and results of the data collected as part of Stage 2 of the study are presented in the form of 'data sheets', and in Section 3, the statistical analyses performed are presented as appendices.

The data sheets, detailed in section 2, show the new data for all age groups. For easier reference these data have been colour coded by age to fit in with the age ranges in CHILDATA, ADULTDATA and OLDER ADULTDATA. The colours used to highlight each age range is that used for the background colour on the cover of each publication. For example CHILDATA is white (□), ADULTDATA is grey (■) and OLDER ADULTDATA is pink (■).

### **Stage 1 – Identification and prioritisation of data 'gaps'**

To identify and prioritise the types of data most needed for design purposes, a survey of users of ergonomics data was carried out. Around eight hundred and fifty designers, manufacturers, ergonomists, consumer safety groups and product testing laboratories were contacted by postal questionnaire. Respondents were asked to detail the sort of data or information which they have needed for their own design purposes but have found difficult to source. In total, eighty responses were received. Most responses requested a need for physical strength data for all age groups: data which could be directly applied in the design

process. In addition, it was felt that data should describe generic functions, rather than be product-specific, so that it can be used in as many design applications as possible. Based on these findings, a series of six realistic but generalisable strength measurements were identified as summarising the most important data needs:

1. finger push strength
2. pinch-pull strength
3. hand grip strength
4. wrist-twisting strength
5. opening strength
6. push and pull strength

A programme of research was instigated and new data were collected in Stage 2 for all six ‘gaps’.

## **Stage 2 – Data collection methodology**

### **Subjects**

To provide designers with a comparable set of design-applicable data for all age groups, children through to older adults were measured in the study. Around 150 British subjects aged between 2 and 86 years were measured for each of the six strength exertions. Subjects were grouped into 5 or 10 year age bands, with around 15 individuals in each band, although this varied slightly between each measurement. Subject numbers are described separately for each force measurement in the data sheets (Section 2). The anthropometric details of the subjects are described in the corresponding appendices. Subjects were not selected to be representative of socio-economic criteria.

### **Measurements**

Measurements were taken for a total of six different force exertions, and are summarised below. Detailed descriptions of each measurement can be found in Section 2.

- *finger push strength* – pushing with the pad of the thumb and index finger in a forwards and downwards direction.
- *pinch-pull strength* – pinching and pulling with 1 hand at three pinch distances. Two pinch types were tested: pulp pinch (pad of the thumb in opposition to pad of the index finger) and chuck pinch (pad of the thumb in opposition to the pads of both the index and middle fingers).
- *hand grip strength* – 1 and 2 handed strength when gripping a series of three rectangular handles of varying size.

- *wrist-twisting strength* – torque (clockwise) using 1 hand on a series of six handles and controls
- *opening strength* – torque (anti-clockwise) on a series of replica jars with smooth and knurled textured lids of various diameters.
- *push and pull strength* – pushing and pulling with 1 and 2 hands on a cylindrical bar, and pulling with 1 hand only on a convex knob.

### **Procedure**

Subjects were asked to exert their maximum strength at all times, described as the highest force he or she could exert without causing injury. Subjects were instructed to build up to their maximum strength in the first few seconds, and to maintain maximum strength for a further few seconds. Where only one-handed strength was measured, subjects were instructed to use their dominant hand. Subjects performed two strength exertions (lasting five seconds) for each experimental condition, and were given a two minute rest interval between each exertion. Subjects stood during testing and were free to adopt their own posture. The testing device was adjusted and positioned at each subject's elbow height (with the exception of opening strength and hand grip strength where the equipment was freely moveable). Subjects were encouraged to exert maximal effort during testing and were able to obtain visual feedback from the testing device.

### **Equipment**

Finger push strength, pinch-pull strength and wrist-twisting strength were measured on a series of specially made handles which were attached to a Mecmesin™ Advanced Force Gauge (AFG 500N). Hand grip strength was measured using a Handgrip Dynamometer (MKIIIa) made by the Medical Physics Department, Queens Medical Centre, Nottingham, UK. Opening strength and push and pull strength were measured with the aid of strain gauges which were attached to custom-made equipment.

### **Results**

The results for each of the six measurements are presented in turn as separate ‘data sheets’. Each measurement is defined, and the method of measurement, number of subjects measured, and the data collected are detailed. Data are presented separately for males and females and are also shown graphically. Differences in strength due to age and sex, as well as differences between experimental conditions, were analysed by means of a t-test, and these findings are presented in Appendices 1 to 6. A correlation coefficient matrix detailing the relationship between all measurements can be found in Appendix 7.

## SECTION 2. DATA SHEETS

### 1. Finger push strength

#### Description

Maximum static forwards and downwards pushing force of the index finger and thumb, exerted for five seconds, in Newtons (N).

#### Method

The subject stands in front of the measuring device and adopts a free posture. A static pushing force is exerted with the pad of the index finger or thumb of the dominant hand on a circular force plate (i.e. the force plate doesn't move). Subjects push in a forwards or downwards direction. Subjects are instructed to build up to their maximum strength in the first few seconds and to maintain maximum strength for a further few seconds.

#### Handle type and size

Circular force plate (diameter 20mm, depth 2mm), positioned at subjects elbow height.



Circular force plate



Experimental trial: Pushing downwards with the index finger

#### Subject numbers

148 subjects were measured:

Age (years)	Male	Female	Total
2-5	9	8	17
6-10	5	10	15
11-15	12	5	17
16-20	6	8	14
21-30	10	7	17
31-50	7	16	23
51-60	5	6	11
61-70	3	8	11
71-80	8	11	19
81-90	0	4	4
<b>Total</b>	<b>65</b>	<b>83</b>	<b>148</b>

#### Effect of sex

For most measurements, no significant differences in maximum strength were found between male and female children (2-15 years). However, in adults aged 16 years and over, males were generally found to be significantly stronger than females.

#### Effect of age

Strength was found to increase with age throughout childhood, to peak in adulthood, and then to decrease with age from around 50 years. Throughout childhood, each successive age group (2-5, 6-10, 11-15 years) was found to be significantly stronger than the previous group for all six measurements. Generally, however, no significant differences in maximum strength were found within the adult (16-20, 21-30, 31-50 years) or older adult (51-60, 61-70, 71-80, 81-90 years) age groups. For most strength exertions, adults (16-50 years) were found to be significantly stronger than older adults (51-90 years), who in turn were significantly stronger than children (2-10 years). No significant differences in maximum strength were generally found between 11-15 year olds and 60-80 year olds, or 6-10 year olds and 80-90 year olds.

#### Using the data

When using the data in this study, there are several factors which must be considered:

- Little or no correlation was found between the six measurements, suggesting that the forces exerted were action-specific. That is, the size, shape and orientation of the handle or control, the direction of force and the number of hands used all affected the amount of force that could be exerted.
- Within each measurement, significant differences were found between the experimental conditions. For example, opening strength was significantly affected by the size and texture of the jar lid, as was hand grip strength by the size of the handle and number of hands used. Exceptions to this finding were finger push strength and push and pull strength, where no significant differences due to the direction of force were found. That is, no differences in strength were found between pushing forwards and downwards with either the thumb or index finger, and similarly when pushing and pulling with both 1 and 2 hands on a vertical bar, or 2 hands on a horizontal bar.
- No restrictions were placed on posture and subjects were able to grip and manipulate the various handles and knobs as they chose (with the exception of pinch-pull strength). The amount of force that can be exerted in such a free posture is known to be greater than that generated in a standardised posture (where subjects are often instructed to stand upright with their elbows flexed to 90 degrees).
- Subjects were instructed to exert their maximum strength (the highest force he or she could exert without causing injury).

Care should therefore be taken when using the data, particularly when applying it to other design scenarios, where, for example, individuals may be restricted in the posture that they can adopt, where comfortable rather than maximal force is required, or where data are needed for handles and controls of a different size, shape or position.

Anthropometric variables (stature, weight, elbow height, hand length and hand breadth) for all subjects can be found in Appendix 1a.

## Analysis

### Effect of sex

For all four measurements (pushing forwards and downwards with the index finger and thumb), no significant differences were found between male and female children (2-15 years). However, in all adult and older adult age groups (16-80 years), males were found to be significantly stronger than females (Appendix 1b).

### Effect of age

Finger push force increases with age throughout childhood, it peaks in adulthood, and then decreases with age from around 50 years. Throughout childhood, each successive age group (2-5, 6-10, 11-15 years) was found to be significantly stronger than the previous for all four measurements. No significant differences were found within the adult (16-20, 21-30, 31-50 years) or older adult (51-60, 61-70, 71-80, 81-90 years) age groups, however, differences were found between the groups, in that adults (16-50 years) were found to be significantly stronger than older adults (51-90), who in turn were stronger than children (Appendix 1c).

### Effect of finger type used and direction of force

The direction of force appears to have little or no effect on maximum finger push strength, as no significant differences were found between forwards and downwards push (with either the index finger or thumb). The finger used, however, did; pushing with the thumb generated significantly higher forces than pushing with the index finger (Appendix 1d). Of the four measurements, children (2-15 years) exerted the greatest force when pushing forwards with the thumb, whilst adults (16-50 years) and older adults (51-90 years) generally exerted the greatest force whilst pushing downwards with the thumb. Correlation coefficients for all 4 measurements can be found in Appendix 1e.

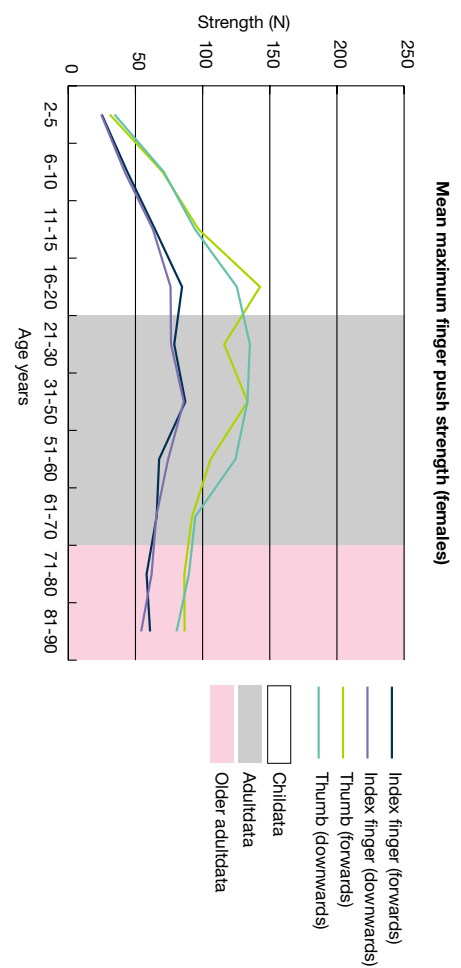
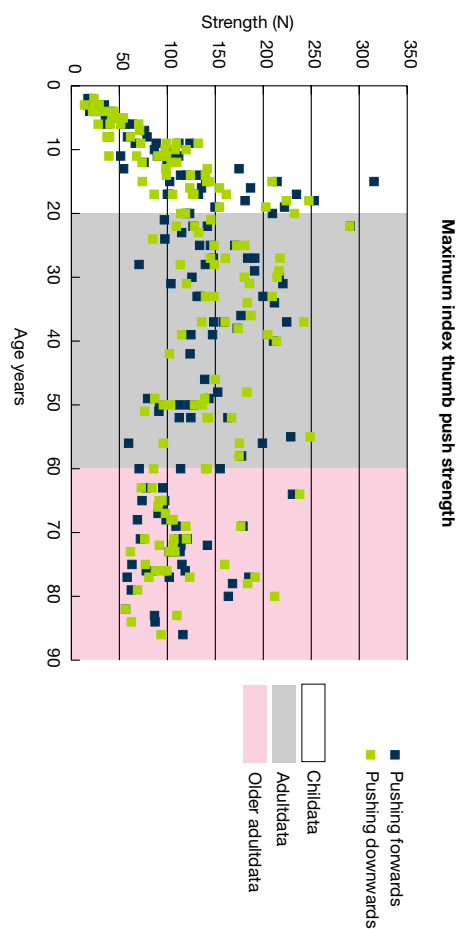
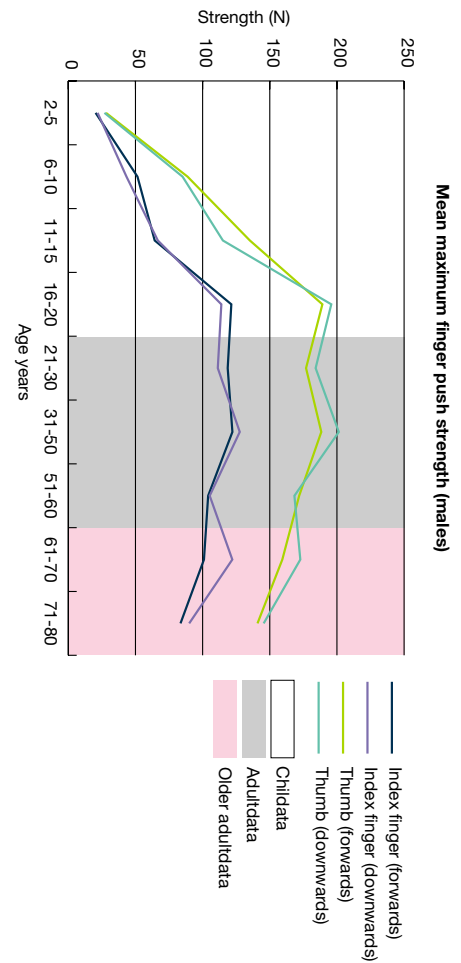
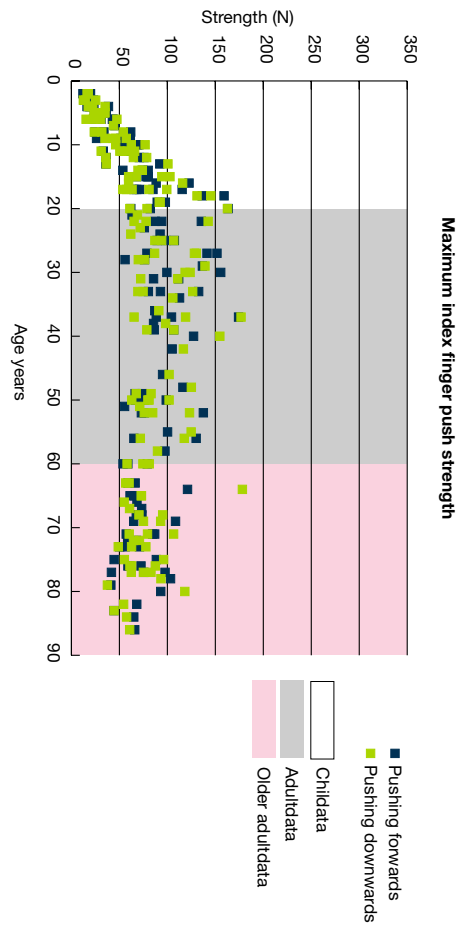
## Results

### Index finger

Age (years)	Sex	No.	Pushing forwards (N)			Pushing downwards (N)		
			Mean	SD	Range	Mean	SD	Range
2-5	m	9	20.32	5.22	16.00 – 35.00	21.82	7.01	14.70 – 35.00
	f	8	24.92	9.56	15.90 – 38.60	24.49	8.07	12.40 – 35.10
6-10	m	5	51.50	13.38	30.80 – 61.80	43.32	16.58	15.30 – 57.10
	f	10	43.99	17.32	23.40 – 70.30	42.00	17.20	22.80 – 76.80
11-15	m	12	64.32	17.75	35.90 – 92.10	66.65	22.56	35.90 – 102.70
	f	5	64.60	18.42	33.20 – 80.00	63.02	19.44	31.00 – 78.40
16-20	m	6	121.37	36.80	82.20 – 163.30	113.93	38.49	60.90 – 162.60
	f	8	84.69	23.17	61.90 – 122.60	76.12	22.18	53.60 – 115.90
21-30	m	10	118.67	28.57	76.00 – 155.60	111.29	26.19	71.70 – 142.50
	f	7	78.87	15.36	55.90 – 98.40	76.47	15.57	61.90 – 106.60
31-50	m	7	122.17	27.53	85.60 – 174.20	127.64	28.70	98.20 – 176.80
	f	16	87.12	13.61	66.40 – 111.80	85.95	18.62	62.90 – 119.00
51-60	m	5	104.12	32.47	55.40 – 137.50	105.28	23.74	71.20 – 124.80
	f	6	67.62	10.04	53.80 – 79.00	74.33	9.26	58.00 – 84.70
61-70	m	3	101.00	24.62	73.50 – 121.00	122.10	48.59	93.00 – 178.20
	f	8	65.78	4.37	59.00 – 73.20	65.45	8.17	55.00 – 75.10
71-80	m	8	83.52	15.61	58.60 – 103.30	90.00	17.64	64.70 – 118.20
	f	11	58.29	14.09	41.10 – 84.60	62.03	12.40	37.50 – 79.20
81-90	f	4	60.87	11.06	44.40 – 68.10	54.25	7.05	44.40 – 60.70

### Thumb

Age (years)	Sex	No.	Pushing forwards (N)			Pushing downwards (N)		
			Mean	SD	Range	Mean	SD	Range
2-5	m	9	28.07	9.99	17.30 – 41.60	26.920	18.85	23.50 – 53.80
	f	8	30.92	8.66	16.80 – 42.80	34.40	14.59	13.60 – 53.90
6-10	m	5	88.80	28.55	53.40 – 126.60	85.08	34.18	51.40 – 132.10
	f	10	70.22	24.61	36.70 – 107.70	71.14	33.56	27.80 – 119.50
11-15	m	12	135.18	71.26	54.40 – 315.40	115.09	40.01	67.90 – 209.10
	f	5	97.02	26.94	51.30 – 119.70	94.34	36.16	39.10 – 139.60
16-20	m	6	189.17	49.04	119.70 – 253.00	195.78	51.50	113.90 – 247.50
	f	8	142.75	45.71	100.00 – 234.60	125.46	24.26	86.20 – 161.40
21-30	m	10	177.00	51.35	114.90 – 290.60	184.14	52.19	109.30 – 290.10
	f	7	116.08	28.22	70.50 – 147.90	135.17	30.35	84.70 – 180.70
31-50	m	7	188.38	30.80	147.10 – 224.40	201.40	23.54	173.70 – 242.20
	f	16	133.51	33.39	79.40 – 220.40	133.36	29.36	86.90 – 187.20
51-60	m	5	171.88	51.42	91.20 – 228.60	168.34	61.27	76.30 – 248.70
	f	6	105.98	35.36	59.60 – 155.00	124.48	26.38	85.60 – 142.80
61-70	m	3	159.33	82.54	68.80 – 230.40	172.73	67.13	103.80 – 237.90
	f	8	92.16	11.41	73.60 – 109.00	94.53	13.97	72.80 – 119.30
71-80	m	8	140.85	27.93	114.40 – 184.90	145.45	46.89	91.60 – 211.80
	f	11	86.39	20.84	58.10 – 113.20	89.83	18.94	61.50 – 123.30
81-90	f	4	86.6	24.41	56.40 – 116.20	80.57	25.37	56.50 – 109.90



## 2. Pinch-pull strength

### Description

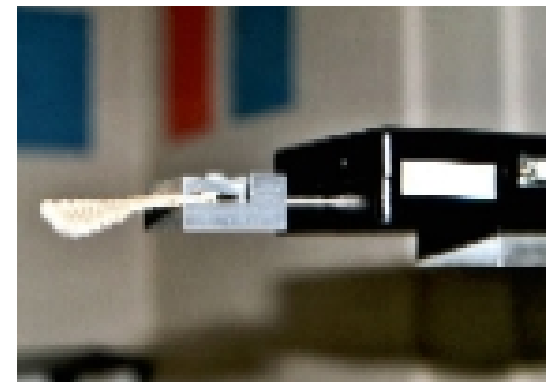
Maximum static pulling strength when pinching and pulling with the thumb, index and middle fingers, exerted for five seconds, in Newtons (N).

### Method

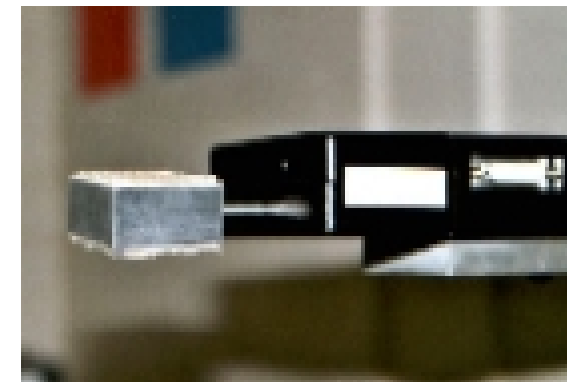
The subject stands in front of the measuring device and adopts a free posture. A static pulling force is exerted whilst pinching on a series of handles with the pad of the thumb in opposition to i) the pad of the index finger (*pulp*-pinch) and ii) the pads of both the index and middle fingers (*chuck*-pinch). Subjects are instructed to build up to their maximum strength in the first few seconds and to maintain maximum strength for a further few seconds.

### Handle type and size

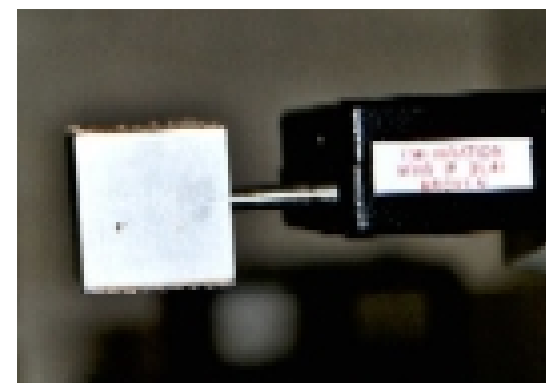
A series of three custom-made handles: a textured fabric strip (40 mm x 40 mm x 2 mm) and two fabric-covered blocks (40 mm x 40 mm x 20 mm and 40 mm x 40 mm x 40 mm), positioned at elbow height.



2mm fabric strip



20mm block



40mm block



Experimental trial: Chuck pinch-pull (20mm block)

## Subject numbers

146 subjects were measured:

Age (years)	Male	Female	Total
2-5	8	5	13
6-10	7	9	16
11-15	10	7	17
16-20	11	7	18
21-30	8	9	17
31-50	5	13	18
51-60	5	6	11
61-70	4	9	13
71-80	8	11	19
81-90	0	4	4
Total	66	80	146

Anthropometric variables (stature, weight, elbow height, hand length and hand breadth) for all subjects can be found in Appendix 2a.

## Analysis

### Effect of sex

No significant differences in maximum pinch-pull strength were found between males and females aged up to 20 years. However, males aged 21 to 80 years were significantly stronger than females for most pinch-pull exertions (Appendix 2b).

### Effect of age

For all six pinch-pull exertions (2 pinch types and 3 pinch distances), maximum strength increases throughout childhood (2-15 years), it peaks in adulthood, and then decreases with age from around 50 years. No significant differences in strength were found within the adult (16-20, 21-30, 31-50 years) or older adult (51-60, 61-70, 71-80, 81-90 years) age groups. However, significant differences were found within the child age groups (2-5, 6-10, 11-15), with each successive group being significantly stronger than the previous for all six measurements (Appendix 2c).

### Effect of pinch type and distance

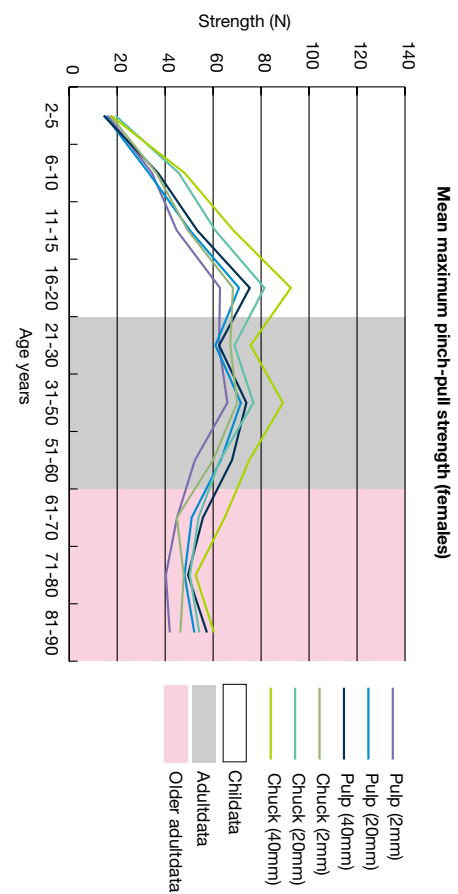
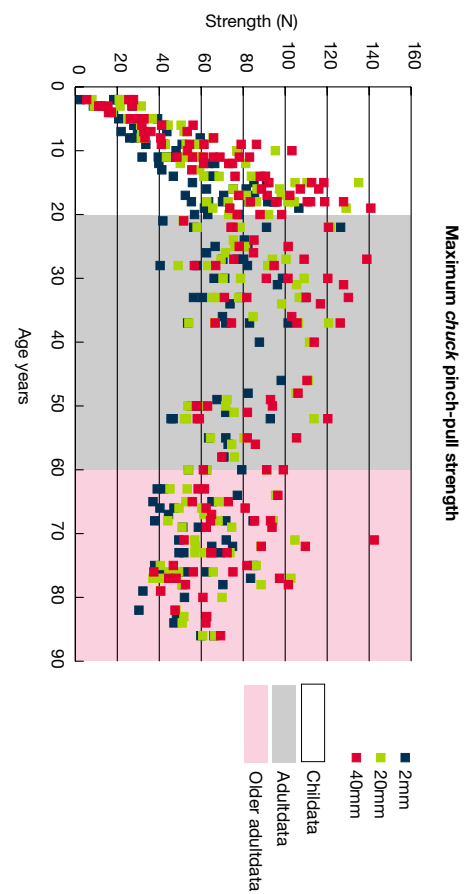
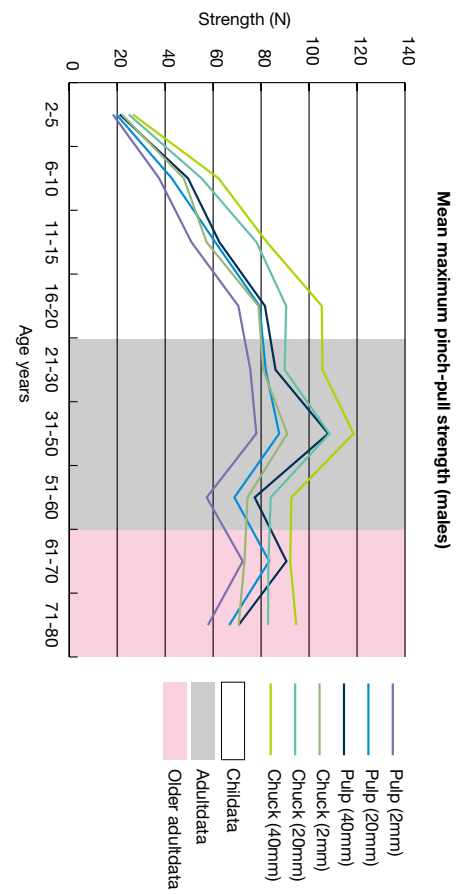
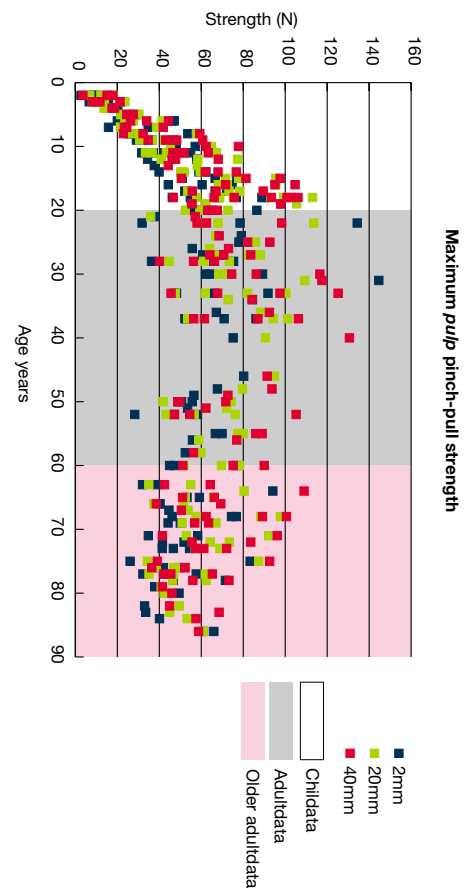
Both the type of pinch and the pinch distance appear to have an effect on maximum strength. For both males and females, pinching and pulling with the pad of the thumb in opposition to the pads of both the index and middle fingers (chuck-pinch) generated

significantly higher forces than pinching with the pad of the thumb in opposition to the pad of the index finger only (pulp-pinch). For both pinch types (pulp and chuck), pulling strength was greatly effected by the pinch distance. That is, as the size of the pinch distance increased from 2 mm to 20 mm and to 40 mm, so did maximum strength (Appendix 2d). Correlation coefficients for all 6 measurements can be found in Appendix 2e.

## Results

Age years	Sex	No.	Pinch	2mm strip (N)			20mm block (N)			40mm block (N)		
				Mean	SD	Range	Mean	SD	Range	Mean	SD	Range
2-5	m	8	pulp	18.22	8.09	10.30 – 29.70	19.69	4.96	12.20 – 27.70	21.10	5.14	15.10 – 27.60
			chuck	21.97	3.73	7.60 – 27.00	24.83	5.62	16.00 – 31.40	26.56	4.44	17.10 – 32.70
			chuck	16.06	8.38	2.70 – 24.50	15.00	8.94	6.90 – 30.30	14.36	6.67	3.60 – 28.30
6-10	f	5	chuck	17.18	12.64	2.50 – 39.20	19.32	10.81	9.00 – 36.70	17.38	8.53	11.10 – 32.20
			pulp	37.50	13.31	20.00 – 57.10	42.78	14.68	23.60 – 64.80	49.54	17.79	26.30 – 60.70
			chuck	47.77	16.65	27.90 – 59.50	55.18	21.05	31.10 – 95.30	62.26	25.15	31.70 – 98.80
11-15	m	10	pulp	34.53	12.42	15.80 – 55.80	33.18	9.80	21.50 – 62.30	37.05	13.21	22.90 – 46.60
			chuck	36.34	12.72	21.80 – 60.70	45.69	15.73	31.60 – 77.00	48.14	15.55	32.60 – 79.00
			chuck	50.95	15.54	33.10 – 76.80	60.89	17.77	36.60 – 92.90	62.61	17.99	44.30 – 97.60
16-20	f	7	chuck	57.27	18.94	39.50 – 91.10	78.08	29.22	50.00 – 135.00	82.41	21.21	55.50 – 118.40
			pulp	44.84	10.08	31.60 – 57.90	50.36	14.06	33.40 – 80.30	53.38	8.40	46.50 – 68.10
			chuck	49.50	11.99	31.80 – 66.40	60.91	12.90	43.40 – 81.20	68.48	13.90	48.40 – 88.10
21-30	m	11	pulp	70.51	18.83	46.20 – 112.50	79.34	20.14	53.60 – 105.70	81.60	21.93	46.70 – 106.10
			chuck	78.90	16.45	55.30 – 106.70	90.44	18.75	62.60 – 129.20	105.30	20.03	73.60 – 141.00
			chuck	62.87	8.58	52.10 – 74.70	70.81	13.88	52.40 – 115.50	75.27	15.76	63.00 – 121.40
31-50	f	7	pulp	68.27	12.57	52.40 – 90.70	81.40	11.25	72.80 – 109.20	92.40	12.92	77.10 – 116.30
			chuck	75.52	29.27	31.80 – 134.30	81.92	16.06	59.00 – 113.60	86.01	17.59	53.20 – 116.50
			chuck	80.86	22.44	56.40 – 126.40	89.82	20.33	58.00 – 121.40	105.50	21.66	75.10 – 138.90
51-60	m	9	pulp	62.48	16.13	36.30 – 79.10	60.95	12.36	35.90 – 73.50	62.49	10.47	40.10 – 74.50
			chuck	67.15	17.88	40.40 – 91.30	68.91	13.22	49.00 – 91.70	75.62	14.95	51.60 – 94.70
			chuck	78.00	9.95	70.90 – 100.90	87.54	11.18	72.80 – 100.30	108.00	19.88	62.20 – 130.60
61-70	f	13	pulp	90.90	14.43	73.60 – 109.40	108.50	8.31	98.30 – 120.70	118.6	9.65	106.10 – 130.10
			chuck	65.94	26.66	47.00 – 144.80	71.55	22.26	41.90 – 109.50	73.86	21.98	44.30 – 117.70
			chuck	70.04	15.04	50.30 – 98.10	76.79	19.51	53.60 – 111.10	89.09	21.73	57.70 – 128.00
71-80	m	5	pulp	57.32	5.69	52.40 – 58.20	68.86	8.95	58.80 – 77.40	77.32	19.51	56.30 – 105.20
			chuck	74.34	10.99	63.50 – 92.90	84.00	16.75	74.50 – 113.70	92.60	20.06	69.80 – 120.30
			chuck	52.40	17.84	24.50 – 77.00	63.22	14.94	43.30 – 79.90	67.85	19.36	51.20 – 90.20
81-90	f	6	pulp	59.93	13.71	45.60 – 79.50	62.82	14.80	52.00 – 91.30	75.07	18.03	58.10 – 99.30
			chuck	72.35	20.72	44.20 – 94.10	83.87	13.00	67.00 – 97.70	90.57	19.79	63.50 – 109.00
			chuck	73.05	11.01	51.00 – 84.70	83.05	13.89	68.00 – 95.40	92.15	4.74	85.40 – 96.50
61-70	f	9	pulp	44.93	8.24	32.00 – 59.10	51.05	9.59	35.00 – 68.90	55.74	10.78	38.60 – 69.30
			chuck	44.88	8.87	37.00 – 65.10	53.91	7.95	44.10 – 71.90	64.83	7.67	55.70 – 80.90
			chuck	57.85	13.53	41.40 – 83.30	66.72	17.11	42.30 – 92.20	70.59	18.94	46.00 – 96.20
71-80	m	8	pulp	70.64	10.90	52.00 – 84.90	82.90	17.18	57.10 – 104.60	94.64	24.75	60.80 – 109.60
			chuck	40.28	7.70	26.10 – 54.40	48.07	10.68	34.40 – 57.90	49.53	11.12	36.40 – 72.10
			chuck	47.74	9.55	32.20 – 69.10	50.30	11.17	37.00 – 73.70	52.70	7.67	37.40 – 72.30
81-90	f	4	pulp	41.92	13.19	33.00 – 61.10	52.17	6.73	45.00 – 60.90	57.40	9.68	44.90 – 68.50
			chuck	46.32	12.14	30.30 – 59.80	54.22	8.21	48.00 – 66.30	60.38	9.16	47.50 – 69.20





### 3. Hand grip strength

#### Description

Maximum static gripping force of 1 and 2 hands, exerted for five seconds, in Newtons (N).

#### Method

The subject stands and adopts a free posture. A static gripping force is exerted with 1 (dominant) or 2 hands on a series of handles (i.e. the handle doesn't move). The handle is held between the middle joints of the thumb and all four fingers. Subjects are instructed to build up to their maximum strength in the first few seconds and to maintain maximum strength for a further few seconds.

#### Handle type and size

Hand grip dynamometer with handle separations of 30mm, 50mm and 70mm (handle length 100mm). Handles are freely moveable.



70, 50 and 30mm handles



Experimental trial: 1 handed grip strength (70mm handle)

## Subject numbers

153 subjects were measured:

Age (years)	Male	Female	Total
2-5	8	9	17
6-10	7	11	18
11-15	10	10	20
16-20	9	7	16
21-30	7	7	14
31-50	6	11	17
51-60	4	6	10
61-70	6	9	15
71-80	8	12	20
81-90	0	6	6
<b>Total</b>	<b>65</b>	<b>88</b>	<b>153</b>

Anthropometric variables (stature, weight, elbow height, hand length and hand breadth) for all subjects can be found in Appendix 3a.

## Analysis

### *Effect of sex*

For all six measurements (gripping with 1 and 2 hands on three handle sizes), no significant differences were found between male and female children (2-15 years). However, in all adult and older adult age groups (16-80 years), males were found to be significantly stronger than females for most hand grip actions (Appendix 3b).

### *Effect of age*

Hand grip strength increases with age throughout childhood, it peaks in adulthood, and then decreases with age from around 50 years. Throughout childhood, each successive age group (2-5, 6-10, 11-15 years) was found to be significantly stronger than the previous for all six measurements. Adults (16-50 years) were generally found to be significantly stronger than older adults (51-90 years), who in turn were significantly stronger than children, with the exception of those aged 11-15 years (Appendix 3c).

### *Effect of handle size and number of hands used*

Both the size of the handle and the number of hands used appear to significantly effect the maximum strength that can be exerted (Appendix 3d). Gripping with 2 hands generated significantly higher forces than those generated with 1 hand only for all three handle sizes

(30, 50 and 70mm). For both males and females, maximum 1 handed grip strength was generally exerted with the medium sized handle (50mm), whilst for 2 handed strength, gripping with the large handle (70mm) generated the highest forces. Gripping on the small handle (30mm) for both 1 and 2 handed strength generated the weakest forces for both males and females of all ages (with the exception of 2-5 year old females who generated the weakest force when gripping the 70mm handle). Correlation coefficients for all 6 measurements can be found in Appendix 3e.

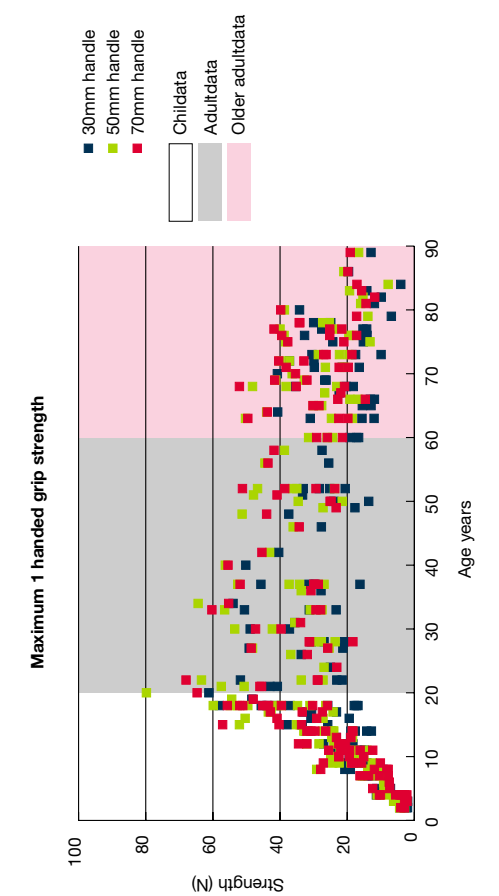
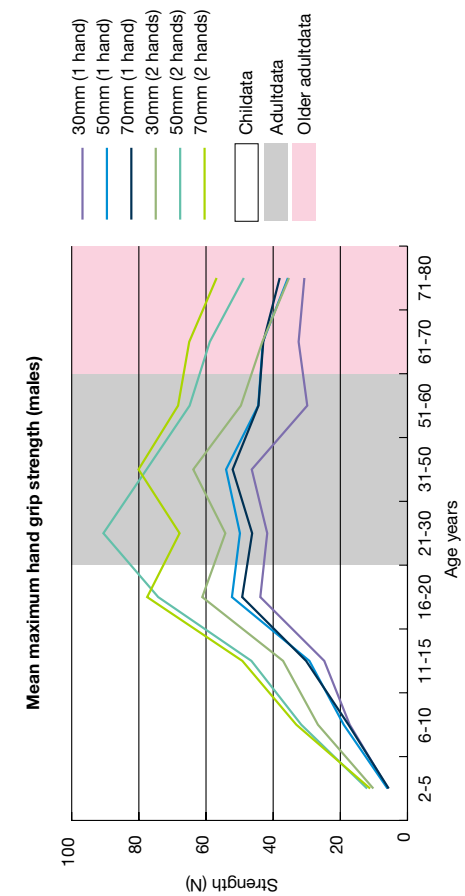
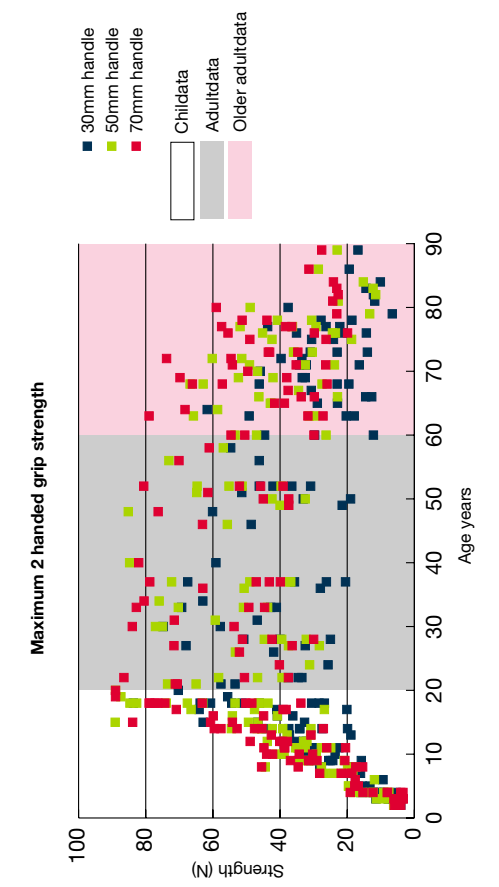
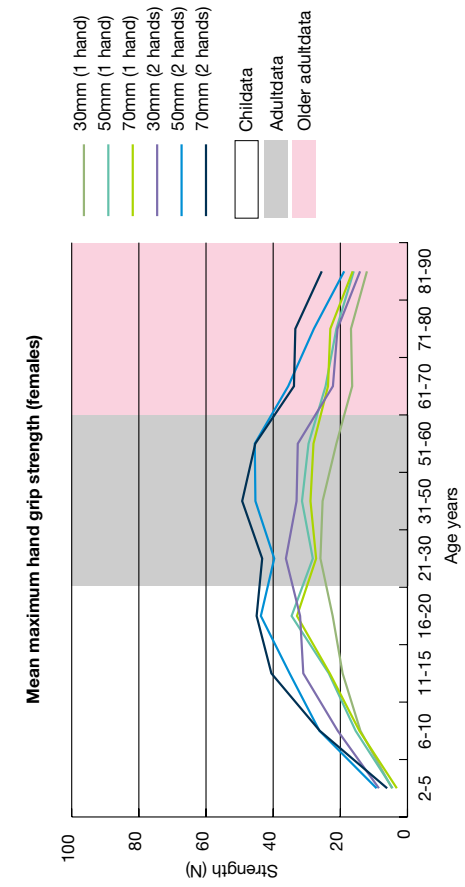
## Results

### *1 handed grip strength*

Age years	Sex	No.	Small handle - 30mm (N)			Medium handle - 50mm (N)			Large handle - 70mm (N)		
			Mean	SD	Range	Mean	SD	Range	Mean	SD	Range
2-5	m	8	5.80	3.84	2.00 - 11.30	5.95	3.05	2.90 - 11.1	5.59	3.98	2.42 - 12.4
	f	9	4.60	1.44	2.84 - 6.18	4.43	1.78	2.33 - 8.31	3.18	1.15	2.20 - 5.50
6-10	m	7	17.20	2.68	13.90 - 20.70	18.99	6.00	12.50 - 29.10	17.58	6.12	10.10 - 27.90
	f	11	14.01	4.28	8.10 - 19.90	15.45	5.50	9.20 - 24.90	14.32	6.76	7.50 - 27.10
11-15	m	10	24.78	7.92	14.20 - 37.90	29.21	9.91	18.40 - 52.10	30.20	11.87	18.90 - 57.10
	f	10	19.32	3.73	12.80 - 24.80	23.44	5.86	14.10 - 32.10	23.14	7.03	12.40 - 34.50
16-20	m	9	43.83	11.31	25.80 - 61.20	52.28	12.96	34.80 - 79.80	49.23	7.68	39.60 - 64.70
	f	7	22.28	6.12	16.80 - 30.80	34.51	9.85	24.20 - 50.40	32.91	6.77	25.90 - 43.40
21-30	m	7	41.77	10.33	21.50 - 51.80	49.90	9.80	33.70 - 63.40	46.26	11.77	28.70 - 68.00
	f	7	25.93	4.84	20.80 - 33.70	28.20	4.25	23.60 - 36.80	27.21	5.10	18.30 - 31.90
31-50	m	6	46.38	6.44	37.40 - 54.00	54.03	7.04	43.10 - 64.40	52.07	6.32	44.00 - 60.30
	f	11	25.28	7.01	13.60 - 35.60	31.42	4.99	21.50 - 37.30	28.89	3.52	23.30 - 34.30
51-60	m	4	29.85	3.95	25.50 - 33.30	44.45	4.08	38.70 - 47.90	44.38	4.69	40.90 - 51.20
	f	6	21.18	4.64	16.60 - 28.30	29.47	5.49	24.30 - 36.20	28.00	6.03	21.40 - 38.60
61-70	m	6	32.42	8.17	20.30 - 40.80	43.07	5.49	36.40 - 50.30	42.95	7.04	35.20 - 52.10
	f	9	16.47	5.12	11.90 - 26.70	24.39	5.47	16.80 - 32.80	23.67	5.53	14.60 - 32.00
71-80	m	8	30.71	3.98	24.30 - 37.20	35.60	6.06	25.30 - 40.00	38.05	3.09	32.90 - 41.80
	f	12	16.83	6.34	6.86 - 30.50	21.17	4.76	13.20 - 28.60	22.98	4.94	17.20 - 34.30
81-90	f	6	12.08	5.12	4.05 - 19.60	16.00	4.56	7.81 - 21.00	16.32	2.99	11.80 - 19.80

2 handed grip strength

Age years	Sex	No.	Small handle - 30mm (N)			Medium handle - 50mm (N)			Large handle - 70mm (N)		
			Mean	SD	Range	Mean	SD	Range	Mean	SD	Range
2-5	m	8	10.17	4.83	4.05 - 16.00	12.03	6.28	5.94 - 19.64	11.13	6.61	4.07 - 19.10
	f	9	8.51	3.02	4.06 - 12.20	9.21	3.51	3.93 - 15.50	6.06	3.01	3.33 - 12.30
6-10	m	7	26.67	5.03	17.60 - 33.00	31.63	7.90	20.90 - 44.40	33.10	8.52	20.70 - 45.50
	f	11	20.77	6.94	9.30 - 33.10	26.21	9.56	11.90 - 41.10	26.12	9.65	15.40 - 44.00
11-15	m	10	37.05	11.96	18.90 - 62.90	46.48	15.70	34.80 - 89.10	49.18	15.20	30.80 - 83.90
	f	10	31.03	6.08	19.90 - 37.40	35.10	8.92	24.90 - 54.50	40.53	12.99	20.50 - 59.60
16-20	m	9	61.12	11.21	46.20 - 83.70	74.24	12.90	53.40 - 89.00	77.53	8.12	63.20 - 89.00
	f	7	31.98	7.74	20.10 - 41.00	43.67	9.85	26.80 - 54.20	44.93	8.23	33.80 - 59.90
21-30	m	7	54.24	15.56	33.50 - 74.80	60.55	17.80	28.30 - 77.10	67.87	17.14	37.50 - 86.50
	f	7	36.21	9.23	25.00 - 50.80	39.68	4.25	31.20 - 53.30	43.27	8.45	30.00 - 52.10
31-50	m	6	63.80	26.35	59.10 - 69.30	77.70	32.30	70.30 - 85.20	80.10	32.78	76.30 - 82.80
	f	11	33.03	10.76	19.00 - 48.60	45.29	8.48	32.50 - 59.30	49.23	11.51	37.40 - 71.50
51-60	m	4	49.62	4.18	46.20 - 54.70	64.88	6.62	56.90 - 73.10	68.32	9.18	61.10 - 80.60
	f	6	32.67	11.64	12.20 - 44.60	45.48	10.90	26.30 - 55.20	45.33	9.33	29.90 - 54.60
61-70	m	6	43.23	13.41	23.00 - 61.70	58.87	7.96	46.70 - 66.80	65.00	10.29	49.60 - 79.00
	f	9	22.21	7.09	12.70 - 32.50	35.52	8.20	22.90 - 46.30	33.81	5.50	26.00 - 41.60
71-80	m	8	35.28	5.04	27.80 - 43.70	48.74	6.14	40.80 - 60.20	56.85	7.54	49.00 - 73.80
	f	12	20.84	7.37	6.60 - 32.20	27.88	7.27	13.30 - 36.30	33.40	8.24	19.90 - 43.90
81-90	f	6	14.12	3.47	10.10 - 19.40	18.85	6.89	11.50 - 28.60	25.53	3.35	22.70 - 31.40



#### 4. Wrist-twisting strength

##### Description

Maximum static torque of 1 (dominant) hand, exerted on knobs and handles in a horizontal and vertical orientation for five seconds, in Newton-metres (Nm).

##### Method

The subject stands in front of the measuring device and adopts a free posture. A static twisting force is exerted with 1 (dominant) hand in a clock-wise direction on a variety of knobs and handles (i.e. the knob doesn't move). Subjects are instructed to build up to their maximum strength in the first few seconds and to maintain maximum strength for a further few seconds.

##### Handle type and size

A series of six handles and knobs:

- i) door lever (diameter 15mm, length 170mm),
- ii) door knob (diameter 65mm, depth 45mm),
- iii) circular knob (diameter 40mm, depth 20mm),
- iv) ridged knob (length 40mm, depth 15mm),
- v) butterfly nut (length 40mm, depth 10mm), and
- vi) tap (diameter 50mm, depth 40mm), positioned at elbow height and orientated vertically (vertical wrist-twisting strength).

The ridged knob, butterfly nut and tap were also orientated horizontally (horizontal wrist-twisting strength).



*i) Door lever*



*ii) Door knob*



*iii) Circular knob*



*iv) Ridged knob*



*v) Butterfly nut*



*vi) Tap*

### Subject numbers

Subjects were measured in 2 experimental sessions: the first for vertical wrist-twisting strength, and the second for horizontal wrist-twisting strength. 150 subjects were measured in each session, although not all subjects attended both sessions.

#### Session 1

Age (years)	Male	Female	Total
2-5	12	7	19
6-10	7	11	18
11-15	11	6	17
16-20	6	8	14
21-30	7	7	14
31-50	5	13	18
51-60	4	6	10
61-70	4	10	14
71-80	8	12	20
81-90	0	6	6
<b>Total</b>	<b>64</b>	<b>86</b>	<b>150</b>

#### Session 2

Age (years)	Male	Female	Total
2-5	8	7	15
6-10	7	11	18
11-15	10	10	20
16-20	9	7	16
21-30	7	7	14
31-50	6	12	18
51-60	3	6	9
61-70	6	9	15
71-80	8	11	19
81-90	0	6	6
<b>Total</b>	<b>64</b>	<b>86</b>	<b>150</b>

Anthropometric variables (stature, weight, elbow height, hand length and hand breadth) for all subjects can be found in Appendix 4a.

### Analysis

#### *Effect of sex*

No significant differences in wrist-twisting strength (vertical and horizontal) were found between male and female children (2-15 years). However, in adults aged 16 years and over, males were generally found to be significantly stronger than females (Appendix 4b).

#### *Effect of age*

Maximum strength for both vertical and horizontal wrist-twisting increases throughout childhood (2-15 years), it peaks in adulthood, and then decreases with age from around 50 years. No significant differences in maximum strength were found in subjects aged between 16 and 60 years. However, both adults and older adults were found to be significantly stronger than children aged from 2 to 10 years. No significant differences in *vertical* wrist-twisting strength were found between 11-15 year olds and those subjects aged 51 or over (Appendix 4c).

#### *Effect of handle type and orientation*

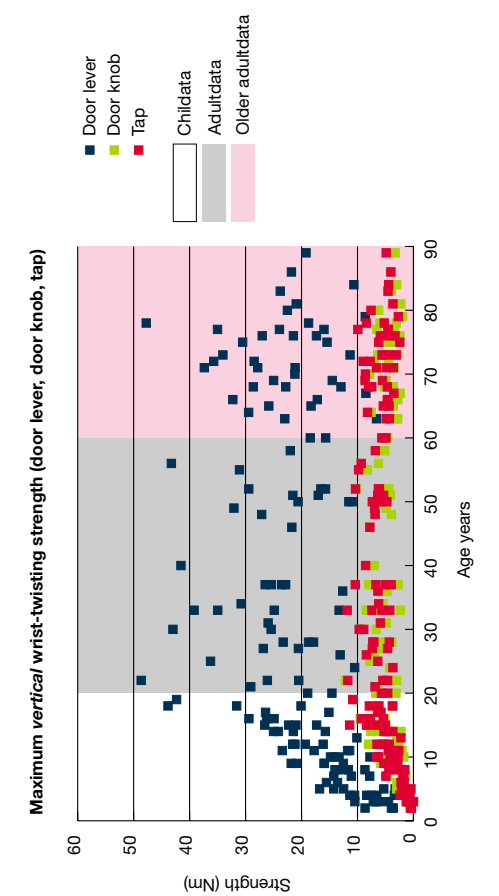
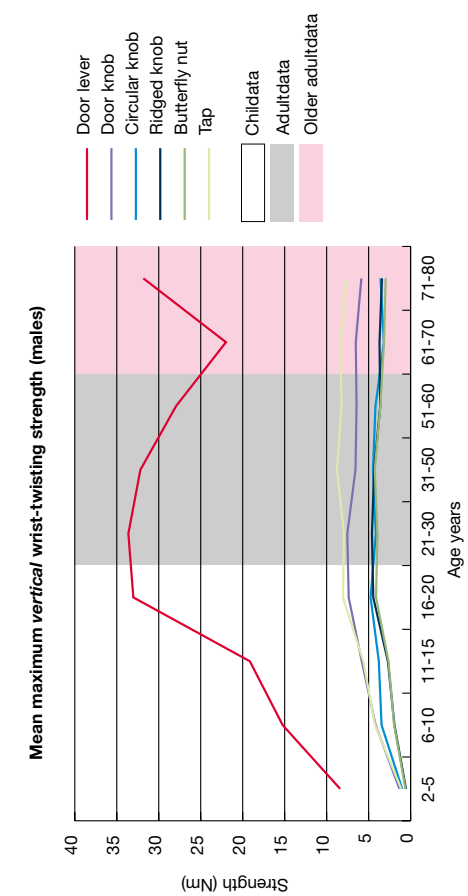
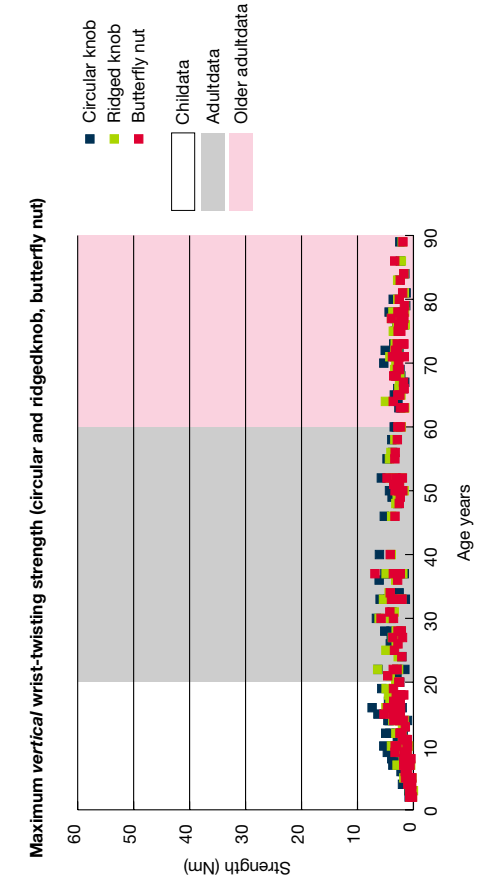
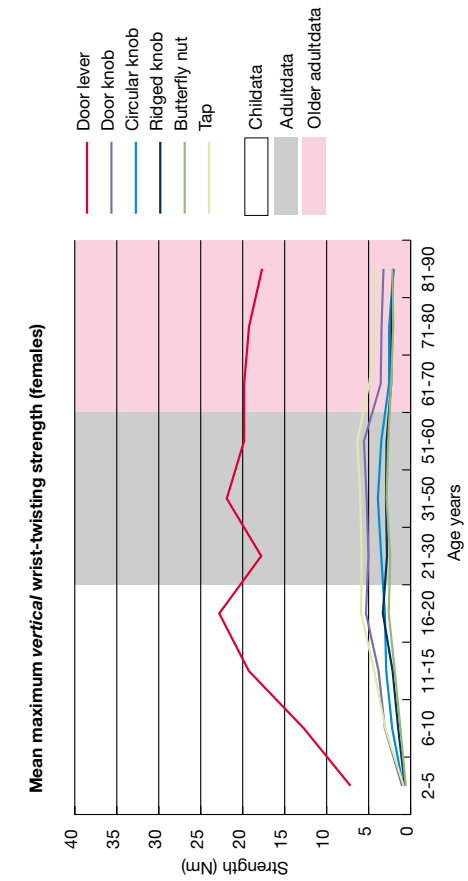
The handle type appears to significantly affect maximum strength, as significant differences were found between all 6 handles and knobs (Appendix 4d). As expected, those handles which allow manipulation with the whole hand (e.g. door knob and tap) generated higher forces than those handles allowing manipulation with the fingers only (e.g. butterfly nut and ridged knob), and this appears true for males and females of all ages. The strength exerted on the door lever far exceeded those strengths exerted on all other handles and controls, for both males and females. No significant differences in strength due to handle orientation were found for the tap (Appendix 4e). However, both males and females exerted higher forces on the ridged knob and butterfly nut when orientated horizontally, as opposed to vertically. Correlation coefficients for all measurements can be found in Appendix 4f.

## Results

### Vertical wrist-twisting strength

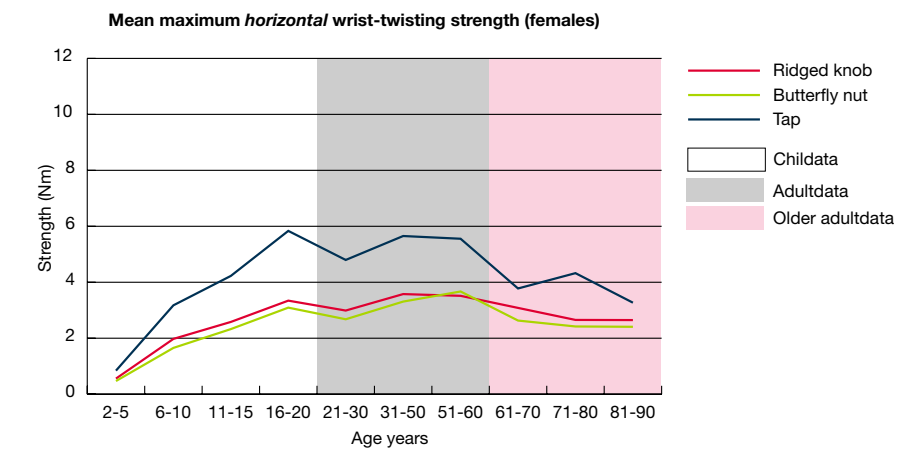
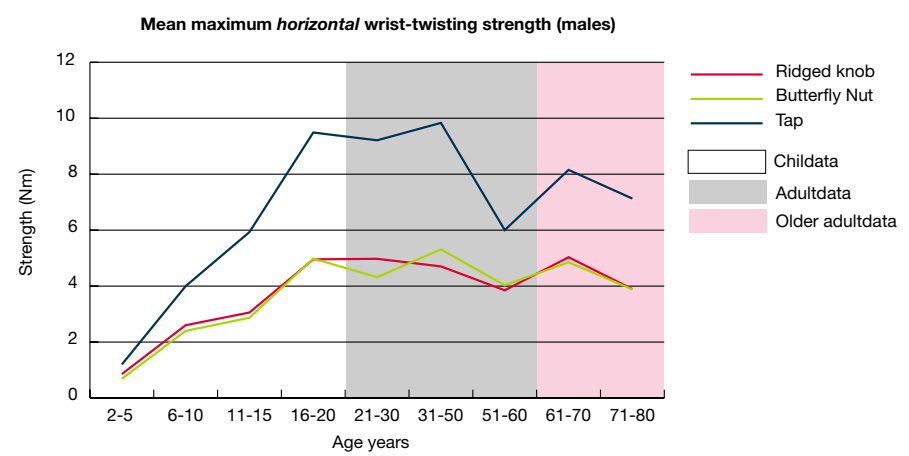
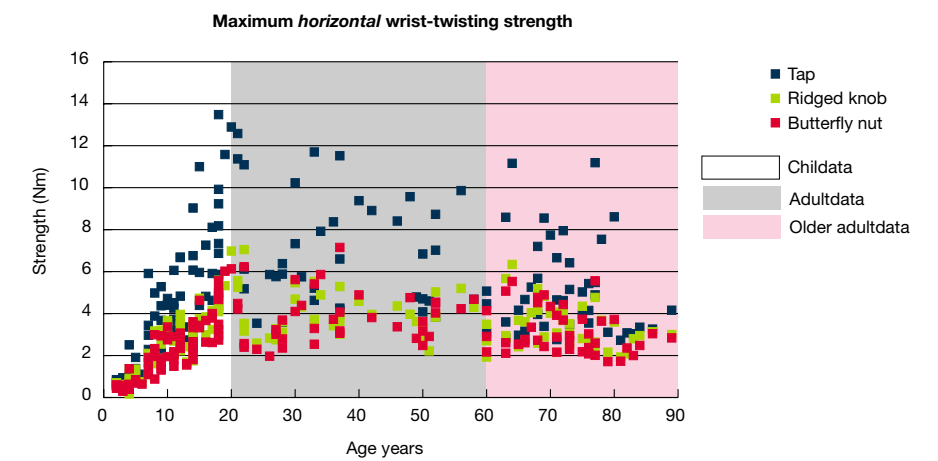
Age years	Sex	No.	Door lever (Nm)			Door knob (Nm)			Tap (Nm)		
			Mean	SD	Range	Mean	SD	Range	Mean	SD	Range
2-5	m	12	8.38	3.81	3.28 – 16.77	1.32	0.72	0.58 – 3.02	1.11	0.71	0.37 – 2.40
	f	7	7.16	4.10	3.41 – 14.24	1.00	0.79	0.45 – 2.34	0.82	0.56	0.50 – 1.76
6-10	m	7	15.23	3.10	12.50 – 21.80	4.16	1.24	1.73 – 5.82	4.23	1.22	2.77 – 6.29
	f	11	12.71	3.96	7.78 – 20.92	3.06	1.45	1.38 – 6.46	3.01	1.65	1.54 – 6.61
11-15	m	11	19.14	4.99	10.11 – 26.50	5.81	2.19	2.73 – 8.41	5.63	2.46	2.24 – 11.40
	f	6	19.27	5.18	11.40 – 25.01	3.81	1.69	2.04 – 6.74	4.32	1.46	2.62 – 6.52
16-20	m	6	33.02	8.74	22.84 – 43.80	7.37	2.50	3.87 – 10.8	8.05	1.76	6.18 – 10.86
	f	8	22.79	6.49	14.57 – 31.60	5.31	1.30	3.13 – 6.72	5.89	1.41	3.70 – 7.89
21-30	m	7	33.61	9.22	25.43 – 48.70	7.53	2.81	3.01 – 12.1	7.93	2.35	4.62 – 11.74
	f	7	17.79	4.49	10.50 – 23.28	5.02	1.00	3.88 – 6.93	5.83	1.76	3.67 – 8.41
31-50	m	5	32.18	6.23	26.50 – 41.55	6.56	1.85	3.94 – 8.42	8.77	2.36	6.22 – 11.85
	f	13	21.90	8.33	10.96 – 39.20	5.23	1.69	2.36 – 7.85	5.99	1.24	4.00 – 7.79
51-60	m	4	27.93	11.40	17.00 – 43.26	6.43	2.68	4.12 – 10.2	8.22	1.92	6.39 – 10.36
	f	6	19.83	25.90	15.69 – 31.10	5.55	1.41	4.40 – 8.24	6.34	1.76	4.93 – 9.80
61-70	m	4	21.99	6.13	14.50 – 29.45	6.53	1.36	5.16 – 7.82	8.37	0.30	8.02 – 8.65
	f	10	19.82	8.59	6.61 – 32.28	3.55	0.81	2.37 – 4.90	4.93	1.05	3.50 – 7.45
71-80	m	8	31.83	9.40	17.30 – 47.75	5.86	0.86	4.43 – 6.91	7.67	1.39	5.92 – 9.93
	f	12	19.23	8.41	5.30 – 34.05	3.45	1.10	1.94 – 6.40	4.05	1.01	2.44 – 5.63
81-90	f	6	17.68	6.00	9.72 – 23.80	3.22	0.68	2.26 – 4.06	4.17	0.54	3.47 – 4.87

Age years	Sex	No.	Circular knob (Nm)			Ridged knob (Nm)			Butterfly nut (Nm)		
			Mean	SD	Range	Mean	SD	Range	Mean	SD	Range
2-5	m	12	1	0.46	0.31 – 1.96	0.54	0.21	0.18 – 0.88	0.6	0.34	0.17 – 1.43
	f	7	0.89	0.45	0.38 – 1.47	0.68	0.52	0.35 – 1.71	0.57	0.24	0.30 – 0.98
6-10	m	7	3.45	1.29	1.73 – 5.30	1.92	0.75	0.88 – 2.93	1.96	0.35	1.03 – 3.29
	f	11	2.19	0.8	1.02 – 3.88	1.47	0.97	0.50 – 3.93	1.21	0.2	0.45 – 2.95
11-15	m	11	3.78	1.51	1.58 – 6.35	2.7	0.81	1.89 – 4.16	2.63	1.13	1.23 – 5.27
	f	6	2.9	1.29	1.07 – 4.36	2.14	0.75	1.29 – 3.14	1.88	0.52	1.09 – 2.46
16-20	m	6	4.76	1.67	2.34 – 7.39	4.44	0.45	3.77 – 4.89	4.11	0.71	3.08 – 4.95
	f	8	3.06	0.85	2.02 – 4.46	3.3	0.82	2.51 – 4.92	2.6	0.64	1.73 – 3.61
21-30	m	7	4.14	1.8	1.54 – 6.62	4.6	1.32	2.66 – 6.40	3.94	0.95	2.97 – 5.79
	f	7	3.49	1.28	2.08 – 5.13	2.8	0.32	2.22 – 3.09	2.42	0.39	1.96 – 2.97
31-50	m	5	4.48	1.69	2.56 – 6.08	4.34	0.85	3.14 – 5.36	4.26	1.6	2.54 – 6.88
	f	13	3.89	1.32	1.45 – 6.13	2.92	0.74	1.67 – 4.21	2.86	0.74	1.90 – 4.22
51-60	m	4	4.18	1.05	3.39 – 5.74	3.61	0.6	2.91 – 4.21	3.59	0.79	2.88 – 4.72
	f	6	3.49	0.65	2.87 – 4.72	2.85	0.82	2.13 – 4.29	2.66	0.5	1.98 – 3.32
61-70	m	4	3.18	1.42	2.26 – 5.30	3.7	0.87	3.14 – 5.01	3.16	0.46	2.67 – 3.61
	f	10	2.56	0.57	1.55 – 3.42	2.31	0.43	1.56 – 2.86	2.32	0.58	1.67 – 3.19
71-80	m	8	3.57	0.8	2.60 – 5.05	3.41	0.52	2.80 – 4.21	2.96	0.66	1.87 – 3.93
	f	12	2.55	0.67	1.38 – 3.52	2.27	0.58	1.47 – 3.27	2.06	0.44	1.61 – 2.90
81-90	f	6	2.03	0.5	1.31 – 2.53	2.06	0.59	1.69 – 3.35	2.15	0.42	1.69 – 3.35



Horizontal wrist-twisting strength

Age years	Sex	No.	Tap (Nm)			Ridged knob (Nm)			Butterfly nut (Nm)		
			Mean	SD	Range	Mean	SD	Range	Mean	SD	Range
2-5	m	8	1.19	0.69	0.60 – 2.51	0.86	0.36	0.48 – 1.37	0.69	0.31	0.40 – 1.37
	f	7	0.84	0.11	0.69 – 1.00	0.56	0.26	0.17 – 0.90	0.47	0.13	0.30 – 0.62
6-10	m	7	3.99	1.25	2.11 – 5.91	2.60	0.72	1.64 – 3.55	2.40	0.72	1.40 – 3.36
	f	11	3.18	1.36	1.11 – 5.28	1.98	0.87	0.75 – 3.67	1.65	0.71	0.64 – 2.89
11-15	m	10	5.93	2.56	2.74 – 11.0	3.05	0.91	1.69 – 4.73	2.87	0.96	1.55 – 4.63
	f	10	4.23	1.46	2.76 – 6.76	2.58	0.74	1.75 – 3.96	2.33	0.57	1.49 – 3.07
16-20	m	9	9.49	2.69	5.91 – 13.48	4.96	0.92	4.09 – 6.98	4.98	0.87	3.49 – 6.13
	f	7	5.84	1.41	4.33 – 8.11	3.34	0.41	2.80 – 3.89	3.09	0.43	2.62 – 3.79
21-30	m	7	9.21	2.75	5.76 – 12.58	4.97	1.29	3.28 – 7.05	4.31	1.30	2.57 – 6.23
	f	7	4.79	1.33	3.15 – 6.38	2.98	0.33	2.59 – 3.61	2.67	0.60	1.97 – 3.69
31-50	m	6	9.83	1.49	7.92 – 11.70	4.70	0.65	3.96 – 5.53	5.31	1.13	3.81 – 7.15
	f	12	5.65	1.55	4.08 – 8.41	3.57	0.48	2.74 – 4.36	3.31	0.57	2.48 – 4.39
51-60	m	3	6.00	2.36	4.60 – 8.73	3.85	1.45	2.22 – 5.03	4.03	0.97	2.91 – 4.68
	f	6	5.55	2.49	3.09 – 9.86	3.51	1.12	1.93 – 5.20	3.67	0.92	2.17 – 4.54
61-70	m	6	8.15	1.82	5.68 – 11.16	5.03	0.89	4.02 – 6.34	4.85	0.42	4.34 – 5.53
	f	9	3.77	0.81	2.83 – 5.26	3.08	0.55	2.42 – 4.04	2.63	0.33	2.11 – 3.35
71-80	m	8	7.12	2.18	4.62 – 11.19	3.89	0.56	2.90 – 4.77	3.88	0.88	2.38 – 5.56
	f	11	4.32	1.10	2.76 – 6.42	2.65	0.43	2.15 – 3.52	2.42	0.43	1.71 – 3.03
81-90	f	6	3.27	0.48	2.73 – 4.16	2.64	0.51	1.93 – 3.13	2.40	0.49	1.73 – 3.04



## 5. Opening strength

### Description

Maximum static torque of the preferred hand, exerted on jar lids for five seconds, in Newton-metres (Nm).

### Method

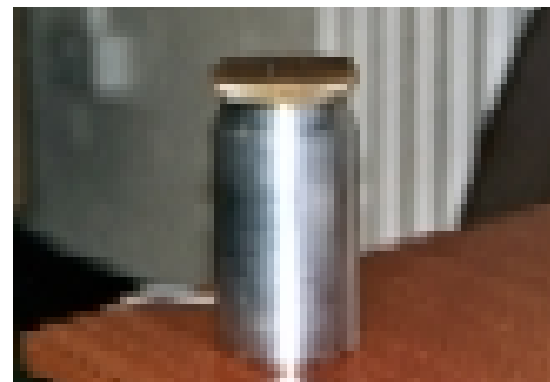
The subject stands and adopts a free posture. The replica jar is held with 1 (preferred) hand and a static twisting force is exerted with the other on the lid of the jar (i.e. the lid doesn't move). Subjects are instructed to build up to their maximum strength in the first few seconds and to maintain maximum strength for a further few seconds.

### Handle type and size

A series of 3 custom-made aluminium jars (height 125mm) with smooth and knurled lids (diameters 45, 65 and 85mm).



45mm jar



65mm jar



85mm jar



Experimental trial: 45mm jar

## Subject numbers

144 subjects were measured:

Age (years)	Male	Female	Total
2-5	7	10	17
6-10	8	10	18
11-15	9	7	16
16-20	5	5	10
21-30	8	9	17
31-50	5	13	18
51-60	4	5	9
61-70	5	9	14
71-80	8	12	20
81-90	0	5	5
<b>Total</b>	<b>59</b>	<b>85</b>	<b>144</b>

Anthropometric variables (stature, weight, elbow height, hand length and hand breadth) for all subjects can be found in Appendix 5a.

### Analysis

#### Effect of sex

Up until the age of 60 years, no significant differences in opening strength were found between males and females. However, in adults aged over 60 years, males were found to be significantly stronger than females, for most torque actions (Appendix 5b).

#### Effect of age

For all six opening strength exertions (3 lid sizes and 2 lid textures), maximum strength increases throughout childhood (2-15 years), it peaks in adulthood, and then decreases with age from around 50 years. No significant differences in maximum strength were found between subjects aged from 16 to 70 years. However, significant differences were found between the child age groups (2-5, 6-10, 11-15 years), with each successive group being significantly stronger than the previous for all six measurements (Appendix 5c).

#### Effect of lid size and texture

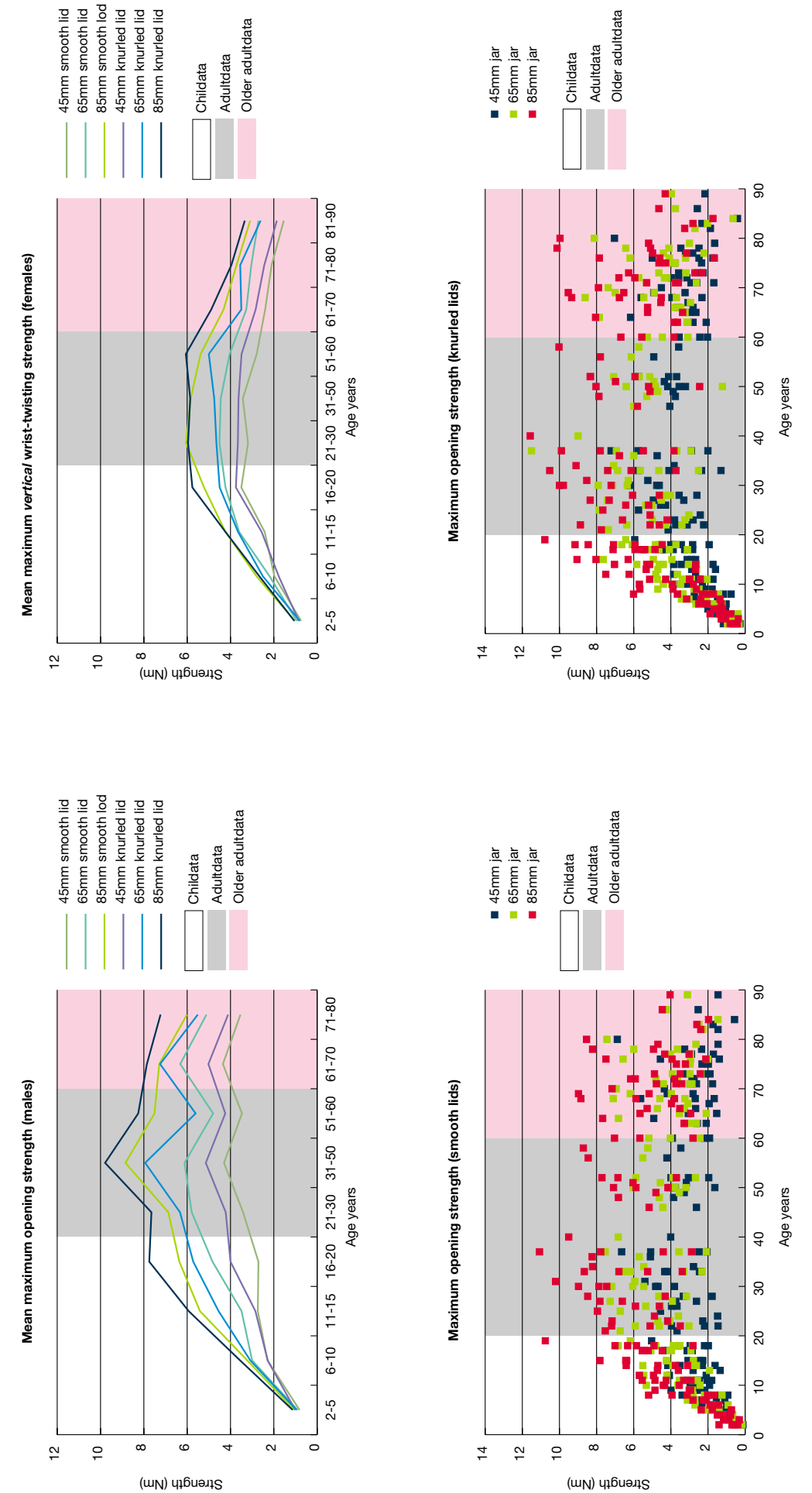
Both the lid size and texture appear to have an effect on maximum strength. For all three lid sizes (45, 65 and 85mm), those with a knurled texture generated significantly higher forces than those with a smooth texture. Both children and adults of all ages exerted their maximum strength on the 85mm lid. Maximum strength decreased as the size of the lid



decreased, for both males and females of all ages. That is, as the size of the lid decreased from 85 to 65 to 45mm, the maximum strength that could be exerted also decreased (Appendix 5d). Correlation coefficients for all 6 measurements can be found in Appendix 5e.

## Results

Age years	Sex	No.	Lid texture	45mm lid (Nm)			65mm lid (Nm)			85mm lid (Nm)		
				Mean	SD	Range	Mean	SD	Range	Mean	SD	Range
2-5	m	7	smooth	0.81	0.48	0.13 – 1.43	0.90	0.54	0.16 – 1.71	1.05	0.50	0.39 – 1.76
			knurled	1.01	0.56	0.29 – 2.00	0.95	0.40	0.32 – 1.52	1.13	0.46	0.57 – 1.88
			f	10	smooth	0.74	0.32	0.11 – 1.15	0.94	0.47	0.35 – 2.07	1.03
			knurled	0.85	0.35	0.27 – 1.48	0.80	0.34	0.37 – 1.24	1.05	0.41	0.36 – 1.67
6-10	m	8	smooth	2.29	0.72	1.09 – 3.39	3.00	1.03	1.85 – 5.32	3.22	1.20	1.51 – 5.19
			knurled	2.28	0.71	1.44 – 3.50	3.08	0.76	1.83 – 4.40	3.55	1.64	1.35 – 6.00
			f	10	smooth	1.97	0.91	0.93 – 3.98	2.19	0.81	0.91 – 3.61	2.79
			knurled	1.77	0.69	0.75 – 3.09	2.50	1.16	1.24 – 4.69	2.66	1.26	1.28 – 5.66
11-15	m	9	smooth	2.74	0.79	1.34 – 4.07	3.49	1.07	1.91 – 5.45	5.54	1.35	3.59 – 7.82
			knurled	2.85	0.62	1.59 – 3.84	4.55	1.39	2.61 – 7.64	5.93	1.99	2.67 – 9.05
			f	7	smooth	2.42	0.86	1.61 – 4.16	3.60	1.24	2.61 – 5.51	4.23
			knurled	2.56	0.72	1.73 – 3.84	3.65	1.25	2.05 – 5.83	4.23	1.91	2.41 – 7.03
16-20	m	5	smooth	2.71	1.88	1.98 – 5.03	4.83	1.70	2.83 – 6.83	6.36	2.93	2.80 – 10.7
			knurled	4.00	1.17	2.82 – 5.94	5.72	0.93	4.61 – 6.64	7.75	2.54	4.46 – 10.7
			f	5	smooth	3.50	0.70	2.84 – 4.35	4.23	0.92	2.91 – 5.15	5.22
			knurled	3.75	0.71	2.82 – 4.48	4.50	0.95	3.10 – 5.48	5.76	0.84	4.85 – 7.11
21-30	m	8	smooth	3.42	1.29	1.45 – 4.81	5.79	1.54	3.02 – 7.26	6.87	1.95	3.49 – 8.97
			knurled	4.22	1.42	2.32 – 6.22	6.33	1.92	3.24 – 7.91	7.65	2.17	4.19 – 9.99
			f	9	smooth	3.19	0.99	1.48 – 4.12	4.51	0.87	3.16 – 6.05	6.05
			knurled	3.66	0.80	2.41 – 4.76	4.65	0.93	3.02 – 6.34	5.96	0.99	4.61 – 7.32
31-50	m	5	smooth	4.30	1.42	2.77 – 6.65	6.12	1.14	4.61 – 7.53	8.85	1.57	6.83 – 11.0
			knurled	5.14	1.67	3.75 – 7.21	7.94	1.67	5.29 – 11.5	9.79	1.40	7.87 – 11.5
			f	13	smooth	3.43	1.27	1.63 – 5.39	4.45	1.71	2.07 – 7.62	5.84
			knurled	3.63	1.27	1.29 – 5.76	4.75	1.72	1.22 – 6.93	5.86	1.83	2.44 – 8.52
51-60	m	4	smooth	3.47	0.52	3.05 – 4.21	4.80	0.72	3.88 – 5.51	7.51	1.28	6.03 – 8.71
			knurled	4.24	0.55	3.57 – 4.91	5.61	0.50	4.91 – 6.13	8.28	1.28	6.98 – 10.0
			f	5	smooth	2.79	1.06	1.91 – 3.99	4.04	1.51	2.43 – 5.88	5.38
			knurled	3.49	1.44	2.02 – 5.74	5.00	1.44	3.07 – 7.07	6.06	1.64	3.83 – 8.32
61-70	m	5	smooth	4.35	1.08	2.68 – 5.62	6.32	1.03	4.59 – 7.10	7.29	2.09	3.80 – 8.97
			knurled	5.02	0.87	3.94 – 6.16	7.25	1.17	5.45 – 8.61	7.86	2.01	4.51 – 9.52
			f	9	smooth	2.40	0.62	1.52 – 3.28	3.27	0.76	2.09 – 4.72	4.32
			knurled	2.84	0.46	2.09 – 3.61	3.50	0.58	2.94 – 4.88	4.89	1.28	3.36 – 6.77
71-80	m	8	smooth	3.54	1.50	2.31 – 6.88	5.11	1.61	2.96 – 7.44	6.01	1.99	3.21 – 8.54
			knurled	4.11	1.33	2.91 – 7.03	5.51	1.43	3.74 – 8.12	7.23	2.18	4.63 – 10.1
			f	12	smooth	2.10	0.54	1.38 – 3.12	3.04	0.59	2.01 – 4.02	3.72
			knurled	2.44	0.58	1.63 – 3.57	3.55	0.76	2.21 – 4.64	3.96	1.35	1.65 – 6.27
81-90	f	5	smooth	1.54	0.70	0.57 – 2.53	2.71	1.03	1.97 – 4.46	3.09	1.09	0.65 – 3.97
			knurled	1.86	0.85	1.46 – 4.24	2.61	1.35	0.41 – 2.57	3.34	1.17	1.73 – 4.65



## 6. Push and pull strength

### Description

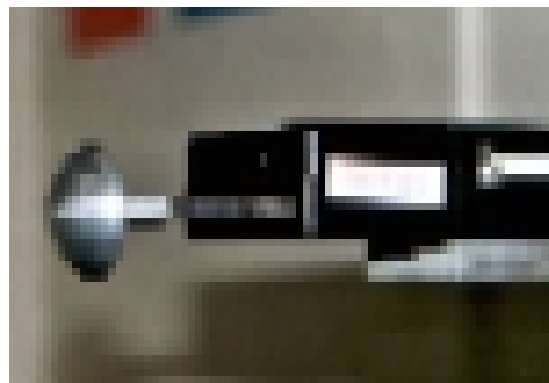
Maximum static pushing and pulling force using 1 and 2 hands on a cylindrical bar and a convex knob (1 handed pull only), exerted for five seconds, in Newtons (N).

### Method

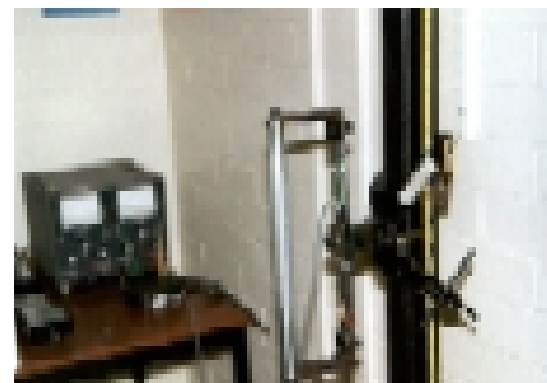
The subject stands in front of the measuring device and adopts a free posture. A static pushing or pulling force is exerted on a cylindrical bar (pulling only on the knob) using 1 (dominant) and 2 hands (i.e. the handle doesn't move). Subjects are instructed to build up to their maximum strength in the first few seconds and to maintain maximum strength for a further few seconds.

### Handle type and size

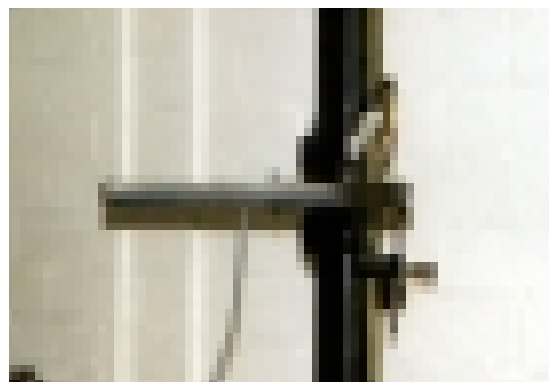
A cylindrical bar (diameter 20mm, length 300mm), orientated vertically and horizontally, and a round, convex knob (diameter 40mm) (1 handed-pull only). Both handles were positioned at elbow height.



Convex knob



Vertical bar



Horizontal bar



Experimental trial: Pushing with 1 hand (vertical bar)

## Subject numbers

Subjects were measured in 2 experimental sessions: the first measured pulling strength on the convex knob, and the second pushing and pulling strength on the cylindrical bar. Around 145 subjects were measured in each session, although not all subjects attended both sessions.

### Session 1

Age (years)	Male	Female	Total
2-5	8	8	16
6-10	5	10	15
11-15	12	5	17
16-20	8	8	16
21-30	7	7	14
31-50	7	17	24
51-60	5	6	11
61-70	4	7	11
71-80	7	9	16
81-90	0	4	4
<b>Total</b>	<b>63</b>	<b>81</b>	<b>144</b>

### Session 2

Age (years)	Male	Female	Total
2-5	12	9	21
6-10	8	11	19
11-15	9	6	15
16-20	6	6	12
21-30	5	9	14
31-50	6	11	17
51-60	3	6	9
61-70	5	9	14
71-80	7	12	19
81-90	0	5	5
<b>Total</b>	<b>61</b>	<b>84</b>	<b>145</b>

Anthropometric variables (stature, weight, elbow height, hand length and hand breadth) for all subjects can be found in Appendix 6a.

## Analysis

### Effect of sex

For most pushing and pulling actions, no significant differences were found between males and females aged between 2 and 20 years. However, in adults aged 21 years and over, males in general were significantly stronger than females (Appendix 6b).

### Effect of age

For both pushing and pulling, maximum strength increases significantly throughout childhood (2-15 years), it peaks in adulthood, and then decreases with age from around 50 years. For most exertions, no significant differences in maximum strength (pushing and pulling) were found in subjects aged between 11 and 70 years. In general, however, adults were found to be stronger than older adults (although not significantly), who in turn were stronger than children (Appendix 6c).

### Effect of handle type and orientation, direction of force and number of hands used

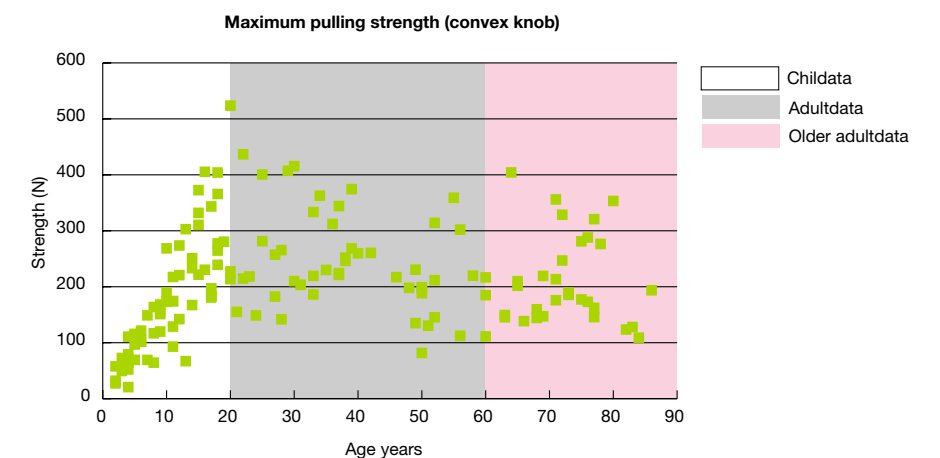
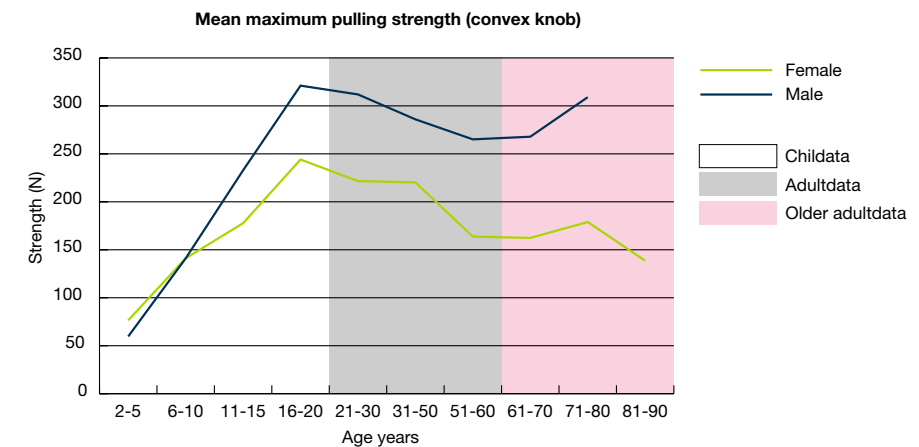
Both males and females exerted their maximum strength when pushing and pulling (both horizontally and vertically) on the cylindrical bar with 2 hands, as opposed to only 1 hand (Appendix 6d).

No significant differences due to handle orientation were found for *pulling* with 1 or 2 hands. However, when *pushing* with both 1 and 2 hands, subjects generally exerted significantly higher forces when the cylindrical bar was orientated vertically. Differences due to the direction of force were also found, however, only for 1 handed strength in a horizontal orientation, where *pulling* generated significantly higher forces than *pushing*. No significant differences in maximum strength were found between pushing and pulling with 2 hands in a horizontal orientation, or pushing and pulling with 1 and 2 hands in a vertical orientation. Pulling with 1 hand on the cylindrical bar generated higher forces than pulling on the convex knob. Correlation coefficients for all measurements can be found in Appendix 6e.

## Results

### Convex knob (1 handed pull)

Age (years)	Sex	No.	Mean (N)	SD (N)	Range (N)
2-5	m	8	59.65	22.32	27.30 - 72.80
	f	8	76.43	34.84	49.50 - 115.80
6-10	m	5	141.02	27.95	104.20 - 168.30
	f	10	141.11	60.99	64.40 - 268.60
11-15	m	12	232.83	91.79	67.00 - 372.60
	f	5	177.74	55.27	93.00 - 233.20
16-20	m	8	321.10	103.44	213.60 - 523.60
	f	8	244.07	84.35	184.00 - 405.40
21-30	m	7	311.92	103.99	210.00 - 436.60
	f	7	221.61	93.87	141.80 - 400.60
31-50	m	7	285.94	70.38	198.10 - 374.40
	f	17	220.24	60.51	81.60 - 344.20
51-60	m	5	265.10	90.48	130.50 - 358.90
	f	6	163.73	47.51	111.20 - 216.70
61-70	m	4	267.85	104.97	159.80 - 404.30
	f	7	162.35	29.99	138.50 - 209.90
71-80	m	7	309.05	41.60	246.90 - 353.30
	f	9	178.95	18.90	145.70 - 213.50
81-90	f	4	138.57	37.63	109.00 - 193.70

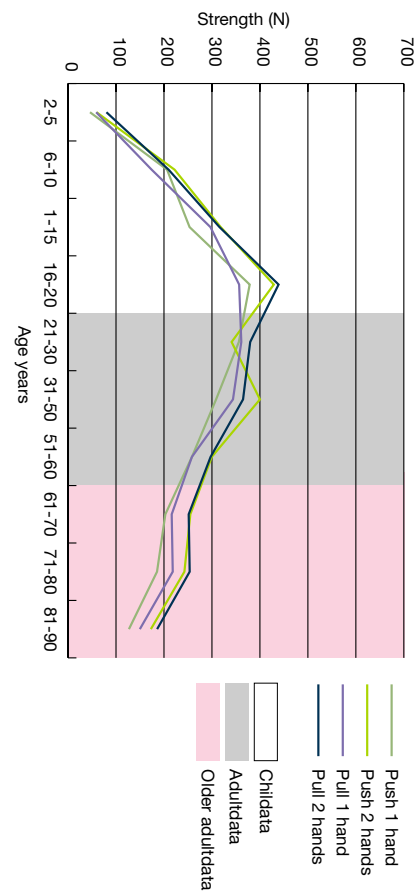
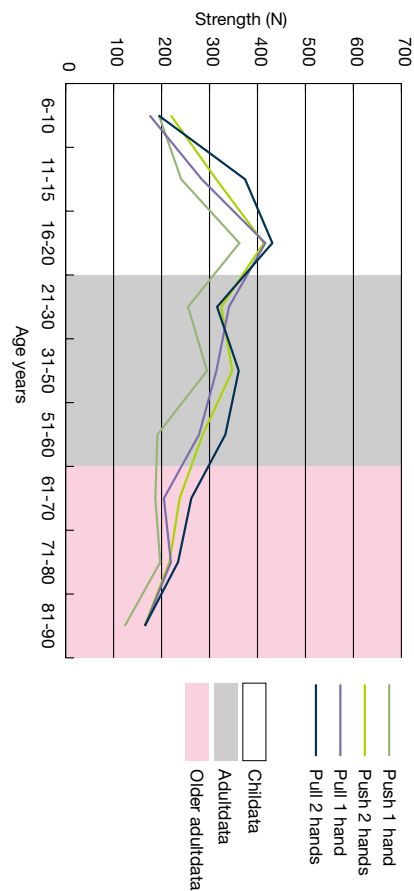
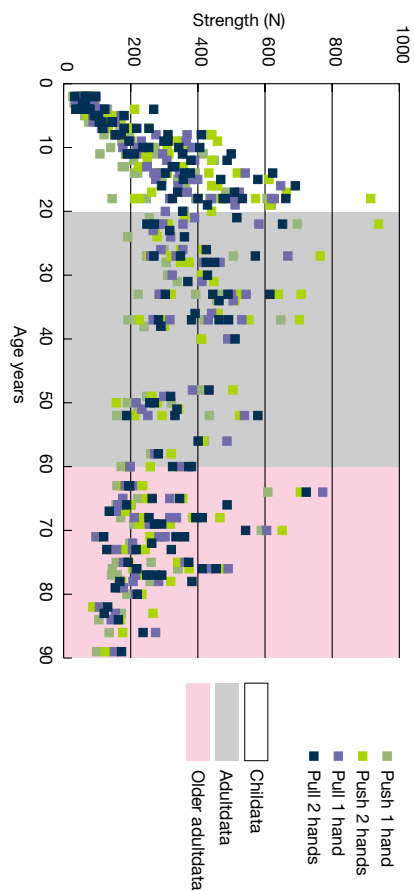
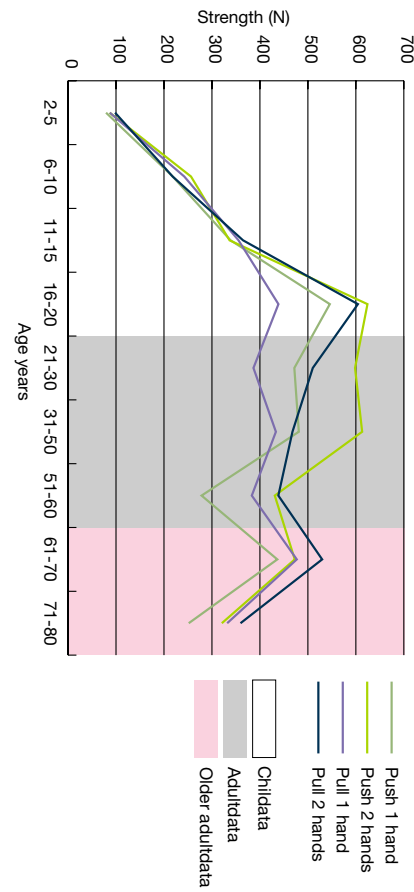
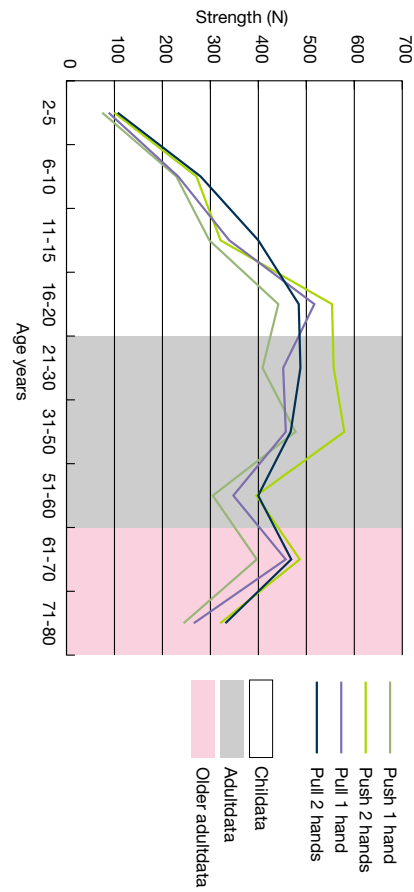
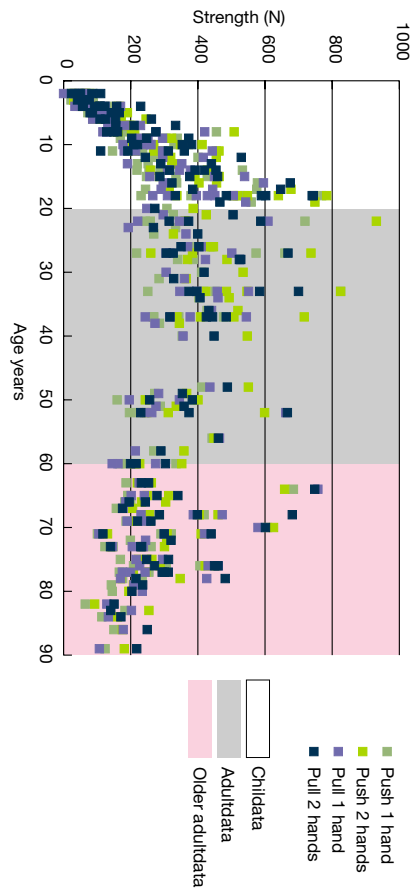


Cylindrical bar - 1 handed strength

Age (years)	Sex	No.	Orientation	Push (N)			Pull (N)		
				Mean	SD	Range	Mean	Sd	Range
2-5	m	12	vertical	79.26	30.38	19.33 – 139.39	87.14	44.06	56.11 – 169.64
	f	9	horizontal	74.53	36.65	44.24 – 130.93	87.99	42.18	51.99 – 171.52
			vertical	45.83	20.06	22.15 – 76.95	58.68	33.45	31.66 – 123.65
horizontal	48.12	15.80	27.39 – 74.53	43.22	34.62	35.41 – 114.60			
6-10	m	8	vertical	218.26	110.19	125.29 – 455.26	242.40	89.05	131.94 – 420.34
	f	11	horizontal	229.14	111.01	120.46 – 429.07	232.97	102.61	111.21 – 381.13
			vertical	206.49	94.76	87.42 – 371.46	174.40	64.59	86.70 – 294.80
horizontal	194.59	88.84	74.53 – 375.49	175.09	75.65	88.21 – 365.30			
11-15	m	9	vertical	338.87	124.04	145.84 – 532.61	355.41	123.48	180.57 – 539.09
	f	6	horizontal	297.77	113.64	108.37 – 448.81	339.41	104.57	194.90 – 540.97
			vertical	260.42	30.95	219.97 – 287.66	296.87	45.43	214.50 – 352.10
horizontal	240.99	80.17	181.29 – 391.60	283.74	45.05	216.76 – 344.94			
16-20	m	6	vertical	545.77	126.22	379.51 – 768.27	438.62	82.52	309.50 – 542.48
	f	6	horizontal	441.58	172.67	144.63 – 618.83	516.72	92.88	398.09 – 627.68
			vertical	378.71	158.02	230.85 – 577.33	356.75	136.07	248.05 – 595.26
horizontal	362.32	74.82	246.56 – 483.06	416.38	138.03	303.09 – 646.53			
21-30	m	5	vertical	471.82	208.03	243.34 – 718.95	386.56	161.72	220.91 – 608.83
	f	9	horizontal	408.80	188.86	255.42 – 695.94	451.70	164.63	295.18 – 668.02
			vertical	356.10	108.11	217.55 – 573.30	361.23	91.51	192.64 – 525.52
horizontal	255.20	107.73	191.29 – 369.04	340.58	67.97	259.74 – 465.95			
31-50	m	6	vertical	481.11	173.02	353.33 – 825.11	433.34	73.73	346.45 – 544.37
	f	11	horizontal	477.30	213.75	408.48 – 647.03	457.22	99.37	290.65 – 543.61
			vertical	310.98	89.59	159.54 – 451.23	343.91	99.02	195.65 – 550.78
horizontal	294.87	96.29	189.75 – 460.09	314.47	136.42	215.91 – 500.26			
51-60	m	3	vertical	278.39	13.67	268.69 – 288.06	383.52	242.78	213.75 – 661.61
	f	6	horizontal	304.98	113.24	221.58 – 433.90	347.83	166.40	233.35 – 538.71
			vertical	258.31	107.95	168.00 – 442.37	258.29	114.18	144.76 – 464.44
horizontal	191.57	134.58	158.33 – 419.80	278.28	118.58	187.73 – 486.69			
61-70	m	5	vertical	436.32	210.21	186.13 – 684.50	476.89	212.16	189.24 – 757.37
	f	9	horizontal	396.68	189.82	209.09 – 608.35	456.98	221.50	255.97 – 771.69
			vertical	202.87	30.97	157.12 – 251.80	216.18	28.56	176.80 – 251.07
horizontal	186.98	35.80	138.59 – 249.79	204.95	54.38	157.20 – 316.29			
71-80	m	7	vertical	244.09	60.21	145.03 – 320.69	331.85	99.73	234.48 – 460.67
	f	12	horizontal	251.63	55.33	188.95 – 341.24	265.34	151.73	205.81 – 490.08
			vertical	197.28	84.90	100.72 – 406.11	218.27	82.62	105.17 – 430.52
horizontal	185.59	68.64	104.75 – 340.03	219.53	82.72	96.50 – 436.17			
81-90	f	5	vertical	126.98	43.98	64.46 – 182.91	149.73	38.93	106.68 – 202.06
			horizontal	123.36	30.60	98.30 – 171.62	165.57	63.52	106.68 – 274.07

Cylindrical bar - 2 handed strength

Age (years)	Sex	No.	Orientation	push (N)			pull (N)		
				Mean	SD	Range	Mean	SD	Range
2-5	m	12	vertical	86.88	55.23	63.17 – 190.16	98.11	60.17	45.91 – 229.58
	f	9	horizontal	99.64	44.92	63.65 – 211.51	106.65	59.89	56.54 – 268.41
			vertical	59.49	24.20	29.00 – 101.93	80.08	43.69	23.75 – 158.33
horizontal	72.07	17.74	53.58 – 101.93	61.78	27.02	33.55 – 122.14			
6-10	m	8	vertical	256.63	116.50	171.62 – 508.04	218.08	119.80	149.40 – 381.51
	f	11	horizontal	270.89	121.87	145.84 – 458.48	279.72	95.68	144.76 – 410.16
			vertical	222.13	87.88	104.34 – 412.55	193.87	89.09	108.57 – 372.84
horizontal	219.53	91.82	132.55 – 367.03	174.40	81.24	106.31 – 343.05			
11-15	m	9	vertical	336.81	153.77	210.62 – 463.31	364.88	124.20	110.45 – 529.29
	f	6	horizontal	321.19	174.85	188.05 – 611.58	399.90	132.94	210.73 – 622.78
			vertical	318.41	65.54	258.65 – 441.16	315.85	91.59	191.50 – 440.32
horizontal	313.98	108.75	234.07 – 517.30	374.22	113.52	189.62 – 499.13			
16-20	m	6	vertical	624.27	119.80	507.23 – 783.62	604.31	119.78	465.58 – 743.79
	f	6	horizontal	553.50	223.51	225.21 – 914.58	484.17	112.00	324.20 – 661.66
			vertical	429.07	131.36	314.65 – 677.25	438.94	175.81	271.80 – 675.18
horizontal	413.16	161.00	211.91 – 663.55	431.02	146.79	291.78 – 690.26			
21-30	m	5	vertical	598.38	234.16	363.80 – 931.57	510.29	120.82	372.46 – 668.40
	f	9	horizontal	556.91	277.83	311.02 – 938.15	487.67	146.26	270.30 – 652.19
			vertical	341.02	144.62	259.76 – 486.68	379.79	93.27	267.66 – 527.78
horizontal	324.59	52.36	255.83 – 416.58	315.87	137.59	248.38 – 450.12			
31-50	m	6	vertical	613.12	128.71	493.13 – 825.11	467.90	68.40	396.59 – 583.95
	f	11	horizontal	579.15	121.61	410.94 – 707.46	467.40	28.69	433.15 – 510.81
			vertical	400.06	82.09	243.34 – 519.32	364.85	166.04	256.33 – 699.69
horizontal	347.54	128.07	157.12 – 551.95	360.98	108.68	256.72 – 614.49			
51-60	m	3	vertical	430.95	145.71	335.60 – 598.68	438.43	200.51	289.90 – 666.51
	f	6	horizontal	395.76	111.71	320.69 – 524.15	399.60	157.53	282.36 – 578.67
			vertical	299.74	90.11	211.91 – 448.00	297.25	103.34	199.42 – 461.05
horizontal	285.84	83.35	193.38 – 414.97	333.13	77.02	187.73 – 400.73			
61-70	m	5	vertical	472.66	179.39	215.54 – 658.31	529.81	217.22	220.16 – 747.94
	f	9	horizontal	486.36	196.15	225.21 – 705.05	468.59	171.48	271.05 – 722.68
			vertical	255.02	35.53	205.47 – 313.04	247.30	50.59	175.67 – 340.42
horizontal	237.88	61.27	177.67 – 354.94	262.04	105.35	136.09 – 487.06			
71-80	m	7	vertical	320.64	80.27	194.59 – 421.82	359.59	102.44	203.57 – 481.41
	f	12	horizontal	320.52	83.91	233.27 – 477.82	331.31	79.67	219.78 – 454.27
			vertical	242.60	87.66	130.93 – 453.24	253.65	85.39	117.24 – 449.74
horizontal	216.45	65.55	101.52 – 373.87	234.39	92.67	119.50 – 412.42			
81-90	f	5	vertical	172.67	57.61	92.66 – 254.22	185.78	46.28	140.61 – 249.18
			horizontal	164.78	67.20	87.42 – 266.30	165.04	45.44	121.01 – 236.74



## APPENDIX 1 – FINGER PUSH STRENGTH

### 1a - Anthropometric characteristics of subjects

Age (years)	Sex	No.	Stature (mm)		Weight (kg)		Elbow height (mm)		Hand length (mm)		Hand breadth (mm)	
			Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
2-5	m	9	1034.55	105.50	17.80	3.04	623.33	76.80	110.77	13.00	55.75	5.17
	f	8	1128.75	108.90	19.10	4.62	673.75	76.30	118.50	15.00	54.25	6.62
6-10	m	5	1366.00	86.40	30.80	5.39	824.00	53.60	145.40	12.10	65.8	6.53
	f	10	1379.50	127.90	30.74	8.49	864.00	86.30	143.70	13.80	64.00	5.05
11-15	m	12	1644.58	138.60	52.39	16.30	1015.83	85.70	169.75	15.6	77.66	7.19
	f	5	1546.00	80.40	47.16	12.70	964.00	63.40	157.80	8.28	68.40	5.31
16-20	m	6	1822.50	69.20	75.90	15.20	1131.66	36.50	190.50	14.10	87.33	6.37
	f	8	1751.25	78.10	64.80	11.90	1103.75	48.30	179.87	14.40	77.75	6.20
21-30	m	10	1837.00	69.60	80.26	28.40	1147.00	49.00	187.70	9.06	84.00	5.67
	f	7	1677.85	66.20	65.48	12.90	1058.57	35.30	172.57	7.29	81.00	7.89
31-50	m	7	1814.28	105.80	84.37	14.00	1140.00	64.80	190.71	7.38	88.14	5.87
	f	16	1670.93	58.80	72.23	15.70	1054.37	47.10	174.18	8.00	75.73	3.80
51-60	m	5	1791.00	49.50	91.00	16.20	1120.00	33.90	192.80	7.39	88.00	0.70
	f	6	1654.16	61.10	68.03	13.40	1035.00	44.10	176.66	8.47	77.50	3.39
61-70	m	3	1835.00	52.60	86.66	15.00	1146.66	46.10	195.66	19.00	90.00	4.35
	f	8	1631.87	68.20	66.85	9.39	1013.75	51.80	176.87	10.90	77.87	2.85
71-80	m	8	1767.50	42.00	82.32	4.72	1082.5	24.90	189.75	8.41	88.25	4.20
	f	11	1643.18	53.20	68.98	8.29	1023.63	25.00	175.45	8.95	76.09	2.30
81-90	f	4	1557.5	60.70	60.40	12.50	98.00	52.20	171.50	12.10	78.00	4.00

### 1b – Differences between males and females (t-test)

#### Index finger

Age (years)	Sex	No.	Forwards			Downwards		
			T	DF	Sig	T	DF	Sig
2-5	m	9	-1.253	15	0.229	-0.729	15	0.477
	f	8						
6-10	m	5	0.846	13	0.413	0.142	13	0.89
	f	10						
11-15	m	12	-0.29	15	0.977	0.314	15	0.758
	f	5						
16-20	m	6	2.322	12	0.039*	2.328	12	0.038*
	f	8						
21-30	m	10	3.341	15	0.004*	3.132	15	0.007*
	f	7						
31-50	m	7	4.142	21	0.000*	4.185	21	0.000*
	f	16						
51-60	m	5	2.632	9	0.027*	2.96	9	0.016*
	f	6						
61-70	m	3	4.254	9	0.002*	3.401	9	0.007*
	f	8						
71-80	m	8	3.686	17	0.002*	4.071	17	0.001*
	f	11						

Key:

$t$  =  $t$  value from  $t$ -test

$df$  = degrees of freedom

$sig$  = level of statistical significance

(\* denotes significant difference at 0.05 level)

Thumb

Age (years)	Sex	No.	Forwards			Downwards		
			T	DF	Sig	T	DF	Sig
2-5	m f	9 8	-0.626	15.000	0.541	-0.905	15.000	0.380
6-10	m f	5 10	1.310	13.000	0.213	0.754	13.000	0.464
11-15	m f	12 5	1.145	15.000	0.270	0.999	15.000	0.334
16-20	m f	6 8	1.824	12.000	0.093	3.420	12.000	0.005*
21-30	m f	10 7	2.835	15.000	0.013*	2.220	15.000	0.042*
31-50	m f	7 16	3.706	21.000	0.001*	5.396	21.000	0.000*
51-60	m f	5 6	2.517	9.000	0.033*	1.598	9.000	0.145
61-70	m f	3 8	2.469	9.000	0.036*	3.401	9.000	0.008*
71-80	m f	8 11	4.880	17.000	0.000*	3.582	17.000	0.002*

Key:  
*t* = *t* value from *t*-test  
*df* = degrees of freedom  
*sig* = level of statistical significance  
 (\* denotes significant difference at 0.05 level)

Thumb

Age (years)	2-5	6-10	11-15	16-20	21-30	31-50	51-60	61-70	71-80	81-90
2-5		*	*	*	*	*	*	*	*	*
6-10			*	*	*	*	*	*	*	X
11-15				*	* not thf	* not thf	* not thf	X	X	X
16-20					X	X	X	*	* not id	* notid
21-30						X	X	* not id	*	*
31-50							X	* not id	*	*
51-60								X	X	* not if, thf
61-70									X	X
71-80										X
81-90										

\* denotes significant difference at 0.05 level

Key:  
*if* = pushing forwards with the index finger  
*id* = pushing downwards with the index finger  
*thf* = pushing forwards with the thumb  
*thd* = pushing downwards with the thumb

1d – Differences between finger type and direction of force (Paired samples test)

Action	t	df	sig
id – if	-0.268	147	0.789
if – thf	-15.173	147	0.000*
if – thd	-16.504	147	0.000*
id – thf	-14.790	147	0.000*
id – thd	-17.214	147	0.000*
thd – thf	0.535	147	0.594

Key:  
*if* = pushing forwards with the index finger  
*id* = pushing downwards with the index finger  
*thf* = pushing forwards with the thumb  
*thd* = pushing downwards with the thumb  
*t* = value from *t*-test  
*df* = degrees of freedom  
*sig* = level of statistical significance (\* denotes significant difference at 0.05 level)

1e – Correlation between measurements (Pearson Correlation)

	if	id	thf	thd
if	1.000	0.932	0.861	0.886
id	0.932	1.000	0.837	0.898
thf	0.861	0.837	1.000	0.920
thd	0.886	0.898	0.920	1.000

Key:  
*if* = pushing forwards with the index finger  
*id* = pushing downwards with the index finger  
*thf* = pushing forwards with the thumb  
*thd* = pushing downwards with the thumb

**APPENDIX 2 – PINCH-PULL STRENGTH**

**2a - Anthropometric characteristics of subjects**

Age (years)	Sex	No.	Stature (mm)		Weight (kg)		Elbow height (mm)		Hand length (mm)		Hand breadth (mm)	
			Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
2-5	m	8	1055.00	111.8	18.75	3.44	618.75	69.7	112.87	10.9	56.42	5.85
	f	5	1050.00	126.4	16.36	2.95	624.00	74.3	113.00	17.7	52.80	5.55
6-10	m	7	1369.28	98.1	32.85	8.31	841.42	83.3	143.28	11.0	62.14	10.9
	f	9	1345.55	139.1	27.88	9.25	834.44	96.1	139.66	15.4	62.22	5.73
11-15	m	10	1623.00	119.5	49.11	13.4	1004.00	78.9	167.70	14.0	76.10	6.80
	f	7	1555.00	104.5	45.71	12.5	991.42	56.1	161.57	11.6	69.00	4.76
16-20	m	11	1808.18	57.6	73.07	12.5	1114.54	43.2	188.18	10.4	85.00	4.35
	f	7	1742.85	64.7	61.54	11.0	1094.28	43.5	176.71	12.9	75.14	6.30
21-30	m	8	1840.62	64.3	82.00	31.5	1145.00	33.8	187.50	7.80	84.37	5.90
	f	9	1702.22	69.5	67.93	16.5	1082.22	41.4	170.77	7.52	78.50	8.41
31-50	m	5	1795.00	109.2	81.28	5.55	1134.00	69.8	190.40	7.30	88.60	6.54
	f	13	1655.76	70.1	69.49	16.6	1037.69	46.7	171.76	9.91	74.08	3.23
51-60	m	5	1791.00	49.2	91.00	16.2	1134.00	32.0	192.80	7.39	88.00	0.70
	f	6	1663.33	70.8	67.86	13.6	1040.00	54.4	184.50	13.3	78.83	4.62
61-70	m	4	1827.50	43.4	84.15	15.2	1130.00	33.6	193.00	16.4	90.25	3.59
	f	9	1624.44	65.9	64.73	10.8	1003.33	42.4	175.44	11.1	77.44	2.96
71-80	m	8	1770.00	44.1	82.32	4.72	1090.00	28.2	189.75	8.41	88.25	4.20
	f	11	1653.18	51.3	68.58	8.86	1035.45	34.4	176.81	7.76	76.81	2.13
81-90	f	4	1555.00	58.0	60.40	12.5	97.00	47.6	171.50	12.1	78.00	4.00

**2b – Differences between males and females (t-test)**

**Chuck pinch**

Age (years)	Sex	No.	T	2mm DF	Sig	T	20mm DF	Sig	T	40mm DF	Sig
2-5	m	8	1.028	11	0.326	1.160	11	0.273	2.579	11	0.026*
	f	5									
6-10	m	7	1.560	14	0.141	1.035	14	0.318	1.383	14	0.188
	f	9									
11-15	m	10	0.955	15	0.355	1.448	15	0.168	1.516	15	0.150
	f	7									
16-20	m	11	1.454	16	0.165	1.143	16	0.270	1.509	16	0.151
	f	7									
21-30	m	8	1.401	15	0.182	2.544	15	0.022*	3.353	15	0.004*
	f	9									
31-50	m	5	2.662	16	0.017*	3.463	16	0.003*	2.886	16	0.011*
	f	13									
51-60	m	5	1.892	9	0.091	2.228	9	0.053	1.533	9	0.160
	f	6									
61-70	m	4	4.935	11	0.000*	4.885	11	0.000*	6.500	11	0.000*
	f	9									
71-80	m	8	4.863	17	0.000*	5.024	17	0.000*	5.027	17	0.000*
	f	11									

Key:  
*t* = value from t-test  
*df* = degrees of freedom  
*sig* = level of statistical significance (\* denotes significant difference at 0.05 level)

**Pulp pinch**

Age (years)	Sex	No.	T	2mm DF	Sig	T	20mm DF	Sig	T	40mm DF	Sig
2-5	m	8	0.463	11	0.652	1.230	11	0.245	2.058	11	0.064
	f	5									
6-10	m	7	0.460	14	0.653	1.571	14	0.138	1.615	14	0.129
	f	9									
11-15	m	10	0.910	15	0.377	1.304	15	0.212	1.255	15	0.229
	f	7									
16-20	m	11	1.001	16	0.332	0.977	16	0.343	0.660	16	0.519
	f	7									
21-30	m	8	1.157	15	0.265	3.038	15	0.008*	3.399	15	0.004*
	f	9									
31-50	m	5	0.970	16	0.346	1.514	16	0.149	3.021	16	0.008*
	f	13									
51-60	m	5	0.587	9	0.571	0.737	9	0.480	0.805	9	0.442
	f	6									
61-70	m	4	3.535	11	0.005*	5.057	11	0.000*	4.191	11	0.002*
	f	9									
71-80	m	8	3.601	17	0.002*	2.931	17	0.009*	3.053	17	0.007*
	f	11									

Key:  
*t* = value from t-test  
*df* = degrees of freedom  
*sig* = level of statistical significance (\* denotes significant difference at 0.05 level)

**2c – Differences between age groups (t-test)**

Age (years)	2-5	6-10	11-15	16-20	21-30	31-50	51-60	61-70	71-80	81-90
2-5		*	*	*	*	*	*	*	*	*
6-10			*	*	*	*	*	*	*	X
11-15				*	*	*	X	X	X	X
16-20					X	X	*	*	*	*
21-30						X	X	*	*	*
31-50							X	*	*	*
51-60								X	X	X
61-70									X	X
71-80										X

\* denotes significant difference at 0.05 level  
 Key:  
*c2* = chuck pinch at 2mm      *p2* = pulp pinch at 2mm  
*c20* = chuck pinch at 20mm      *p20* = pulp pinch at 20mm  
*c40* = chuck pinch at 40mm      *p40* = pulp pinch at 40mm

**APPENDIX 3 – HAND GRIP STRENGTH**

**2d – Differences between type of pinch and pinch distance (Paired samples test)**

Action	t	df	sig	Key:
c2 – c20	-10.32	144	0.000*	c2 = chuck pinch at 2mm
c2 – c40	-14.65	145	0.000*	c20 = chuck pinch at 20mm
c2 – p2	6.95	145	0.000*	c40 = chuck pinch at 40mm
c2 – p20	-0.09	145	0.922	p2 = pulp pinch at 2mm
c2 – p40	-3.78	145	0.000*	p20 = pulp pinch at 20mm
c20 – c40	-9.41	144	0.000*	p40 = pulp pinch at 40mm
c20 – p2	12.93	144	0.000*	t = value from t-test
c20 – p20	9.35	144	0.000*	df = degrees of freedom
c20 – p40	4.37	144	0.000*	sig = level of statistical significance (* denotes significant difference at 0.05 level)
c40 – p2	15.87	145	0.000*	
c40 – p20	15.58	145	0.000*	
c40 – p40	11.72	145	0.000*	
p2 – p20	-6.77	145	0.000*	
p2 – p40	-8.73	145	0.000*	
p20 – p40	-4.59	145	0.000*	

**2e – Correlation between measurements (Pearson Correlation)**

	c2	c20	c40	p2	p20	p40	Key:
c2	1.000	0.918	0.886	0.891	0.893	0.865	c2 = chuck pinch at 2mm
c20	0.918	1.000	0.933	0.845	0.900	0.869	c20 = chuck pinch at 20mm
c40	0.886	0.933	1.000	0.802	0.901	0.890	c40 = chuck pinch at 40mm
p2	0.891	0.845	0.802	1.000	0.886	0.839	p2 = pulp pinch at 2mm
p20	0.893	0.900	0.901	0.886	1.000	0.915	p20 = pulp pinch at 20mm
p40	0.865	0.869	0.890	0.839	0.915	1.000	p40 = pulp pinch at 40mm

**3a - Anthropometric characteristics of subjects**

Age (years)	Sex	No.	Stature (mm)		Weight (kg)		Elbow height (mm)		Hand length (mm)		Hand breadth (mm)	
			Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
2-5	m	8	1041.25	119.60	18.00	3.45	617.50	76.20	103.56	39.20	57.71	7.34
	f	9	1018.88	71.31	16.36	2.32	620.00	78.10	106.00	8.15	53.88	4.37
6-10	m	7	1391.42	78.60	31.48	10.80	857.14	53.40	143.85	10.30	63.14	10.60
	f	11	1375.90	128.60	29.34	9.13	861.81	88.50	141.63	14.50	63.09	5.55
11-15	m	10	1631.00	116.30	50.23	12.70	1026.00	57.50	167.60	12.80	76.9	6.47
	f	10	1586.50	90.70	50.54	12.70	1006.00	55.60	164.70	10.30	72.00	5.61
16-20	m	9	1829.44	61.40	78.11	11.50	1124.44	58.80	192.66	13.10	86.77	5.28
	f	7	1747.85	76.30	67.45	12.70	1110.00	56.20	182.85	12.60	79.14	6.09
21-30	m	7	1815.71	82.20	84.62	33.40	1147.14	50.80	189.28	7.84	86.71	5.79
	f	7	1685.00	72.80	69.51	9.63	1051.42	40.10	170.00	7.89	79.16	9.21
31-50	m	6	1783.33	98.50	79.56	6.50	1111.66	79.80	188.83	7.57	88.16	5.94
	f	11	1663.18	77.00	72.16	16.50	1044.54	53.30	173.00	9.33	74.70	3.19
51-60	m	4	1780.00	53.50	93.65	17.50	1137.50	48.50	193.00	8.52	88.00	0.81
	f	6	1650.00	48.50	68.46	13.10	1021.66	37.10	178.33	6.47	76.16	4.16
61-70	m	6	1797.50	51.70	83.45	11.90	1118.33	44.00	189.00	14.50	88.16	4.66
	f	9	1622.77	66.10	64.73	10.80	1000.00	47.90	175.44	11.10	76.77	3.86
71-80	m	8	1763.12	48.40	82.32	4.72	1082.50	24.90	189.75	8.41	88.28	4.20
	f	12	1643.75	53.40	67.85	8.82	1025.83	29.30	175.58	8.55	76.41	2.46
81-90	f	6	1581.66	64.30	57.86	10.40	986.66	40.80	168.83	13.30	76.83	4.21

**3b – Differences between males and females (t-test)**

**1 handed strength**

Age (years)	Sex	No.	30mm			50mm			70mm		
			T	DF	Sig	T	DF	Sig	T	DF	Sig
2-5	m	8	0.872	15	0.397	1.272	15	0.223	2.468	15	0.026*
	f	9									
6-10	m	7	1.754	16	0.099	1.287	16	0.216	1.030	16	0.318
	f	11									
11-15	m	10	1.972	18	0.064	1.583	18	0.131	1.617	18	0.123
	f	10									
16-20	m	9	4.528	14	0.000*	3.005	14	0.009*	4.435	14	0.001*
	f	7									
21-30	m	7	3.673	12	0.003*	5.373	12	0.000*	3.928	12	0.002*
	f	7									
31-50	m	6	6.089	15	0.000*	7.742	15	0.000*	9.837	15	0.000*
	f	11									
51-60	m	4	3.052	8	0.016*	4.632	8	0.002*	4.560	8	0.002*
	f	6									
61-70	m	6	4.677	13	0.000*	6.464	13	0.000*	5.943	13	0.000*
	f	9									
71-80	m	8	5.486	18	0.000*	5.957	18	0.000*	7.654	18	0.000*
	f	12									

Key:  
t = value from t-test  
df = degrees of freedom  
sig = level of statistical significance (\* denotes significant difference at 0.05 level)



## 2 handed strength

Age (years)	Sex	No.	T	30mm DF	Sig	T	50mm DF	Sig	T	70mm DF	Sig
2-5	m f	8 9	0.860	15	0.403	1.161	15	0.264	2.077	15	0.055
6-10	m f	7 11	1.940	16	0.070	1.251	16	0.229	1.562	16	0.138
11-15	m f	10 10	1.419	18	0.173	1.984	18	0.063	1.368	18	0.188
16-20	m f	9 7	5.856	14	0.000*	5.554	14	0.000*	7.674	14	0.000*
21-30	m f	7 7	2.636	12	0.022*	2.851	12	0.015*	3.406	12	0.005*
31-50	m f	6 11	2.258	15	0.039*	1.927	15	0.073	1.634	15	0.123
51-60	m f	4 6	2.752	8	0.025*	3.154	8	0.014*	3.840	8	0.005*
61-70	m f	6 9	3.987	13	0.002*	5.458	13	0.000*	7.685	13	0.000*
71-80	m f	8 12	4.819	18	0.000*	6.665	18	0.000*	6.441	18	0.000*

Key:

t = value from t-test

df = degrees of freedom

sig = level of statistical significance (\* denotes significant difference at 0.05 level)

## 3c – Differences between age groups (t-test)

age (years)	2-5	6-10	11-15	16-20	21-30	31-50	51-60	61-70	71-80	81-90
2-5		*	*	*	*	*	*	*	*	*
6-10			*	*	*	*	*	not s2	not s2	not s2, m2
11-15				*	*	not s2, m2, l2	not s2, m2, l2	X	X not s2	*
16-20					X	X	X	*	*	*
21-30						X	X not s2	X not s1, s2	*	*
31-50							X not s1	X not s1, s2	*	*
51-60								X	* not s1, l1	*
61-70									X	*
71-80										*

\* denotes significant difference at 0.05 level

Key:

s1 = 1 handed strength on small (30mm) handle

s2 = 2 handed strength on small (30mm) handle

m1 = 1 handed strength on medium (50mm) handle

m2 = 2 handed strength on medium (50mm) handle

l1 = 1 handed strength of large (70mm) handle

l2 = 2 handed strength on large (70mm) handle

## 3d – Differences between handle size and number of hands used (Paired samples test)

Action	t	df	sig
s1 - m1	11.133	152	0.000*
s1 - l1	9.276	152	0.000*
s1 - s2	-12.126	152	0.000*
s1 - m2	17.448	152	0.000*
s1 - l2	19.595	152	0.000*
m1 - l1	-1.923	152	0.000*
m1 - s2	-4.247	152	0.000*
m1 - m2	-15.037	152	0.000*
m1 - l2	4.561	152	0.000*
l1 - s2	9.276	152	0.000*
l1 - m2	-14.650	152	0.000*
l1 - l2	-18.41	152	0.000*
s2 - m2	10.709	152	0.000*
s2 - l2	13.258	152	0.000*
m2 - l1	4.561	152	0.000*

Key:

s1 = 1 handed strength on small (30mm) handle

s2 = 2 handed strength on small (30mm) handle

m1 = 1 handed strength on medium (50mm) handle

m2 = 2 handed strength on medium (50mm) handle

l1 = 1 handed strength of large (70mm) handle

l2 = 2 handed strength on large (70mm) handle

t = value from t-test

df = degrees of freedom

sig = level of statistical significance (\* denotes significant difference at 0.05 level)

## 3e – Correlation between measurements (Pearson Correlation)

	s1	m1	l1	s2	m2	l2
s1	1.000	0.925	0.906	0.865	0.829	0.865
m1	0.925	1.000	0.957	0.831	0.891	0.912
l1	0.906	0.957	1.000	0.818	0.869	0.916
s2	0.865	0.831	0.818	1.000	0.877	0.881
m2	0.829	0.891	0.869	0.877	1.000	0.937
l2	0.865	0.912	0.916	0.881	0.937	1.000

Key:

s1 = 1 handed strength on small (30mm) handle

s2 = 2 handed strength on small (30mm) handle

m1 = 1 handed strength on medium (50mm) handle

m2 = 2 handed strength on medium (50mm) handle

l1 = 1 handed strength of large (70mm) handle

l2 = 2 handed strength on large (70mm) handle

**APPENDIX 4 – WRIST-TWISTING STRENGTH**

**4a - Anthropometric characteristics of subjects**

**Session 1 – Vertical wrist-twisting strength**

Age (years)	Sex	No.	Stature (mm)		Weight (kg)		Elbow height (mm)		Hand length (mm)		Hand breadth (mm)	
			Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
2-5	m	12	1060.83	113.30	18.43	3.16	625.00	74.80	113.75	13.00	57.72	6.19
	f	7	1038.57	113.60	15.97	2.98	612.85	63.90	111.42	14.80	53.14	4.18
6-10	m	7	1423.57	58.20	36.54	5.37	877.14	41.90	149.14	6.51	68.00	3.26
	f	11	1348.18	125.60	28.72	8.50	831.81	90.50	139.72	12.40	62.45	5.20
11-15	m	11	1664.54	148.00	51.22	12.50	1039.09	87.30	170.09	14.70	77.45	6.40
	f	6	1566.66	108.30	47.93	13.50	990.00	83.10	162.16	12.10	69.66	5.39
16-20	m	6	1807.50	50.90	77.83	14.30	1136.66	35.50	189.00	8.57	87.33	3.44
	f	8	1758.75	71.40	67.52	12.10	1116.25	47.40	181.37	12.70	77.50	6.82
21-30	m	7	1821.42	76.90	84.65	33.40	1128.57	49.10	188.28	8.03	86.14	6.59
	f	7	1692.14	68.00	69.51	9.63	1071.42	19.10	170.00	7.89	79.16	9.21
31-50	m	5	1796.00	108.90	80.80	4.97	1108.00	62.60	190.80	6.83	88.60	6.54
	f	13	1653.07	73.40	69.49	16.60	1043.07	48.10	171.76	9.91	74.08	3.23
51-60	m	4	1777.50	51.20	93.65	17.50	1125	49.30	193.00	8.52	88.00	0.81
	f	6	1685.00	93.00	71.86	13.50	1046.66	61.20	181.50	8.19	79.16	5.38
61-70	m	4	1813.75	57.90	86.52	13.00	1115.00	53.20	193.25	16.30	89.25	3.86
	f	10	1648.00	86.40	64.82	9.83	1014.00	57.50	176.40	10.90	78.80	5.11
71-80	m	8	1769.37	42.20	82.32	4.79	1086.25	23.20	189.75	8.41	88.25	4.20
	f	12	1641.25	57.30	67.85	8.82	1011.66	31.80	175.58	8.55	76.41	2.46
81-90	f	6	1585.00	68.30	57.86	10.40	996.66	57.50	168.83	13.30	76.83	4.21

**Session 2 – Horizontal wrist-twisting strength**

Age (years)	Sex	No.	Stature (mm)		Weight (kg)		Elbow height (mm)		Hand length (mm)		Hand breadth (mm)	
			Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
2-5	m	8	1041.25	119.60	18.00	3.45	617.5	76.20	115.37	11.90	57.71	7.34
	f	7	1052.85	98.60	16.31	3.46	628.57	74.20	107.85	9.99	51.57	6.07
6-10	m	7	1391.42	78.60	31.40	10.80	857.14	53.40	143.85	10.30	63.14	10.60
	f	11	1375.90	128.60	29.34	9.13	961.81	88.50	141.63	14.50	63.09	5.55
11-15	m	10	1571.00	216.80	50.18	12.70	1026.00	57.50	167.60	12.80	76.90	6.47
	f	10	1586.50	90.73	50.48	12.80	1006.00	55.60	164.70	10.30	72.00	5.61
16-20	m	9	1829.44	61.40	78.11	11.50	1128.88	46.70	192.66	13.10	86.77	5.28
	f	7	1747.85	76.30	67.45	12.70	1110.00	56.20	182.85	12.60	79.14	6.09
21-30	m	7	1815.71	82.20	84.62	33.40	1147.14	50.80	189.28	7.84	86.74	5.79
	f	7	1685.00	72.80	69.51	9.63	1051.42	40.10	170.00	7.89	79.16	9.21
31-50	m	6	1783.33	98.50	79.56	6.50	1116.66	74.40	188.83	7.57	88.16	5.94
	f	12	1662.91	73.40	71.28	16.00	1044.16	50.80	172.66	9.50	74.36	3.23
51-60	m	3	1796.66	51.30	89.40	18.80	1146.66	55.00	196.33	6.50	88.00	1.00
	f	6	1661.66	58.70	76.10	19.80	1038.33	49.50	180.00	6.72	79.00	5.51
61-70	m	6	1797.50	51.70	83.45	11.90	1116.66	44.10	189.00	14.50	87.83	4.75
	f	9	1622.77	66.10	64.73	10.80	998.88	47.80	175.44	11.10	76.77	3.86
71-80	m	8	1763.12	48.40	82.32	4.72	1082.50	24.90	189.75	8.41	85.75	8.64
	f	11	1637.72	51.60	68.98	8.29	1017.27	31.30	175.45	8.95	76.09	2.30
81-90	f	6	1581.66	64.30	57.86	10.40	986.66	40.80	168.83	13.30	76.83	4.21

**4b – Differences between males and females (t-test)**

**Session 1 – Vertical wrist-twisting strength**

Age (years)	Sex	No.	T	Door lever		T	Door knob		T	Circular knob	
				DF	Sig		DF	Sig		DF	Sig
2-5	m	12	0.656	17	0.521	0.883	17	0.390	0.468	17	0.646
	f	7									
6-10	m	7	1.421	16	0.175	1.649	16	0.119	2.557	16	0.021*
	f	11									
11-15	m	11	-0.048	15	0.962	1.927	15	0.073	1.200	15	0.249
	f	6									
16-20	m	6	2.521	12	0.027*	2.014	12	0.067	2.485	12	0.029*
	f	8									
21-30	m	7	4.081	12	0.002*	2.226	12	0.046*	0.803	12	0.438
	f	7									
31-50	m	5	2.487	16	0.024*	1.459	16	0.164	0.777	16	0.449
	f	13									
51-60	m	4	1.488	8	0.175	0.689	8	0.510	1.280	8	0.237
	f	6									
61-70	m	4	0.455	12	0.657	5.120	12	0.000*	1.205	12	0.252
	f	10									
71-80	m	8	3.130	18	0.006*	5.187	18	0.000*	3.069	18	0.007*
	f	12									

age (years)	sex	no.	ridged knob			butterfly nut			t	tap df	sig
			t	df	sig	t	df	sig			
2-5	m	12	-0.830	17	0.418	0.202	17	0.842	0.916	17	0.372
	f	7									
6-10	m	7	1.026	16	0.320	1.991	16	0.064	1.671	16	0.114
	f	11									
11-15	m	11	1.389	15	0.185	1.506	15	0.153	1.182	15	0.256
	f	6									
16-20	m	6	3.035	12	0.010*	4.119	12	0.001*	2.544	12	0.026*
	f	8									
21-30	m	7	3.470	12	0.005*	3.902	12	0.002*	1.883	12	0.084
	f	7									
31-50	m	5	3.485	16	0.003*	2.598	16	0.019*	3.305	16	0.004*
	f	13									
51-60	m	4	1.565	8	0.156	2.307	8	0.050*	1.597	8	0.149
	f	6									
61-70	m	4	4.053	12	0.002*	2.538	12	0.026*	6.288	12	0.000*
	f	10									
71-80	m	8	4.416	18	0.000*	3.665	18	0.002*	6.731	18	0.000*
	f	12									

Key:

t = value from t-test

df = degrees of freedom

sig = level of statistical significance (\* denotes significant difference at 0.05 level)

### Session 2 – Horizontal wrist-twisting strength

Age (years)	Sex	No.	Ridged knob			Butterfly nut			T	Tap DF	Sig
			T	DF	Sig	T	DF	Sig			
2-5	m f	8 7	1.843	13	0.088	1.719	13	0.109	1.354	13	0.199
6-10	m f	7 11	1.588	16	0.132	2.164	16	0.046	1.289	16	0.216
11-15	m f	10 10	1.275	18	0.219	1.541	18	0.141	1.829	18	0.084
16-20	m f	9 7	4.285	14	0.001*	5.132	14	0.000*	3.240	14	0.006*
21-30	m f	7 7	3.937	12	0.002*	3.025	12	0.011*	3.813	12	0.002*
31-50	m f	6 12	4.156	16	0.001*	5.052	16	0.000*	5.435	16	0.000*
51-60	m f	3 6	0.386	7	0.711	0.543	7	0.604	0.258	7	0.804
61-70	m f	6 9	5.256	13	0.000*	11.44	13	0.000*	6.400	13	0.000*
71-80	m f	8 11	5.462	17	0.000*	4.763	17	0.000*	3.684	17	0.002*

Key:  
*t* = value from *t*-test  
*df* = degrees of freedom  
*sig* = level of statistical significance (\* denotes significant difference at 0.05 level)

### 4c – Differences between age groups (t-test)

#### Session 1 – Vertical wrist-twisting strength

Age (years)	2-5	6-10	11-15	16-20	21-30	31-50	51-60	61-70	71-80	81-90
2-5		*	*	*	*	*	*	*	*	*
6-10			*	*	*	*	*	*	*	X
11-15				*	*	*	X	X	X	X
16-20				not 2, 3	not 2, 3	not 2, 3	X	not 6	*	*
21-30					X	X	X	*	*	*
31-50						X	X	not 1	not 1, 6	not 1
51-60						X	X	X	not 3	not 1
61-70								X	X	*
71-80									not 2, 3, 5	not 1
81-90									X	X

\* denotes significant difference at 0.05 level  
 Key:  
 1 = door lever    3 = circular knob    5 = butterfly nut  
 2 = door knob    4 = ridged knob    6 = tap

### Session 2 – Horizontal wrist-twisting strength

Age (years)	2-5	6-10	11-15	16-20	21-30	31-50	51-60	61-70	71-80	81-90
2-5		*	*	*	*	*	*	*	*	*
6-10			*	*	*	*	*	*	*	X
11-15				*	*	*	*	*	X	X
16-20					X	X	X	X	*	*
21-30						X	X	X	X	*
31-50							X	X	*	*
51-60								X	X	*
61-70									X	*
71-80										X
81-90										X

\* denotes significant difference at 0.05 level  
 Key:  
 1 = ridged knob  
 2 = butterfly nut  
 3 = tap

### 4d – Differences between handle type (Paired samples test)

#### Session 1 – Vertical wrist-twisting strength

Handle	t	df	sig
Door lever – door knob	-22.693	149	0.000*
Door lever – circular knob	-23.134	149	0.000*
Door lever – ridged knob	24.352	149	0.000*
Door lever – butterfly nut	24.166	149	0.000*
Door lever - tap	-19.550	149	0.000*
Door knob – circular knob	-14.442	149	0.000*
Door knob – ridged knob	16.961	149	0.000*
Door knob butterfly nut	16.959	149	0.000*
Door knob - tap	-6.215	149	0.000*
Circular knob – ridged knob	5.121	149	0.000*
Circular knob – butterfly nut	7.432	149	0.000*
Circular knob - tap	-15.633	149	0.000*
Ridged knob – butterfly nut	-3.990	149	0.000*
Ridged knob - tap	-19.303	149	0.000*
Butterfly nut - tap	-19.550	149	0.000*

**APPENDIX 5 – OPENING STRENGTH**

**5a - Anthropometric characteristics of subjects**

Age (years)	Sex	No.	Stature (mm)		Weight (kg)		Elbow height (mm)		Hand length (mm)		Hand breadth (mm)	
			Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
2-5	m	7	1044.28	121.6	17.65	3.27	617.14	82.2	111.42	13.80	55.16	5.56
	f	10	1061.00	106.7	16.70	3.23	627.00	71.9	112.30	14.20	51.60	4.97
6-10	m	8	1392.50	79.2	33.65	7.24	861.25	63.3	147.37	7.53	66.37	3.85
	f	10	1354.00	119.0	27.74	8.27	847.00	91.6	138.40	14.1	62.00	5.37
11-15	m	9	1653.33	110.3	51.34	13.0	1043.33	66.3	169.44	12.1	78.00	6.85
	f	7	1561.42	89.3	46.28	11.8	977.14	46.8	160.71	8.49	70.00	5.19
16-20	m	5	1801.00	65.2	76.04	11.6	1104.00	37.8	186.40	12.0	84.80	3.76
	f	5	1772.00	96.5	71.84	19.0	1136.00	73.0	182.20	18.0	82.40	4.27
21-30	m	8	1822.50	72.6	76.05	21.0	1131.20	44.5	189.62	9.11	84.12	4.01
	f	9	1706.11	54.4	70.44	8.92	1073.33	40.6	172.00	6.42	75.75	8.69
31-50	m	5	1792.00	106.6	81.28	5.55	1134.00	69.8	190.40	7.30	88.60	6.54
	f	13	1657.69	69.2	69.49	16.6	1036.92	47.6	171.76	9.91	74.16	3.35
51-60	m	4	1782.50	49.9	93.65	17.5	1125.00	41.2	193.50	9.32	88.00	0.81
	f	5	1647.00	55.4	69.84	14.1	1022.00	38.9	179.00	7.00	77.20	3.70
61-70	m	5	1810.00	50.9	83.34	13.3	1126.00	49.7	191.60	14.6	89.60	3.43
	f	9	1623.33	68.5	64.73	10.8	1011.11	47.5	175.44	11.1	77.44	2.96
71-80	m	8	1766.87	43.6	82.32	4.72	1082.50	30.1	189.75	8.41	88.25	4.20
	f	12	1649.16	49.4	67.85	8.82	1030.00	35.9	175.58	8.55	76.41	2.46
81-90	f	5	1586.00	77.0	59.08	11.2	994.00	62.2	172.60	10.7	78.00	3.46

**5b – Differences between males and females (t-test)**

**Smooth lids**

Age (years)	Sex	No.	45mm			65mm			85mm		
			T	DF	Sig	T	DF	Sig	T	DF	Sig
2-5	m	7	0.392	15	0.701	-0.181	15	0.859	0.082	15	0.936
	f	10									
6-10	m	8	0.814	16	0.428	1.819	15	0.089	0.720	15	0.483
	f	10									
11-15	m	9	0.771	14	0.454	-0.164	12	0.872	1.793	14	0.095
	f	7									
16-20	m	5	-0.877	8	0.406	0.693	8	0.508	0.853	8	0.418
	f	5									
21-30	m	8	0.417	15	0.683	2.141	15	0.049*	0.986	15	0.340
	f	9									
31-50	m	5	1.255	16	0.227	1.987	16	0.064	2.889	16	0.011*
	f	13									
51-60	m	4	1.159	7	0.285	0.915	7	0.391	1.765	7	0.121
	f	5									
61-70	m	5	4.334	12	0.001*	6.360	12	0.000*	3.461	12	0.005*
	f	9									
71-80	m	8	3.059	18	0.007*	4.062	17	0.001*	3.512	17	0.001*
	f	12									

Key:  
*t* = value from *t*-test  
*df* = degrees of freedom  
*sig* = level of statistical significance (\* denotes significant difference at 0.05 level)

**Session 2 – Horizontal wrist-twisting strength**

Handle	t	df	sig
Ridged knob – butterfly nut	-4.219	149	0.000*
Ridged knob - tap	-14.155	149	0.000*
Butterfly nut - tap	-15.081	149	0.000*

Key:  
*t* = value from *t*-test  
*df* = degrees of freedom  
*sig* = level of statistical significance (\* denotes significant difference at 0.05 level)

**4e – Differences between vertical and horizontal wrist-twisting strength (t-test)**

Handle	t	df	sig
Ridged knob	3.459	149	0.001*
Butterfly nut	3.697	149	0.000*
Tap	0.357	149	0.721

Key:  
*t* = value from *t*-test  
*df* = degrees of freedom  
*sig* = level of statistical significance (\* denotes significant difference at 0.05 level)

**4f – Correlation between measurements (Pearson Correlation)**

**Session 1 – Vertical wrist-twisting strength**

	Door lever	Door knob	Circular knob	Ridged knob	Butterfly nut	Tap
Door lever	1.000	0.661	0.547	0.762	0.678	0.722
Door knob	0.661	1.000	0.870	0.845	0.789	0.879
Circular knob	0.547	0.870	1.000	0.698	0.693	0.818
Ridged knob	0.762	0.845	0.698	1.000	0.882	0.872
Butterfly nut	0.678	0.789	0.693	0.882	1.000	0.844
Tap	0.722	0.879	0.818	0.872	0.844	1.000

**Session 2 – Horizontal wrist-twisting strength**

	Ridged knob	Butterfly nut	Tap
Ridged knob	1.000	0.931	0.867
Butterfly nut	0.931	1.000	0.839
Tap	0.867	0.839	1.000

### Knurled lids

Age (years)	Sex	No.	T	45mm DF	Sig	T	65mm DF	Sig	T	85mm DF	Sig
2-5	m f	7 10	0.713	15	0.487	0.796	15	0.438	0.380	15	0.710
6-10	m f	8 10	1.526	16	0.147	1.211	16	0.244	1.290	16	0.215
11-15	m f	9 7	0.875	14	0.397	1.340	14	0.202	1.723	14	0.107
16-20	m f	5 5	0.408	8	0.694	2.040	8	0.076	1.662	8	0.135
21-30	m f	8 9	1.016	15	0.326	2.348	15	0.033*	2.100	15	0.053
31-50	m f	5 13	1.938	15	0.072	3.174	16	0.006*	4.299	16	0.001*
51-60	m f	4 5	0.970	7	0.364	0.802	7	0.449	2.204	7	0.063
61-70	m f	5 9	6.186	12	0.000*	8.095	12	0.000*	3.274	11	0.007*
71-80	m f	8 12	3.822	18	0.001*	3.867	17	0.001*	4.058	17	0.001

Key:

t = value from t-test

df = degrees of freedom

sig = level of statistical significance (\* denotes significant difference at 0.05 level)

### 5c – Differences between age groups (t-test)

Age (years)	2-5	6-10	11-15	16-20	21-30	31-50	51-60	61-70	71-80	81-90
2-5		*	*	*	*	*	*	*	*	*
6-10			* not ss	*	*	*	*	*	* not ss	X
11-15				X not sk	*	*	* not ss, ms	*	*	X not ss, lk
16-20					X	X	X	X	X	*
21-30						X	X	X	* not ss	*
31-50							X	X	*	*
51-60								X	X not lk	*
61-70									X	* not ms
71-80										X not sk, mk
81-90										

\* denotes significant difference at 0.05 level

Key:

ss = small sized lid (45mm) with smooth texture

sk = small sized lid (45mm) with knurled texture

ms = medium sized lid (65mm) with smooth texture

mk = medium sized lid (65mm) with knurled texture

ls = large sized lid (85mm) with smooth texture

lk = large sized lid (85mm) with knurled texture

### 5d – Differences between lid size and texture (Paired samples test)

Jar size and lid type	t	df	sig
ss - sk	-6.824	143	0.000*
ms - mk	-5.400	139	0.000*
ls - lk	-5.407	141	0.000*
ss - ms	-14.536	140	0.000*
ss - ls	-16.901	143	0.000*
ss - mk	-14.111	143	0.000*
ss - lk	-16.452	142	0.000*
ms - ls	-10.964	139	0.000*
ms - sk	10.237	139	0.000*
ms - lk	-12.496	138	0.000*
ls - sk	15.114	142	0.000*
ls - mk	6.758	142	0.000*
sk - mk	-13.015	142	0.000*
sk - lk	-15.481	141	0.000*
mk - lk	-10.290	141	0.000*

Key: ss = small sized lid (45mm) with smooth texture

sk = small sized lid (45mm) with knurled texture

ms = medium sized lid (65mm) with smooth texture

mk = medium sized lid (65mm) with knurled texture

ls = large sized lid (85mm) with smooth texture

lk = large sized lid (85mm) with knurled texture

t = value from t-test

df = degrees of freedom

sig = level of statistical significance (\* denotes significant difference at 0.05 level)

### 5e – Correlation between measurements (Pearson Correlation)

	ss	ms	ls	sk	mk	lk
ss	1.000	0.889	0.851	0.904	0.827	0.812
ms	0.889	1.000	0.909	0.903	0.906	0.904
ls	0.851	0.909	1.000	0.872	0.894	0.948
sk	0.904	0.903	0.872	1.000	0.896	0.854
mk	0.827	0.906	0.894	0.896	1.000	0.911
lk	0.812	0.904	0.948	0.854	0.911	1.000

Key: ss = small sized lid (45mm) with smooth texture

sk = small sized lid (45mm) with knurled texture

ms = medium sized lid (65mm) with smooth texture

mk = medium sized lid (65mm) with knurled texture

ls = large sized lid (85mm) with smooth texture

lk = large sized lid (85mm) with knurled texture

## APPENDIX 6 – PUSH AND PULL STRENGTH

### 6a - Anthropometric characteristics of subjects

#### Session 1 - Pull on convex door knob

Age (years)	Sex	No.	Stature (mm)		Weight (kg)		Elbow height (mm)		Hand length (mm)		Hand breadth (mm)	
			Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
2-5	m	8	1021.37	104.60	17.27	2.78	615.00	77.60	109.50	13.30	55.57	5.56
	f	8	1133.75	108.80	19.00	4.66	677.50	78.30	118.50	15.00	54.25	6.62
6-10	m	5	1366.00	86.40	30.80	5.39	824.00	53.60	145.40	12.10	65.8	6.53
	f	10	1380.50	127.50	30.74	8.49	864.00	86.30	142.70	14.70	64.00	5.05
11-15	m	12	1645.16	139.20	52.39	16.30	1015.83	85.7	169.75	15.60	77.66	7.19
	f	5	1546.00	80.40	47.16	12.70	964.00	63.40	157.80	8.28	68.40	5.31
16-20	m	8	1823.75	61.50	73.60	13.90	1133.75	33.30	189.37	13.10	86.25	5.67
	f	8	1751.25	78.10	65.80	11.90	1103.75	48.30	179.87	14.40	77.75	6.20
21-30	m	7	1808.57	52.30	80.65	34.00	1131.42	50.80	186.57	7.50	84.00	6.55
	f	7	1700.71	53.00	67.17	12.30	1082.85	21.30	172.66	7.99	79.00	8.76
31-50	m	7	1813.57	105.30	84.37	14.00	1141.42	66.10	190.71	7.38	88.14	5.87
	f	17	1668.82	53.50	70.20	15.40	1054.11	43.50	173.06	6.86	75.06	3.56
51-60	m	5	1791.00	49.50	88.00	453.00	1120.00	33.90	192.8	7.39	88.00	0.70
	f	6	1654.16	61.10	68.03	13.40	1030.00	39.40	166.66	30.80	77.50	3.39
61-70	m	4	1813.75	60.46	87.65	12.40	1130.00	50.30	195.50	15.50	91.25	4.34
	f	7	1632.14	73.70	68.02	9.48	1012.85	55.80	177.42	11.70	78.14	2.96
71-80	m	7	1770.00	44.80	82.00	5.01	1088.57	19.50	189.00	8.79	87.28	3.45
	f	9	1632.77	49.60	69.04	9.08	1025.55	24.50	173.11	8.13	75.66	2.34
81-90	f	4	1557.50	60.70	60.40	12.50	980.00	52.20	171.50	12.10	78.00	4.00

#### Session 2 - Push & pull on cylindrical bar

Age (years)	Sex	No.	Stature (mm)		Weight (kg)		Elbow height (mm)		Hand length (mm)		Hand breadth (mm)	
			Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
2-5	m	12	1050.83	103.70	17.53	3.02	624.16	67.00	112.41	12.60	56.27	6.19
	f	9	1038.88	100.50	16.24	3.25	617.78	76.40	109.55	9.93	51.88	5.03
6-10	m	8	1387.50	81.30	32.37	7.61	817.50	119.00	148.75	6.98	65.87	4.01
	f	11	1355.90	129.40	27.65	8.96	843.63	103.00	140.27	14.00	61.54	7.22
11-15	m	9	1640.00	101.30	48.07	7.21	1034.44	61.40	152.13	52.00	78.00	6.85
	f	6	1573.33	99.90	47.83	11.40	998.33	54.10	161.66	12.70	69.66	5.85
16-20	m	6	1813.33	65.70	79.40	13.20	1111.66	38.60	188.83	12.30	86.00	4.47
	f	6	1775.00	69.80	70.36	16.60	1130.00	66.60	184.50	13.10	78.00	7.89
21-30	m	5	1831.00	83.50	83.68	40.70	1158.00	50.60	191.20	8.67	85.80	6.49
	f	9	1675.00	51.70	70.88	7.98	1070.00	41.20	168.50	7.28	77.85	9.52
31-50	m	6	1790.00	95.40	82.30	5.55	1133.33	61.50	191.66	6.79	87.83	6.14
	f	11	1670.00	66.80	69.87	16.70	1040.00	45.20	172.40	8.89	74.44	3.46
51-60	m	3	1806.66	51.30	89.06	18.20	1136.66	28.80	196.33	6.50	88.00	1.00
	f	6	1660.83	60.30	76.10	19.80	1038.33	39.20	179.66	6.47	79.00	5.51
61-70	m	5	1810.00	50.90	83.34	13.30	1126.00	49.70	191.60	14.60	89.600	3.43
	f	9	1622.77	69.30	64.73	10.80	1015.55	43.90	175.44	11.20	77.44	2.96
71-80	m	7	1772.14	41.60	82.62	5.02	1082.85	29.20	189.57	9.07	87.42	3.77
	f	12	1649.58	49.20	67.85	8.82	1028.33	35.80	175.58	8.55	76.41	2.46
81-90	f	5	1586.00	77.00	59.08	11.20	1004.00	43.50	172.60	10.70	78.00	3.46

### 6b – Differences between males and females (t-test)

#### Session 1 - Pull on convex knob

Age (years)	Sex	No.	T	DF	Sig
2-5	m	8	-1.147	14	0.270
	f	8			
6-10	m	5	-0.003	13	0.998
	f	10			
11-15	m	12	1.238	15	0.235
	f	5			
16-20	m	8	1.632	14	0.125
	f	8			
21-30	m	7	1.706	12	0.114
	f	7			
31-50	m	7	2.309	22	0.031*
	f	17			
51-60	m	5	2.393	9	0.040*
	f	6			
61-70	m	4	2.575	9	0.030*
	f	7			
71-80	m	7	8.394	14	0.000*
	f	9			

Key:

*t* = value from t-test

*df* = degrees of freedom

*sig* = level of statistical significance

(\* denotes significant difference at 0.05 level)

#### Session 2 - Push with 1 hand on cylindrical bar

Age (years)	Sex	No.	Horizontal			Vertical		
			T	DF	Sig	T	DF	Sig
2-5	m	12	2.016	19	0.058	2.857	19	0.010*
	f	9						
6-10	m	8	0.754	17	0.461	0.250	17	0.806
	f	11						
11-15	m	9	1.055	13	0.310	1.630	13	0.127
	f	6						
16-20	m	6	1.032	10	0.327	2.023	10	0.071
	f	6						
21-30	m	5	1.966	12	0.073	1.392	12	0.189
	f	9						
31-50	m	6	1.386	15	0.186	2.789	15	0.014*
	f	11						
51-60	m	3	1.245	7	0.253	-0.820	7	0.439
	f	6						
61-70	m	5	3.315	12	0.006*	3.376	12	0.006*
	f	9						
71-80	m	7	1.277	17	0.219	3.016	17	0.008*
	f	12						

Key:

*t* = value from t-test

*df* = degrees of freedom

*sig* = level of statistical significance

(\* denotes significant difference at 0.05 level)

**Session 2 - Push with 2 hands on cylindrical bar**

Age (years)	Sex	No.	T	Horizontal DF	Sig	T	Vertical DF	Sig
2-5	m f	12 9	1.734	19	0.099	1.385	19	0.182
6-10	m f	8 11	1.050	17	0.308	0.738	17	0.471
11-15	m f	9 6	0.089	13	0.930	0.274	13	0.788
16-20	m f	6 6	1.248	10	0.240	2.689	10	0.023*
21-30	m f	5 9	2.509	12	0.027*	2.570	12	0.025*
31-50	m f	6 11	3.623	15	0.003*	4.195	15	0.001*
51-60	m f	3 6	1.683	7	0.136	1.703	7	0.132
61-70	m f	5 9	3.598	12	0.004*	3.628	12	0.003*
71-80	m f	7 12	1.927	17	0.071	2.161	17	0.045*

Key:  
*t* = value from *t*-test  
*df* = degrees of freedom  
*sig* = level of statistical significance  
 (\* denotes significant difference at 0.05 level)

**Session 2 - Pull with 1 hand on cylindrical bar**

Age (years)	Sex	No.	T	Horizontal DF	Sig	T	Vertical DF	Sig
2-5	m f	12 9	2.591	19	0.018*	1.616	19	0.123
6-10	m f	8 11	1.420	17	0.174	1.935	17	0.070
11-15	m f	9 6	1.219	13	0.245	1.101	13	0.291
16-20	m f	6 6	1.477	10	0.170	0.260	10	0.236
21-30	m f	5 9	1.810	12	0.095	0.380	12	0.711
31-50	m f	6 11	2.245	15	0.040*	1.928	15	0.073
51-60	m f	3 6	0.734	7	0.487	1.095	7	0.310
61-70	m f	5 9	3.343	12	0.006*	3.749	12	0.003*
71-80	m f	7 12	0.860	17	0.402	2.682	17	0.016*

Key:  
*t* = value from *t*-test  
*df* = degrees of freedom  
*sig* = level of statistical significance  
 (\* denotes significant difference at 0.05 level)

**Session 2 - Pull with 2 hands on cylindrical bar**

Age (years)	Sex	No.	T	Horizontal DF	Sig	T	Vertical DF	Sig
2-5	m f	12 9	2.084	19	0.051	0.759	19	0.457
6-10	m f	8 11	2.112	17	0.050*	0.177	17	0.862
11-15	m f	9 6	0.387	13	0.705	0.825	13	0.424
16-20	m f	6 6	0.705	10	0.497	1.904	10	0.086
21-30	m f	5 9	2.192	12	0.049*	2.265	12	0.043*
31-50	m f	6 11	2.323	15	0.035*	1.438	15	0.171
51-60	m f	3 6	0.883	7	0.406	1.444	7	0.192
61-70	m f	5 9	2.823	12	0.015*	3.790	12	0.003*
71-80	m f	7 12	2.308	17	0.034*	2.427	17	0.027*

Key:  
*t* = value from *t*-test  
*df* = degrees of freedom  
*sig* = level of statistical significance  
 (\* denotes significant difference at 0.05 level)

**6c – Differences between age groups (t-test)**

**Session 1 - Pull on convex knob**

Age (years)	2-5	6-10	11-15	16-20	21-30	31-50	51-60	61-70	71-80	81-90
2-5		*	*	*	*	*	*	*	*	*
6-10			*	*	*	*	*	*	*	X
11-15				*	X	X	X	X	X	*
16-20					X	X	X	*	X	*
21-30						X	X	X	X	*
31-50							X	X	X	*
51-60								X	X	X
61-70									X	X
71-80										*
81-90										*

\* denotes significant difference at 0.05 level

**Session 2 - Push & pull on cylindrical bar**

Age (years)	2-5	6-10	11-15	16-20	21-30	31-50	51-60	61-70	71-80	81-90
2-5		*	*	*	*	*	*	*	*	*
6-10			* not 1	*	*	*	* not 1, 2, 5	* not 1, 2, 5	X not 8	X
11-15				* not 4, 5	X	X not 6	X	X	* not 2, 6, 8	*
16-20					X	X	* not 4, 7, 8	* not 7	*	*
21-30						X	X not 5	X	*	*
31-50							X not 5, 6	X not 6	*	*
51-60								X not 4	X not 4	* not 1, 3, 5, 7
61-70									X	X not 4, 6
71-80										* not 7
81-90										

\* denotes significant difference at 0.05 level

Key:  
 1 = horizontal push with 1 hand      5 = vertical push with 1 hand  
 2 = horizontal push with 2 hands      6 = vertical push with 2 hands  
 3 = horizontal pull with 1 hand      7 = vertical pull with 1 hand  
 4 = horizontal pull with 2 hands      8 = vertical pull with 2 hands

**6d – Differences between direction of force and number of hands used (Paired samples test)**

**Session 2 - Push & pull on cylindrical bar**

Action	t	df	sig
hpush1-hpush2	-7.435	144	0.000*
hpull1 – hpush1	4.018	144	0.000*
hpull2 – hpush1	7.453	144	0.000*
hpush1 – vpush1	-2.790	144	0.006*
hpush1 – vpush2	-8.300	144	0.000*
hpush1 – vpull1	-4.660	144	0.000*
hpush1 – vpull2	-7.196	144	0.000*
hpull1 – hpush2	-3.248	144	0.001*
hpull2 – hpush2	0.234	144	0.815
hpush2 – vpush1	4.706	144	0.000*
hpush2 – vpush2	-2.188	144	0.030*
hpush2 – vpull1	3.128	144	0.002*
hpush2 – vpull2	-1.156	144	0.249
hpull1 – hpull2	-4.657	144	0.000*
hpull1 – vpush1	0.985	144	0.326
hpull1 – vpush2	-5.201	144	0.000*
hpull1 – vpull1	-0.229	144	0.819
hpull1 – vpull2	-5.217	144	0.000*
hpull2 – vpush1	4.156	144	0.000*
hpull2 – vpush2	-1.390	144	0.167
hpull2 – vpull1	4.014	144	0.000*
hpull2 – vpull2	-1.147	144	0.253
vpush1 – vpush2	-6.886	144	0.000*
vpull1 – vpush1	1.142	144	0.255
vpull2 – vpush1	4.977	144	0.000*
vpull1 – vpush2	-5.270	144	0.000*
vpull2 – vpush2	-0.457	144	0.649
vpull1 – vpull2	-5.403	144	0.000*

Key:

hpush1 = horizontal push with 1 hand  
 hpush2 = horizontal push with 2 hands  
 hpull1 = horizontal pull with 1 hand  
 hpull2 = horizontal pull with 2 hands  
 vpush1 = vertical push with 1 hand  
 vpush2 = vertical push with 2 hands  
 vpull1 = vertical pull with 1 hand  
 vpull2 = vertical pull with 2 hands

t = value from t-test

df = degrees of freedom

sig = level of statistical significance (\* denotes significant difference at 0.05 level)



**6e – Correlation between measurements (Pearson Correlation)**

**Session 2 - Push and pull on cylindrical bar**

	hpush1	hpush2	vpush1	vpush2	hpull1	hpull2	vpull1	vpull2
hpush1	1.000	0.842	0.764	0.813	0.797	0.789	0.822	0.742
hpush2	0.842	1.000	0.871	0.903	0.833	0.792	0.836	0.802
vpsh1	0.764	0.871	1.000	0.885	0.832	0.785	0.820	0.792
vpush2	0.813	0.903	0.885	1.000	0.855	0.813	0.871	0.834
hpull1	0.797	0.833	0.832	0.885	1.000	0.889	0.898	0.868
hpull2	0.789	0.792	0.785	0.813	0.889	1.000	0.857	0.859
vpull1	0.822	0.836	0.820	0.871	0.898	0.857	1.000	0.886
vpull2	0.742	0.802	0.792	0.834	0.868	0.859	0.886	1.000

Key:  
 hpush1 = horizontal push with 1 hand    hpull2 = horizontal pull with 2 hands    vpull1 = vertical pull with 1 hand  
 hpush2 = horizontal push with 2 hands    vpush1 = vertical push with 1 hand    vpull2 = vertical pull with 2 hands  
 hpull1 = horizontal pull with 1 hand    vpush2 = vertical push with 2 hands

**APPENDIX 7 – CORRELATION BETWEEN MEASUREMENTS**

		Finger push strength			
		Index forwards	Index downwards	Thumb forwards	Thumb downwards
Finger push strength	index forwards	1.000	0.932**	0.861**	0.886**
	index downwards	0.932**	1.000	0.837**	0.898**
	thumb forwards	0.861**	0.837**	1.000	0.920**
	thumb downwards	0.886**	0.898**	0.920**	1.000
Pinch pull strength	pulp 2mm	0.018	0.006	-0.068	-0.041
	pulp 20mm	0.062	0.068	-0.028	0.008
	pulp 40mm	0.090	0.080	-0.009	0.027
	chuck 2mm	0.016	-0.001	-0.065	-0.031
	chuck 20mm	0.056	0.027	-0.065	-0.024
	chuck 40mm	0.091	0.071	-0.022	0.013
Hand grip strength	1 hand - 30mm	-0.164*	-0.126	-0.176*	-0.109
	2 hands - 30mm	-0.092	-0.047	-0.101	-0.037
	1 hand - 50mm	-0.077	-0.050	-0.099	-0.047
	2 hands - 50mm	-0.010	0.016	-0.035	0.024
	1 hand 70mm	-0.120	-0.096	-0.141	-0.083
	2 hands - 70mm	-0.041	-0.006	-0.074	-0.018
Wrist-twisting strength	<i>vertical</i>				
	door lever	-0.057	-0.110	-0.020	-0.089
	door knob	-0.072	-0.092	-0.023	-0.048
	circular knob	-0.078	-0.097	0.015	-0.024
	ridged knob	-0.107	-0.128	-0.053	-0.104
	butterfly nut	-0.046	-0.048	0.010	-0.048
	tap	-0.076	-0.079	-0.028	-0.066
	<i>horizontal</i>				
	ridged knob	0.004	0.036	0.016	0.023
	butterfly nut	0.009	0.037	0.008	0.021
tap	-0.067	-0.067	-0.022	-0.033	
Opening strength	smooth 45mm	0.135	0.131	0.128	0.104
	knurled 45mm	0.093	0.094	0.108	0.080
	smooth 65mm	0.190*	0.173*	0.167*	0.158
	knurled 65mm	0.105	0.119	0.103	0.079
	smooth 85mm	0.159	0.146	0.147	0.135
	knurled 85mm	0.150	0.143	0.138	0.122
Push and pull strength	convex knob	0.077	0.109	0.042	0.077
	<i>cylindrical bar</i>				
	<i>horizontal:</i>				
	1 hand push	0.065	0.107	0.025	0.037
	2 hands push	-0.003	0.033	-0.035	-0.032
	1 hand pull	0.017	0.04	-0.032	-0.034
	2 hands pull	0.056	0.081	-0.003	0.013
	<i>vertical:</i>				
	1 hand push	0.010	0.042	-0.042	-0.024
	2 hands push	-0.007	0.040	-0.034	-0.028
	1 hand pull	0.018	0.044	-0.0312	-0.032
	2 hands pull	0.031	0.054	-0.015	-0.007

Key:  
 \* denotes significant correlation at 0.05 level  
 \*\* denotes significant correlation at 0.01 level

		Pinch-pull strength					
		Pulp 2mm	Pulp 20mm	Pulp 40mm	Chuck 2mm	Chuck 20mm	Chuck 40mm
<b>Finger push strength</b>	index forwards	0.018	0.062	0.090	0.016	0.056	0.091
	index downwards	0.006	0.068	0.080	-0.001	0.027	0.071
	thumb forwards	-0.068	-0.028	-0.009	-0.069	-0.065	-0.022
	thumb downwards	-0.041	0.008	0.027	-0.031	-0.024	0.013
<b>Pinch pull strength</b>	pulp 2mm	1.000	0.886**	0.839**	0.891**	0.845**	0.802**
	pulp 20mm	0.886**	1.000	0.915**	0.893**	0.900**	0.901**
	pulp 40mm	0.839**	0.915**	1.000	0.865**	0.869**	0.890**
	chuck 2mm	0.891**	0.893**	0.865**	1.000	0.918**	0.886**
	chuck 20mm	0.845**	0.900**	0.869**	0.918**	1.000	0.933**
	chuck 40mm	0.802**	0.901**	0.890**	0.886**	0.933**	1.000
<b>Hand grip strength</b>	1 hand - 30mm	0.091	0.039	0.052	0.088	0.127	0.082
	2 hands - 30mm	0.034	-0.001	0.009	0.037	0.061	0.011
	1 hand - 50mm	0.074	0.022	0.044	0.082	0.129	0.083
	2 hands - 50mm	0.025	0.003	0.012	0.046	0.091	0.060
	1 hand 70mm	0.099	0.025	0.044	0.105	0.123	0.089
	2 hands - 70mm	0.072	0.028	0.040	0.079	0.119	0.091
<b>Wrist-twisting strength</b>	<i>vertical</i>						
	door lever	-0.047	-0.071	-0.136	-0.084	-0.081	-0.076
	door knob	0.007	-0.074	-0.098	-0.038	-0.053	-0.069
	circular knob	-0.039	-0.097	-0.139	-0.075	-0.086	-0.058
	ridged knob	0.004	-0.069	-0.114	-0.032	-0.057	-0.065
	butterfly nut	0.075	0.034	-0.008	0.042	0.032	0.041
	tap	0.013	-0.031	-0.065	-0.023	-0.046	-0.030
	<i>horizontal</i>						
	ridged knob	0.141	0.090	0.153	0.125	0.083	0.107
	butterfly nut	0.150	0.091	0.173*	0.131	0.083	0.100
	tap	0.139	0.077	0.116	0.119	0.060	0.073
	<b>Opening strength</b>	smooth 45mm	-0.116	-0.043	0.038	-0.096	-0.060
knurled 45mm		-0.157	-0.076	0.002	-0.115	-0.078	-0.087
smooth 65mm		-0.062	0.015	0.092	-0.022	0.019	0.020
knurled 65mm		-0.074	0.001	0.074	-0.028	0.010	0.009
smooth 85mm		-0.022	0.080	0.172*	0.035	0.091	0.107
knurled 85mm		-0.010	0.065	0.139	0.041	0.089	0.095
<b>Push and pull strength</b>	convex knob	-0.119	-0.034	-0.007	-0.118	-0.068	-0.032
	<i>cylindrical bar horizontal:</i>						
	1 hand push	0.297**	0.281**	0.313**	0.312**	0.283**	0.310**
	2 hands push	0.250**	0.223**	0.255**	0.252**	0.242**	0.244**
	1 hand pull	0.210*	0.199*	0.238**	0.230**	0.202*	0.216*
	2 hands pull	0.223**	0.217**	0.237**	0.253**	0.231**	0.221**
	<i>vertical:</i>						
	1 hand push	0.204*	0.174*	0.221**	0.216**	0.202*	0.195*
	2 hands push	0.231**	0.219**	0.241**	0.233**	0.224**	0.201*
	1 hand pull	0.190*	0.187*	0.213*	0.224**	0.200*	0.209*
	2 hands pull	0.165*	0.175*	0.215*	0.197*	0.174*	0.168*

Key:

\* denotes significant correlation at 0.05 level

\*\* denotes significant correlation at 0.01 level

		Hand grip strength					
		1 hand 30mm	2 hands 30mm	1 hand 50mm	2 hands 50mm	1 hand 70mm	2 hands 70mm
<b>Finger push strength</b>	index forwards	-0.164*	-0.092	-0.077	-0.010	-0.120	-0.041
	index downwards	-0.126	-0.047	-0.050	0.016	-0.096	-0.006
	thumb forwards	-0.176*	-0.101	-0.099	-0.035	-0.141	-0.074
	thumb downwards	-0.109	-0.037	-0.047	0.024	-0.083	-0.018
<b>Pinch pull strength</b>	pulp 2mm	0.091	0.034	0.074	0.025	0.099	0.072
	pulp 20mm	0.039	-0.001	0.022	0.003	0.025	0.028
	pulp 40mm	0.052	0.009	0.044	0.012	0.044	0.040
	chuck 2mm	0.088	0.037	0.082	0.046	0.105	0.079
	chuck 20mm	0.127	0.061	0.129	0.091	0.123	0.119
	chuck 40mm	0.082	0.011	0.083	0.060	0.089	0.091
<b>Hand grip strength</b>	1 hand - 30mm	1.000	0.865**	0.925**	0.829**	0.906**	0.865**
	2 hands - 30mm	0.865**	1.000	0.831**	0.877**	0.818**	0.881**
	1 hand - 50mm	0.925**	0.831**	1.000	0.891**	0.957**	0.912**
	2 hands - 50mm	0.829**	0.877**	0.891**	1.000	0.869**	0.937**
	1 hand 70mm	0.906**	0.818**	0.957**	0.869**	1.000	0.916**
	2 hands - 70mm	0.865**	0.881**	0.912**	0.937**	0.916**	1.000
<b>Wrist-twisting strength</b>	<i>vertical</i>						
	door lever	-0.071	0.008	-0.081	-0.006	-0.051	-0.050
	door knob	-0.002	0.050	-0.004	0.025	-0.021	-0.003
	circular knob	0.014	0.049	0.023	0.067	0.015	0.041
	ridged knob	-0.087	-0.032	-0.083	-0.047	-0.083	-0.070
	butterfly nut	-0.034	0.024	-0.027	0.005	-0.026	-0.017
	tap	-0.052	0.007	-0.050	-0.001	-0.051	-0.034
	<i>horizontal</i>						
	ridged knob	0.210*	0.278**	0.272**	0.284**	0.310**	0.271**
	butterfly nut	0.181*	0.272**	0.224**	0.252**	0.250**	0.223**
	tap	0.142	0.211**	0.194*	0.192*	0.260**	0.198*
	<b>Opening strength</b>	smooth 45mm	0.118	0.067	0.067	0.055	0.025
knurled 45mm		0.088	0.041	0.004	0.003	-0.037	0.007
smooth 65mm		0.136	0.091	0.041	0.023	0.009	0.019
knurled 65mm		0.120	0.065	0.052	0.015	0.012	0.027
smooth 85mm		0.166*	0.107	0.093	0.070	0.048	0.078
knurled 85mm		0.189*	0.136	0.127	0.086	0.074	0.098
<b>Push and pull strength</b>	convex knob	0.068	0.074	0.003	0.003	-0.035	0.005
	<i>cylindrical bar horizontal:</i>						
	1 hand push	-0.094	-0.164	-0.129	-0.106	-0.127	-0.107
	2 hands push	-0.116	-0.195*	-0.131	-0.111	-0.132	-0.128
	1 hand pull	-0.105	-0.164	-0.113	-0.114	-0.110	-0.092
	2 hands pull	-0.104	-0.195*	-0.114	-0.090	-0.117	-0.110
	<i>vertical:</i>						
	1 hand push	-0.079	-0.161	-0.108	-0.103	-0.109	-0.103
	2 hands push	-0.097	-0.174*	-0.118	-0.109	-0.121	-0.116
	1 hand pull	-0.132	-0.209*	-0.125	-0.108	-0.128	-0.113
	2 hands pull	-0.145	-0.221**	-0.140	-0.127	-0.144	-0.134

Key:

\* denotes significant correlation at 0.05 level

\*\* denotes significant correlation at 0.01 level

		Wrist twisting strength (vertical)					
		Door lever	Door knob	Circular knob	Ridged knob	Butterfly nut	Tap
Finger push strength	index forwards	-0.057	-0.072	-0.078	-0.107	-0.046	-0.076
	index downwards	-0.110	-0.092	-0.097	-0.128	-0.048	-0.079
	thumb forwards	-0.020	-0.023	0.015	-0.053	0.010	-0.028
	thumb downwards	-0.089	-0.048	-0.024	-0.104	-0.048	-0.066
Pinch pull strength	pulp 2mm	-0.047	0.007	-0.039	0.004	0.075	0.013
	pulp 20mm	-0.071	-0.074	-0.097	-0.069	0.034	-0.031
	pulp 40mm	-0.136	-0.098	-0.139	-0.114	-0.008	-0.065
	chuck 2mm	-0.084	-0.038	-0.075	-0.032	0.042	-0.023
	chuck 20mm	-0.081	-0.053	-0.086	-0.057	0.032	-0.046
	chuck 40mm	-0.076	-0.069	-0.058	-0.065	0.041	-0.030
Hand grip strength	1 hand - 30mm	-0.071	-0.002	0.014	-0.087	-0.034	-0.052
	2 hands - 30mm	0.008	0.050	0.049	-0.032	0.024	0.007
	1 hand - 50mm	-0.081	-0.004	0.023	-0.083	-0.027	-0.050
	2 hands - 50mm	-0.006	0.025	0.067	-0.047	0.005	-0.001
	1 hand 70mm	-0.051	-0.021	0.015	-0.083	-0.026	-0.051
	2 hands - 70mm	-0.050	-0.003	0.041	-0.070	-0.017	-0.030
Wrist-twisting strength	<i>vertical</i>						
	door lever	1.000	0.661**	0.547**	0.762**	0.678**	0.722**
	door knob	0.661**	1.000	0.870**	0.845**	0.789**	0.879**
	circular knob	0.547**	0.870**	1.000	0.698**	0.693**	0.818**
	ridged knob	0.762**	0.845**	0.698**	1.000	0.882**	0.872**
	butterfly nut	0.678**	0.789**	0.693**	0.882**	1.000	0.844**
	tap	0.722**	0.879**	0.818**	0.872**	0.844**	1.000
	<i>horizontal</i>						
	ridged knob	-0.146	-0.047	-0.035	-0.107	-0.048	-0.033
	butterfly nut	-0.173*	-0.052	-0.035	-0.102	-0.057	-0.027
	tap	-0.130	-0.021	-0.010	-0.059	-0.041	-0.018
	Opening strength	smooth 45mm	-0.116	-0.075	-0.015	-0.128	-0.113
knurled 45mm		-0.067	-0.026	-0.003	-0.072	-0.048	0.035
smooth 65mm		-0.117	-0.044	-0.022	-0.11	-0.085	-0.028
knurled 65mm		-0.107	-0.061	-0.019	-0.105	-0.054	0.010
smooth 85mm		-0.156	-0.062	-0.018	-0.105	-0.061	-0.019
knurled 85mm		-0.168*	-0.065	0.007	-0.102	-0.047	-0.022
Push and pull strength	convex knob	0.076	0.072	0.044	-0.022	0.049	0.061
	<i>cylindrical bar</i>						
	<i>horizontal:</i>						
	1 hand push	-0.116	-0.163	-0.258**	-0.093	-0.113	-0.161
	2 hands push	-0.115	-0.128	-0.234**	-0.072	-0.136	-0.154
	1 hand pull	-0.125	-0.121	-0.227**	-0.071	-0.130	-0.136
	2 hands pull	-0.125	-0.098	-0.176*	-0.044	-0.065	-0.111
	<i>vertical:</i>						
	1 hand push	-0.069	-0.061	-0.182*	-0.024	-0.113	-0.094
	2 hands push	-0.100	-0.087	-0.210*	-0.060	-0.113	-0.118
	1 hand pull	-0.107	-0.119	-0.232*	-0.052	-0.112	-0.128
	2 hands pull	-0.112	-0.099	-0.203*	-0.067	-0.098	-0.122

Key:

\* denotes significant correlation at 0.05 level

\*\* denotes significant correlation at 0.01 level

		Wrist twisting strength (horizontal)		
		Ridged knob	Butterfly nut	Tap
Finger push strength	index forwards	0.004	0.009	-0.067
	index downwards	0.036	0.037	-0.067
	thumb forwards	0.016	0.008	-0.022
	thumb downwards	0.023	0.021	-0.033
Pinch pull strength	pulp 2mm	0.141	0.150	0.139
	pulp 20mm	0.090	0.091	0.077
	pulp 40mm	0.153	0.173*	0.116
	chuck 2mm	0.125	0.131	0.119
	chuck 20mm	0.083	0.083	0.060
	chuck 40mm	0.107	0.100	0.073
Hand grip strength	1 hand - 30mm	0.210*	0.181*	0.142
	2 hands - 30mm	0.278**	0.272**	0.211**
	1 hand - 50mm	0.272**	0.224**	0.194*
	2 hands - 50mm	0.284**	0.252**	0.192*
	1 hand 70mm	0.310**	0.250**	0.260**
	2 hands - 70mm	0.271**	0.223**	0.198*
Wrist-twisting strength	<i>vertical</i>			
	door lever	-0.146	-0.173*	-0.130
	door knob	-0.047	-0.052	-0.021
	circular knob	-0.035	-0.035	-0.010
	ridged knob	-0.107	-0.102	-0.059
	butterfly nut	-0.048	-0.057	-0.041
	tap	-0.033	-0.027	-0.018
	<i>horizontal</i>			
	ridged knob	1.000	0.931**	0.867**
	butterfly nut	0.931**	1.000	0.839**
	tap	0.867**	0.839**	1.000
	Opening strength	smooth 45mm	0.070	0.071
knurled 45mm		0.029	0.040	-0.042
smooth 65mm		0.055	0.091	0.001
knurled 65mm		0.066	0.082	-0.022
smooth 85mm		0.109	0.129	0.015
knurled 85mm		0.119	0.138	0.022
Push and pull strength	convex knob	0.120	0.116	-0.012
	<i>cylindrical bar</i>			
	<i>horizontal:</i>			
	1 hand push	-0.029	-0.022	-0.045
	2 hands push	-0.023	-0.013	-0.028
	1 hand pull	-0.026	-0.017	0.011
	2 hands pull	-0.035	-0.015	-0.037
	<i>vertical:</i>			
	1 hand push	-0.111	-0.092	-0.095
	2 hands push	-0.045	-0.039	-0.049
	1 hand pull	-0.062	-0.048	-0.040
	2 hands pull	-0.077	-0.061	-0.032

Key:

\* denotes significant correlation at 0.05 level

\*\* denotes significant correlation at 0.01 level

		Opening strength					
		Smooth 45mm	Knurled 45mm	Smooth 65mm	Knurled 65mm	Smooth 85mm	Knurled 85mm
<b>Finger push strength</b>	index forwards	0.135	0.093	0.190*	0.105	0.159	0.150
	index downwards	0.131	0.094	0.173*	0.119	0.146	0.143
	thumb forwards	0.128	0.108	0.167*	0.103	0.147	0.138
	thumb downwards	0.104	0.080	0.158	0.079	0.135	0.122
<b>Pinch pull strength</b>	pulp 2mm	-0.116	-0.157	-0.062	-0.074	-0.022	-0.010
	pulp 20mm	-0.043	-0.076	0.015	0.001	0.080	0.065
	pulp 40mm	0.038	0.002	0.092	0.074	0.172*	0.139
	chuck 2mm	-0.096	-0.115	-0.022	-0.028	0.035	0.041
	chuck 20mm	-0.060	-0.078	0.019	0.010	0.091	0.089
	chuck 40mm	-0.038	-0.087	0.020	0.009	0.107	0.095
<b>Hand grip strength</b>	1 hand - 30mm	0.118	0.088	0.136	0.120	0.166*	0.189*
	2 hands - 30mm	0.067	0.041	0.091	0.065	0.107	0.136
	1 hand - 50mm	0.067	0.004	0.041	0.052	0.093	0.127
	2 hands - 50mm	0.055	0.003	0.023	0.015	0.070	0.086
	1 hand 70mm	0.025	-0.037	0.009	0.012	0.048	0.074
	2 hands - 70mm	0.062	0.007	0.019	0.027	0.078	0.098
<b>Wrist-twisting strength</b>	<i>vertical</i>						
	door lever	-0.116	-0.067	-0.117	-0.107	-0.156	-0.168*
	door knob	-0.075	-0.026	-0.044	-0.061	-0.062	-0.065
	circular knob	-0.015	-0.003	-0.022	-0.019	-0.018	0.007
	ridged knob	-0.128	-0.072	-0.110	-0.105	-0.105	-0.102
	butterfly nut	-0.113	-0.048	-0.085	-0.054	-0.061	-0.047
	tap	-0.028	0.035	-0.028	0.010	-0.019	-0.022
	<i>horizontal</i>						
	ridged knob	0.070	0.029	0.055	0.066	0.109	0.119
	butterfly nut	0.071	0.040	0.091	0.082	0.129	0.138
	tap	-0.002	-0.042	0.001	-0.022	0.015	0.022
	<b>Opening strength</b>	smooth 45mm	1.000	0.904**	0.889**	0.827**	0.851**
knurled 45mm		0.904**	1.000	0.903**	0.896**	0.872**	0.0854**
smooth 65mm		0.889**	0.903**	1.000	0.906**	0.909**	0.904**
knurled 65mm		0.827**	0.896**	0.906**	1.000	0.894**	0.911**
smooth 85mm		0.851**	0.872**	0.909**	0.894**	1.000	0.948**
knurled 85mm		0.812**	0.854**	0.904**	0.911**	0.948**	1.000
<b>Push and pull strength</b>	convex knob	0.334**	0.417**	0.425**	0.421**	0.410**	0.404**
	<i>cylindrical bar horizontal:</i>						
	1 hand push	-0.146	-0.139	-0.139	-0.134	-0.094	-0.122
	2 hands push	-0.121	-0.141	-0.119	-0.121	-0.083	-0.111
	1 hand pull	-0.087	-0.110	-0.092	-0.091	-0.031	-0.055
	2 hands pull	-0.088	-0.097	-0.079	-0.057	-0.009	-0.019
	<i>vertical:</i>						
	1 hand push	-0.086	-0.082	-0.078	-0.063	-0.031	-0.060
	2 hands push	-0.098	-0.065	-0.089	-0.072	-0.040	-0.059
	1 hand pull	-0.096	-0.110	-0.095	-0.109	-0.047	-0.063
	2 hands pull	-0.084	-0.081	-0.075	-0.070	-0.020	-0.031

Key:

\* denotes significant correlation at 0.05 level

\*\* denotes significant correlation at 0.01 level

		Push and pull strength (horizontal)			
		1 hand push	2 hands push	1 hand pull	2 hands pull
<b>Finger push strength</b>	index forwards	0.065	-0.003	0.017	0.056
	index downwards	0.107	0.033	0.040	0.081
	thumb forwards	0.025	-0.035	-0.032	0.003
	thumb downwards	0.037	-0.032	-0.034	0.013
<b>Pinch pull strength</b>	pulp 2mm	0.297**	0.250**	0.210*	0.223**
	pulp 20mm	0.281**	0.223**	0.199*	0.217**
	pulp 40mm	0.313**	0.255**	0.238**	0.237**
	chuck 2mm	0.312**	0.252**	0.230**	0.253**
	chuck 20mm	0.283**	0.242**	0.202*	0.231**
	chuck 40mm	0.311**	0.244**	0.216*	0.221**
<b>Hand grip strength</b>	1 hand - 30mm	-0.094	-0.116	-0.105	-0.104
	2 hands - 30mm	-0.164	-0.195*	-0.164	-0.195*
	1 hand - 50mm	-0.129	-0.131	-0.113	-0.114
	2 hands - 50mm	-0.106	-0.111	-0.114	-0.090
	1 hand 70mm	-0.127	-0.132	-0.110	-0.117
	2 hands - 70mm	-0.107	-0.128	-0.092	-0.110
<b>Wrist-twisting strength</b>	<i>vertical</i>				
	door lever	-0.116	-0.115	-0.125	-0.125
	door knob	-0.163	-0.128	-0.121	-0.098
	circular knob	-0.258**	-0.234**	-0.227**	-0.176*
	ridged knob	-0.093	-0.072	-0.071	-0.044
	butterfly nut	-0.113	-0.136	-0.130	-0.065
	tap	-0.161	-0.154	-0.136	-0.111
	<i>horizontal</i>				
	ridged knob	-0.029	-0.023	-0.026	-0.035
	butterfly nut	-0.022	-0.013	-0.017	-0.015
	tap	-0.045	-0.028	0.011	-0.037
	<b>Opening strength</b>	smooth 45mm	-0.146	-0.121	-0.087
knurled 45mm		-0.139	-0.141	-0.110	-0.097
smooth 65mm		-0.139	-0.119	-0.092	-0.079
knurled 65mm		-0.134	-0.121	-0.091	-0.057
smooth 85mm		-0.094	-0.083	-0.031	-0.009
knurled 85mm		-0.122	-0.111	-0.055	-0.019
<b>Push and pull strength</b>	convex knob	-0.152	-0.123	-0.129	0.193*
	<i>cylindrical bar horizontal:</i>				
	1 hand push	1.000	0.944**	0.878**	0.823*
	2 hands push	0.944**	1.000	0.861**	0.836**
	1 hand pull	0.878**	0.861**	1.000	0.914**
	2 hands pull	0.823**	0.836**	0.914**	1.000
	<i>vertical:</i>				
	1 hand push	0.917**	0.913**	0.893**	0.850**
	2 hands push	0.927**	0.935**	0.891**	0.850**
	1 hand pull	0.878**	0.863**	0.919**	0.883**
	2 hands pull	0.798**	0.825**	0.901**	0.885**

Key:

\* denotes significant correlation at 0.05 level

\*\* denotes significant correlation at 0.01 level

## REFERENCES

Norris, B. J. and Wilson, J. R., 1995, CHILDDATA: The Handbook of Child Measurements and Capabilities – Data for Design Safety, Department of Trade and Industry, London, UK.

Peebles, L. and Norris, B. J., 1998, ADULTDATA: The Handbook of Adult Anthropometric and Strength Measurements – Data for Design Safety, Department of Trade and Industry, London, UK.

Smith, S. A., Norris, B. J. and Peebles, L., 2000, OLDER ADULTDATA: The Handbook of Measurements and Capabilities of the Older Adult – Data for Design Safety, Department of Trade and Industry, London, UK.

### Copies of the above publications are available from:

DTI Publications  
ADMAIL 528  
London  
SW1W 8YT

Telephone 0870 1502 500  
Fax 0870 1502 333  
Internet [www.dti.gov.uk](http://www.dti.gov.uk)

or

Product Safety and Testing Group  
Division of Manufacturing Engineering and Operations Management  
University of Nottingham  
University Park  
Nottingham  
NG7 2RD

Telephone +44 (0)115 9514038/9  
Internet [www.virart.nottingham.ac.uk/PSTG](http://www.virart.nottingham.ac.uk/PSTG)

		Push and pull strength (horizontal)				
		1 hand push	2 hands push	1 hand pull	2 hands pull	convex knob
<b>Finger push strength</b>	index forwards	0.010	-0.007	0.018	0.031	0.077
	index downwards	0.042	0.040	0.044	0.054	0.109
	thumb forwards	-0.042	-0.034	-0.032	-0.015	0.042
	thumb downwards	-0.024	-0.028	-0.032	-0.007	0.077
<b>Pinch pull strength</b>	pulp 2mm	0.204*	0.231**	0.190*	0.165*	-0.119
	pulp 20mm	0.174*	0.219**	0.187*	0.175*	-0.034
	pulp 40mm	0.221**	0.241**	0.213*	0.215*	-0.007
	chuck 2mm	0.216**	0.233**	0.224**	0.197*	-0.118
	chuck 20mm	0.202*	0.224**	0.200*	0.174*	-0.068
	chuck 40mm	0.195*	0.201*	0.209*	0.168*	-0.032
<b>Hand grip strength</b>	1 hand - 30mm	-0.079	-0.097	-0.132	-0.145	0.068
	2 hands - 30mm	-0.161	-0.174*	-0.209*	-0.221**	0.074
	1 hand - 50mm	-0.108	-0.118	-0.125	-0.140	0.003
	2 hands - 50mm	-0.103	-0.109	-0.108	-0.127	0.003
	1 hand 70mm	-0.109	-0.121	-0.128	-0.144	-0.035
	2 hands - 70mm	-0.103	-0.116	-0.113	-0.134	0.005
<b>Wrist-twisting strength</b>	<i>vertical</i>					
	door lever	-0.069	-0.100	-0.107	-0.112	0.076
	door knob	-0.061	-0.087	-0.119	-0.099	0.072
	circular knob	-0.182*	-0.210*	-0.232**	-0.203*	0.044
	ridged knob	-0.024	-0.060	-0.052	-0.067	-0.022
	butterfly nut	-0.113	-0.113	-0.112	-0.098	0.049
	tap	-0.094	-0.118	-0.128	-0.122	0.061
	<i>horizontal</i>					
	ridged knob	-0.111	-0.045	-0.062	-0.077	0.120
	butterfly nut	-0.092	-0.039	-0.048	-0.061	0.116
tap	-0.095	-0.049	-0.040	-0.032	-0.012	
<b>Opening strength</b>	smooth 45mm	-0.086	-0.098	-0.096	-0.084	0.334**
	knurled 45mm	-0.082	-0.065	-0.110	-0.081	0.417**
	smooth 65mm	-0.078	-0.089	-0.095	-0.075	0.425**
	knurled 65mm	-0.063	-0.072	-0.109	-0.070	0.421**
	smooth 85mm	-0.031	-0.040	-0.047	-0.020	0.410**
	knurled 85mm	-0.060	-0.059	-0.063	-0.031	0.404**
<b>Push and pull strength</b>	convex knob	-0.084	-0.107	-0.126	-0.1321	1.000
	<i>cylindrical bar</i>					
	<i>horizontal:</i>					
	1 hand push	0.917**	0.927**	0.878**	0.798**	-0.152
	2 hands push	0.913**	0.935**	0.863**	0.825**	-0.123
	1 hand pull	0.893**	0.891**	0.919**	0.901**	-0.129
	2 hands pull	0.850**	0.850**	0.883**	0.885**	-0.193*
	<i>vertical:</i>					
	1 hand push	1.000	0.943**	0.879**	0.848**	-0.084
	2 hands push	0.943**	1.000	0.886**	0.867**	-0.107
	1 hand pull	0.879**	0.886**	1.000	0.895**	-0.126
	2 hands pull	0.848**	0.867**	0.895**	1.000	-0.132

Key:

\* denotes significant correlation at 0.05 level

\*\* denotes significant correlation at 0.01 level

