

STRENGTH DATA FOR DESIGN SAFETY

Phase 2



GOVERNMENT CONSUMER SAFETY RESEARCH

dti

Department of Trade and Industry

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Introduction and background

This report summarises the results of the second phase of a research study funded by the Consumer and Competition Policy 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 worked with DTI to produce a series of publications containing ergonomics data. The three publications on children, adults and older adults ('Childata', 'Adultdata' and 'Older Adultdata') contain the most up-to-date anthropometric and physical strength data for countries around the world. However, their production highlighted important 'gaps' in the data available for direct use in product design.

This report describes the second phase of the two stage research program which was undertaken to try to address some of these data 'gaps'. In the first phase, potential needs for design-applicable data were identified and prioritised and new strength data were collected to meet some of those needs. Data were collected on the following strength measurements:

- Finger push strength
- Pinch-pull strength
- Hand grip strength
- Wrist twisting strength
- Push and pull strength.

These data are available in a previous report from the DTI:

Strength Data for Design Safety – Phase 1. DTI, October 2000, URN 00/1070.

Which is available from

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Consumer and Competition Policy Directorate
1 Victoria Street, London SW1H 0ET
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Internet: www.dti.gov.uk
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This current report presents data from a second series of strength measurements. The report consists of three main sections:

1. Data collection methodology
2. Data sheets
3. Appendices

In Section 1 of the report, the research methodology is described. In Section 2, detailed descriptions of the measurements and the results are presented in the form of 'data sheets', and in Section 3, the statistical analyses performed are presented as appendices. The data sheets are repeated on pull out pages at the back of the report, for easy reference.

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 (■).

Section 1

Data Collection Methodology

In this second phase of research, data have been collected on a total of 8 strength measurements.

These are:

1. Push and pull strength
2. Push with the thumb or 2 or more fingers
3. Push with the shoulder (at 90% and 100% of shoulder height)
4. Pull with different grips
5. Wrist twisting and push-and-turn strength
6. Pull on a can ring-pull
7. Press and lift with the foot
8. Pull on 20mm knob

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 subjects from the UK aged from 2 to 90 years have been measured for each strength measurement. 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 eight different force exertions, and are summarised below. Detailed descriptions of each measurement can be found in Section 2.

- *push and pull strength* - maximum static strength when pushing and pulling on a cylindrical bar, whilst standing, and using both one (dominant) hand and two hands. The bar was placed at shoulder height, and positioned both vertically and horizontally.
- *push with the thumb or 2 or more fingers* - maximum static pushing strength on a button using either the thumb or two or more fingers, whilst either standing or seated. The button was positioned at elbow height whilst standing, and at seat pan height whilst seated (small children allowed to rest feet on box). Forward pushing strength was measured with the fingers and downwards strength with the thumb and with the fingers.
- *push with the shoulder (at 90% and 100% of shoulder height)* - maximum static pushing force with the shoulder pushing on a force plate whilst standing. The force plate was positioned at 90% and 100% of the shoulder height.
- *pull with different grips* - maximum static pulling force on two different handle types (an under-hand grip handle and a round handle), whilst standing, and using both one (dominant) hand and two hands. The handle was positioned at elbow height.
- *wrist twisting and push and turn strength* - maximum static torque (clock-wise) on two different handle types, whilst standing, and using one (dominant) hand. Two knobs were used: a circular knob

(20mm diameter) and a push-and-turn knob (40mm). The push-and-turn knob had two push resistances, 10 Newtons and 20 Newtons. Both knobs were positioned at elbow height, vertically and horizontally.

- *pull on a can ring-pull* - maximum static pull strength when opening a can ring-pull, whilst standing. The can was held with one hand and pull force exerted with the other. The cans were freely moveable and subjects were free to adopt their own posture. Pull strength was measured with the ring-pull in the starting position (flat to the top of the can) and at an angle of 75° to the top of the can.
- *press and lift with the foot* - maximum static strength when pressing and lifting with the foot on a bar and a pedal, whilst standing, and using one (dominant) foot. The pedal and bar were positioned at instep height.
- *pull on 20mm knob* - maximum static pulling strength on a small round knob, whilst standing, and using both one (dominant) hand and two hands. The handle was positioned at elbow height.

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 repetitions (lasting five seconds) for each experimental condition, and were given a two-minute rest interval between each exertion. If standing during testing subjects were free to adopt their own posture. The testing devices were adjusted and positioned at various heights according to which test was being performed, however the positions were always specified according to each subject's anthropometric measurements, such as shoulder height or instep height. Subjects were encouraged to exert maximal effort during testing and were able to obtain visual feedback from the testing device.

Equipment

Pull on 20mm knob, push with thumb or two or more fingers and wrist-twisting/push and turn strength (with torque attachment) were measured on a series of specially made handles which were attached to a Mecmesin™ Advanced Force Gauge (AFG 500N). Push and pull strength, pull with different grips and push with shoulder at 90% and 100% of shoulder height were measured with strain gauges attached to custom-made equipment. Press and lift with foot strength was measured by attaching a bar and pedal to a Kistler Type 9281B11 force plate fitted into the floor. Pull force on the can ring-pulls was measured using specially designed cans containing strain gauges.

Results

The results for each of the 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- 8. A correlation coefficient matrix detailing the relationship between all measurements can also be found in Appendix 9.

Effect of sex

For most measurements, no significant differences in maximum strength were found between male and female children (2-15 years). With some exceptions, in adults aged 16 years and over, males were generally found to be significantly stronger than females. Notable exceptions were: pushing with the shoulder at 90% of shoulder height and pulling on a very small handle (a 20mm diameter knob).

Effect of age

Generally, strength was seen to increase with age throughout childhood, to peak in adulthood, and then to decrease with age from around 50 years. There were generally significant differences between each successive age group.

Using the data

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

- Little correlation was found between the eight measurements, suggesting that the forces exerted were action-specific. That is, the size, shape and orientation of the handle or control, the directions of force and the number of hands used all affected the amount of force that could be exerted. However, some relationships were found: pushing force on a bar correlated significantly (across all conditions) with pushing forwards or downwards with the thumb or four fingers and with pushing with the shoulder (at 100% of shoulder height). Also wrist twisting strength (on a round knob and on a push and turn knob) correlated significantly with pulling strength on a can ring-pull.
- Within each measurement, significant differences were found between the experimental conditions. Biomechanical factors such as posture and the direction of movement affected strength. For instance, in all cases where measurements were made with one and two hands, the forces exerted with two hands were significantly higher than with one hand. Pushing on a bar generated significantly higher forces than pulling, as did pushing with the shoulder at 90% of shoulder height compared to pushing at 100%. Pressing down with the foot was significantly higher than lifting with the foot, and pushing down with the fingers was significantly higher than pushing down with just the thumb. The size, design and orientation of the handle or control also affected strength. Pulling on a round (55mm) handle generated significantly higher forces than pulling with an under-hand grip; wrist twisting strength on a push and turn knob with a push resistance of 10 Newtons was significantly higher than a knob with a push resistance of 20 Newtons. Pulling strength on a vertical can ring-pull was significantly higher than when the ring-pull was flat to the top of the can.
- No restrictions were placed on posture and subjects were able to grip and manipulate the various handles and knobs as they chose. 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).

Section 2

Data Sheets

1 Push and pull strength

Description

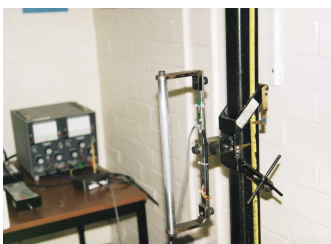
Maximum static strength when pushing and pulling with one and two hands on a cylindrical bar placed at shoulder height, in Newtons (N).

Method

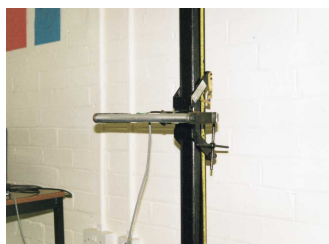
The subject stands in front of the measuring device and adopts a free posture. A static pushing or pulling force is exerted on a cylindrical bar placed at shoulder height (ie the bar doesn't move), with the dominant hand then with both hands. Subjects are stood behind a line on the floor, level with the bar. Subjects are instructed to build up 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 (20mm round and 300mm long), oriented vertically and horizontally, with the middle of the bar positioned at shoulder height.



Vertical bar for push/pull



Horizontal bar for push/pull



Pulling with two hands



Pushing with one hand

Subject numbers

154 subjects were measured:

Age (Years)	Male	Female	Total
2-5	7	8	15
6-10	4	8	12
11-15	7	6	13
16-20	18	5	23
21-30	6	8	14
31-50	9	9	18
51-60	4	5	9
61-70	5	14	19
71-80	9	13	22
81-90	2	7	9
Total	71	83	154

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 pushing and pulling actions, no significant difference was found between males and females aged between 2 and 30, with the exception of pushing with one hand in a vertical position in the 11 to 15 age group, where females exerted significantly higher forces. Males were found to exert significantly higher forces than females between ages 31 and 50 and 61 and 70 for all pulling conditions, and for pushing with two hands horizontally (ages 31-50 only) and vertically (ages 61-70 only) (Appendix 1b).

Effect of age

Mean maximum push and pull strength in males increases generally up to aged 50 and then decreases gradually to 90 years. This same general pattern was found for females, strength increasing up to 50 years then decreasing, however mean maximum strength appears to dip between the ages of 6 and 10 years and 20 to 30 years. However few significant differences were found between the age groups (Appendix 1c).

Effect of number of hands, orientation of the bar and pushing versus pulling

A significant difference in strength was found between both the number of hands used, and the orientation of bar, for both males and females. As expected, two hands exerted higher forces than one hand. Pushing was found to yield higher forces than pulling for both males and females in both orientations. Pushing with the handle in the vertical orientation with one hand yielded significantly higher forces than the horizontal orientation (Appendix 1d). Correlation coefficients for all measurements can be found in Appendix 1e.

Results

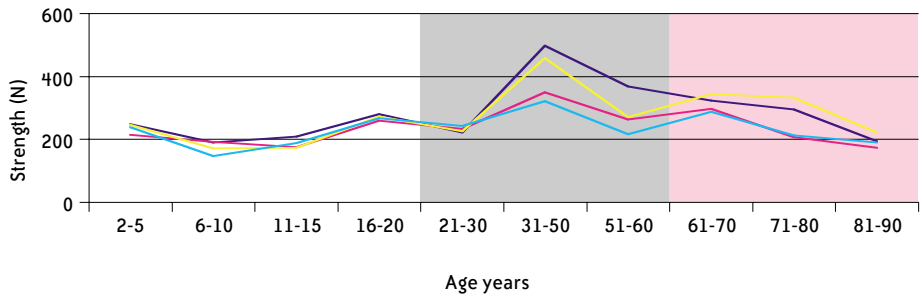
Push and pull on a cylindrical bar - one handed strength

Age (years)	Sex	Orientation	Push (N)				Pull (N)			
			No.	Mean	SD	Range	No.	Mean	SD	Range
2 – 5	m	Vertical	7	246.28	68.33	147.30 - 334.68	7	237.27	72.87	163.56 - 356.02
		Horizontal		246.90	82.89	129.87 - 360.82		214.46	66.48	106.24 - 310.97
	f	Vertical	8	245.89	152.80	51.44 - 456.69	8	223.96	147.41	44.82 - 442.01
		Horizontal		259.51	167.29	47.08 - 456.69		227.54	131.67	32.53 - 384.68
6 – 10	m	Vertical	4	170.18	99.45	86.30 - 304.17	4	146.16	84.14	69.39 - 261.84
		Horizontal		188.70	141.71	60.15 - 378.25		191.20	144.78	48.91 - 380.58
	f	Vertical	9	187.49	107.90	86.30 - 452.33	9	147.64	63.45	77.58 - 294.60
		Horizontal		177.81	124.78	81.94 - 500.26		150.83	84.97	57.10 - 364.21
11 – 15	m	Vertical	6	172.72	87.17	47.08 - 286.74	6	186.77	88.72	36.63 - 302.79
		Horizontal		207.58	117.10	47.08 - 400.04		175.17	70.61	44.82 - 253.65
	f	Vertical	6	312.89	125.14	169.09 - 500.26	6	260.47	83.66	143.09 - 372.40
		Horizontal		292.55	126.76	173.45 - 522.05		222.26	56.12	147.19 - 310.97
16 – 20	m	Vertical	14	271.80	117.33	164.73 - 565.62	14	267.10	116.97	130.81 - 499.33
		Horizontal		279.90	110.30	138.59 - 504.62		258.33	96.94	167.66 - 487.05
	f	Vertical	5	349.49	159.20	134.23 - 504.62	5	229.90	96.87	106.24 - 323.26
		Horizontal		340.78	174.21	112.44 - 508.98		238.91	92.23	110.33 - 315.07
21 - 30	m	Vertical	6	225.01	90.08	73.23 - 317.25	6	242.05	127.25	81.67 - 421.53
		Horizontal		221.38	99.02	77.58 - 339.03		231.81	107.92	110.33 - 384.68
	f	Vertical	8	231.73	183.49	60.15 - 609.20	8	224.99	154.07	102.14 - 548.47
		Horizontal		223.56	183.01	55.80 - 569.98		212.19	135.34	65.29 - 429.72
31 – 50	m	Vertical	10	457.12	171.77	190.88 - 722.49	10	320.39	90.15	196.32 - 495.24
		Horizontal		497.21	193.85	195.24 - 879.36		347.83	96.22	212.70 - 495.24
	f	Vertical	9	315.31	111.16	147.30 - 482.83	9	225.90	41.44	163.56 - 282.31
		Horizontal		328.38	137.59	129.87 - 574.34		233.17	51.06	147.19 - 298.69
51 – 60	m	Vertical	4	270.40	53.77	208.31 - 339.03	4	215.77	33.50	184.04 - 261.84
		Horizontal		367.36	71.29	278.03 - 443.61		261.84	26.54	233.17 - 286.41
	f	Vertical	5	315.50	101.38	208.31 - 426.18	5	229.08	89.24	134.90 - 323.26
		Horizontal		272.80	97.99	177.81 - 391.32		226.62	51.27	163.56 - 278.22
61 – 70	m	Vertical	5	342.52	207.99	64.51 - 648.42	5	286.41	152.03	40.72 - 442.01
		Horizontal		322.48	198.36	51.44 - 609.20		295.41	164.56	44.82 - 507.52
	f	Vertical	14	206.75	135.78	55.80 - 508.98	14	153.04	95.27	40.72 - 384.68
		Horizontal		190.88	111.29	51.44 - 426.18		152.74	83.62	57.10 - 327.35
71 – 80	m	Vertical	8	331.02	128.42	124.90 - 539.49	9	211.20	124.63	26.77 - 346.14
		Horizontal		293.92	119.33	63.66 - 459.40		206.53	111.89	22.57 - 320.93
	f	Vertical	13	247.42	150.88	116.80 - 680.82	13	239.28	113.60	106.24 - 472.21
		Horizontal		261.21	132.91	116.80 - 577.18		244.96	108.77	134.90 - 514.23
81 – 90	m	Vertical	2	221.48	69.96	172.01 - 270.95	2	188.56	74.29	136.03 - 241.08
		Horizontal		193.21	16.66	181.44 - 204.99		171.75	38.63	144.43 - 199.06
	f	Vertical	7	258.16	164.64	101.35 - 534.78	7	225.48	154.15	47.78 - 472.21
		Horizontal		245.37	143.18	82.50 - 506.51		223.07	137.45	51.98 - 455.40

Push and pull on a cylindrical bar - two handed strength

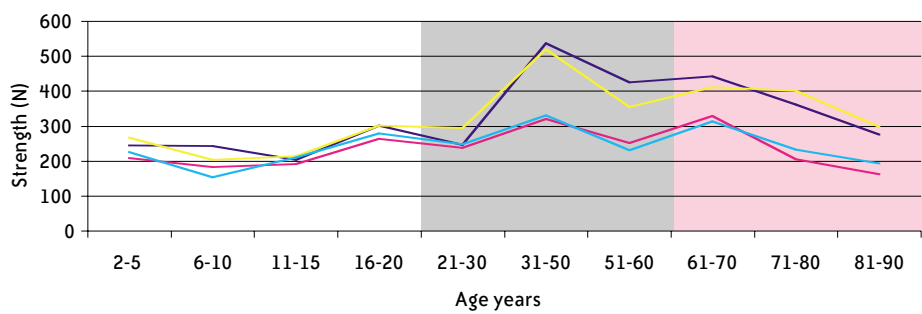
Age (years)	Sex	Orientation	Push (N)				Pull (N)			
			No.	Mean	SD	Range	No.	Mean	SD	Range
2 – 5	m	Vertical	7	266.20	59.78	164.73 - 334.68	7	225.59	75.74	126.70 - 323.30
		Horizontal		244.41	78.67	147.30 - 373.89		208.01	63.02	110.30 - 294.60
	f	Vertical	8	296.00	210.41	42.72 - 604.84	8	258.76	171.06	44.80 - 491.10
		Horizontal		280.21	182.76	60.15 - 539.48		248.00	188.54	28.40 - 560.80
6 – 10	m	Vertical	4	202.86	149.79	77.58 - 413.11	4	152.30	82.38	57.10 - 253.60
		Horizontal		243.17	176.93	99.37 - 495.90		183.03	111.42	61.20 - 306.90
	f	Vertical	9	214.60	141.70	108.09 - 574.34	9	164.01	63.55	69.40 - 270.00
		Horizontal		137.14	25.96	99.37 - 190.88		146.27	66.12	57.10 - 294.60
11 – 15	m	Vertical	6	212.67	138.32	47.08 - 461.04	6	209.28	129.86	48.90 - 442.00
		Horizontal		203.23	103.13	68.87 - 386.97		190.85	104.45	48.90 - 372.40
	f	Vertical	6	376.80	137.35	195.24 - 565.62	6	278.90	91.90	151.30 - 417.40
		Horizontal		318.70	122.62	190.88 - 522.05		232.50	61.04	134.90 - 323.30
16 – 20	m	Vertical	14	301.68	108.62	177.81 - 600.48	14	278.51	122.30	130.80 - 597.60
		Horizontal		301.37	130.42	138.59 - 626.63		263.61	115.15	139.00 - 585.30
	f	Vertical	5	389.58	160.95	151.66 - 530.76	5	229.06	94.81	102.10 - 347.80
		Horizontal		372.15	184.48	142.95 - 583.05		216.78	75.30	102.10 - 290.50
21 – 30	m	Vertical	6	294.73	125.61	86.30 - 421.83	6	248.18	113.30	106.20 - 384.70
		Horizontal		245.35	109.22	90.66 - 356.46		237.27	99.78	122.60 - 356.00
	f	Vertical	8	256.24	209.03	55.80 - 644.06	8	237.78	179.79	102.10 - 618.10
		Horizontal		230.64	205.09	55.80 - 644.06		206.56	122.38	94.00 - 454.30
31 – 50	m	Vertical	10	518.56	185.49	221.38 - 805.29	10	329.41	96.64	171.80 - 499.30
		Horizontal		536.86	216.83	212.67 - 905.51		320.39	91.70	188.10 - 450.20
	f	Vertical	9	353.56	125.42	164.73 - 556.91	9	219.99	54.30	139.00 - 298.70
		Horizontal		329.35	155.50	125.52 - 648.42		223.61	61.69	134.90 - 302.80
51- 60	m	Vertical	4	354.29	49.11	286.74 - 404.40	4	231.13	26.42	208.60 - 265.90
		Horizontal		425.09	74.32	347.75 - 526.41		251.60	24.66	225.00 - 278.20
	f	Vertical	5	391.32	140.96	199.59 - 530.76	5	258.58	113.32	159.50 - 425.60
		Horizontal		305.05	82.01	199.59 - 382.61		232.38	68.96	155.40 - 323.30
61 – 70	m	Vertical	5	410.50	242.55	86.30 - 766.07	5	313.42	166.97	53.00 - 499.30
		Horizontal		441.87	331.46	112.44 - 1001.37		328.16	190.24	40.70 - 568.90
	f	Vertical	14	226.05	128.61	77.58 - 513.33	14	154.21	93.53	57.10 - 331.40
		Horizontal		212.36	105.96	68.87 - 382.61		155.66	83.24	48.90 - 298.70
71 – 80	m	Vertical	8	399.92	185.21	115.48 - 737.36	9	232.20	140.05	35.20 - 434.40
		Horizontal		361.64	114.65	139.03 - 482.95		205.12	108.68	35.20 - 333.50
	f	Vertical	13	309.65	177.29	129.87 - 798.60	13	264.37	116.66	134.90 - 514.20
		Horizontal		313.84	185.10	138.59 - 826.87		264.36	122.89	122.60 - 518.40
81 – 90	m	Vertical	2	296.86	96.61	228.55 - 365.17	2	192.75	56.50	152.80 - 232.70
		Horizontal		275.66	6.66	270.95 - 280.37		161.25	59.47	119.20 - 203.30
	f	Vertical	7	336.91	225.53	106.06 - 756.20	7	214.09	114.83	77.20 - 396.60
		Horizontal		282.39	177.57	77.79 - 563.04		191.87	101.99	56.20 - 346.10

Mean maximum push and pull strength with one hand (males)



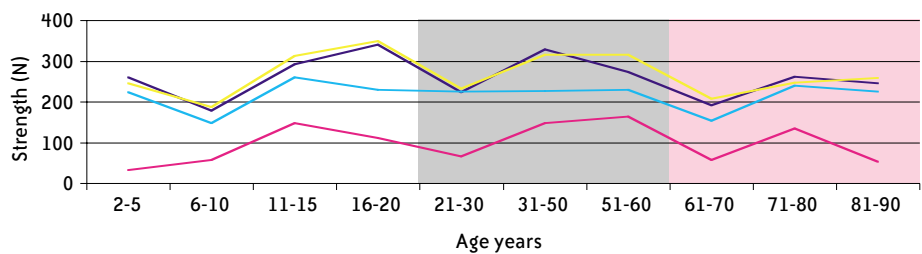
- Horizontal push with 1 hand
 - Horizontal pull with 1 hand
 - Vertical push with 1 hand
 - Vertical pull with 1 hand
- Childdata
 Adultdata
 Older adultdata

Mean maximum push and pull strength with two hands (males)



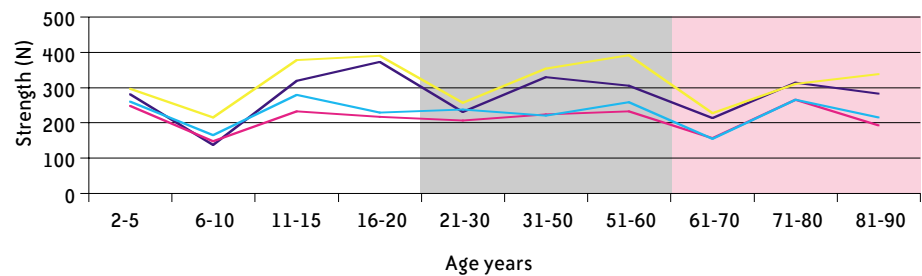
- Horizontal push 2 hands
 - Horizontal pull 2 hands
 - Vertical push 2 hands
 - Vertical pull 2 hands
- Childdata
 Adultdata
 Older adultdata

Mean maximum push and pull strength with one hand (females)



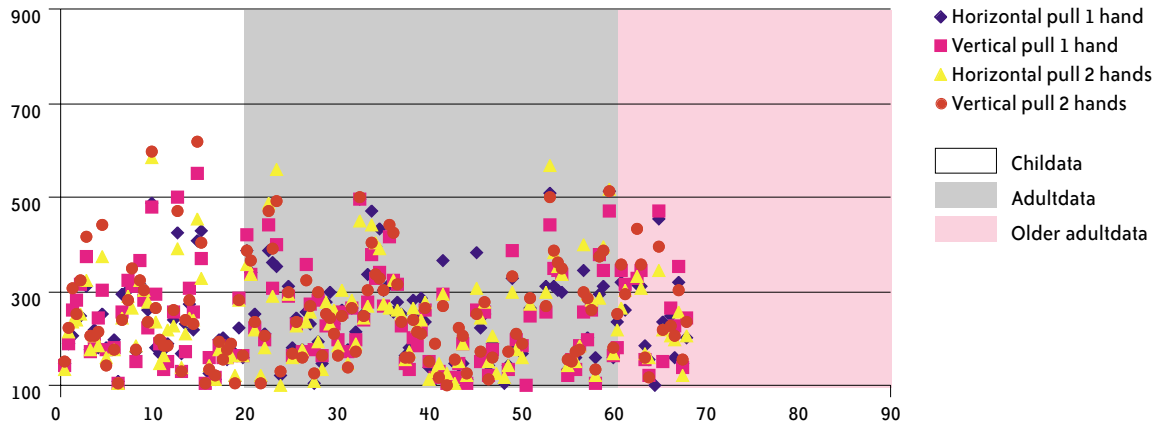
- Horizontal push 1 hand
 - Horizontal pull 1 hand
 - Vertical push 1 hand
 - Vertical pull 1 hand
- Childdata
 Adultdata
 Older adultdata

Mean maximum push and pull strength with two hands (females)

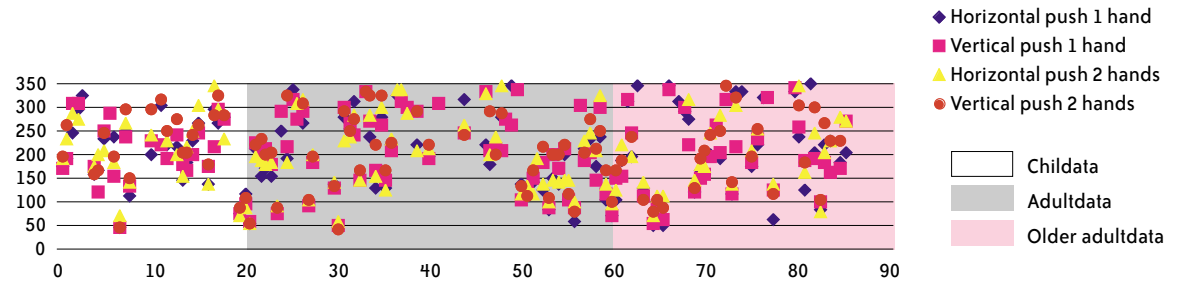


- Horizontal push 2 hands
 - Horizontal pull 2 hands
 - Vertical push 2 hands
 - Vertical pull 2 hands
- Childdata
 Adultdata
 Older adultdata

Maximum pull strength



Maximum push strength



2 Push with the thumb or 2 or more fingers

Description

Maximum static pushing strength using the thumb or two or more fingers, in Newtons (N).

Method

A static pushing force is exerted on a button using either the thumb or two or more fingers (subject can use as many fingers as they wish), using the dominant hand. The subject is either standing, with the button positioned at elbow height, or seated with the button positioned at the side of the hip, at seat pan height (430mm). Small children are allowed to rest their feet on a box. Subjects are instructed to build up their maximum strength in the first few seconds and to maintain maximum strength for a further few seconds. Three measurements were taken in each posture:

- 1) Pushing forward using finger pads only
- 2) Pushing down with thumb
- 3) Pushing down with finger pads

Button type and size

A plastic cube (50mm x 50mm).



Experimental trial: pushing down with the fingers at seat height



Experimental trial: pushing forward with the fingers at elbow height

Subject numbers

152 subjects were measured

Age (Years)	Male	Female	Total
2-5	8	8	16
6-10	5	8	13
11-15	7	5	12
16-20	14	5	19
21-30	7	9	16
31-50	7	8	15
51-60	4	5	9
61-70	4	15	19
71-80	9	14	23
81-90	2	8	10
Total	67	85	152

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 difference was found from ages 2 to 15. However from ages 16 to 60 and 71 to 80 males exerted significantly higher force than females (Appendix 2b).

Effect of age

Pushing strength using two or more fingers or the thumb generally increases through childhood (2 to15), peaks in adulthood and decreases after 50 years for both males and females. A significant difference was found between nearly all age groups for all conditions (Appendix 2c).

Effect of pushing with the thumb or the fingers, and of orientation and position of the button

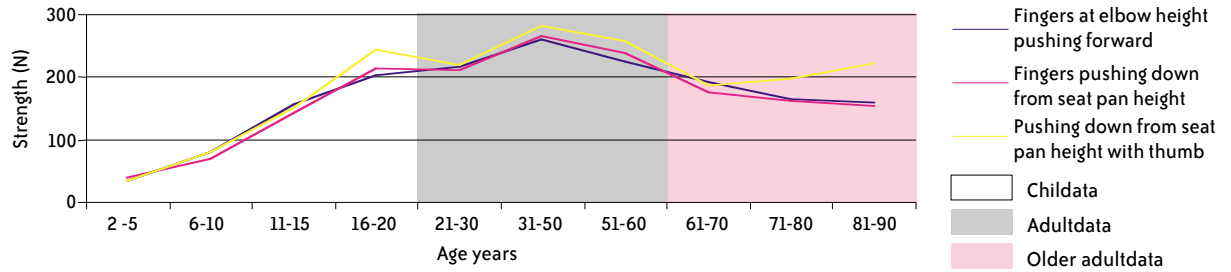
Pushing forward from the elbow with the fingers yielded significantly higher forces than pushing down from the hip with the fingers or with the thumb. Also, pushing down from the hip with the fingers yielded significantly higher forces than pushing down from the hip with the thumb (Appendix 2d). Correlation coefficients for all measurements can be found in Appendix 2e.

Results

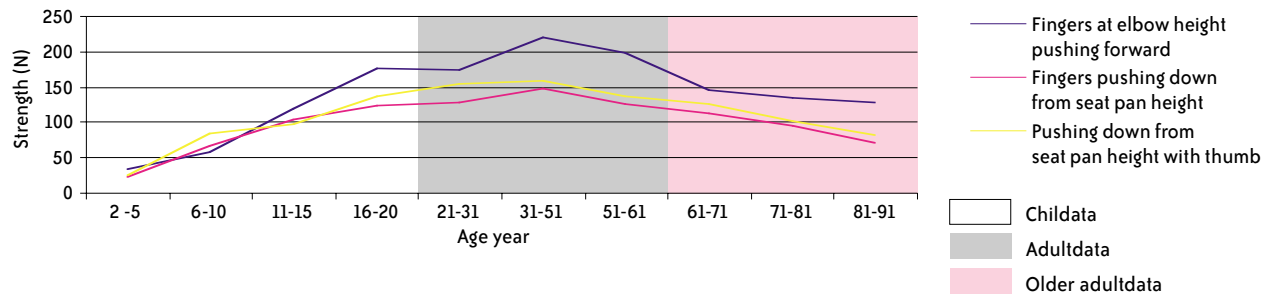
Pushing strength with the thumb or two or more fingers

		Pushing with two or more fingers (N)								Pushing with the thumb (N)			
		Pushing forward at elbow height				Pushing down at seat pan height				Pushing down at seat pan height			
Age (yrs)	Sex	No.	Mean	SD	Range	No.	Mean	SD	Range	No.	Mean	SD	Range
2 – 5	m	9	27.49	13.30	6.70 - 42.00	8	31.95	13.20	12.00 - 50.20	8	26.80	11.94	13.60 - 51.20
	f	8	20.80	9.93	6.10 - 34.70	8	22.26	9.61	9.00 - 37.50	8	24.16	8.30	10.30 - 36.30
6 – 10	m	5	65.86	24.06	36.10 - 91.30	5	56.18	20.78	33.70 - 82.30	5	66.62	31.28	36.10 - 104.10
	f	8	78.04	29.89	47.20 - 124.70	8	66.81	20.58	44.80 - 98.80	8	82.75	35.70	35.50 - 142.60
11 – 15	m	7	129.51	32.37	80.30 - 172.10	7	117.60	29.89	73.00 - 161.80	7	124.43	44.60	86.00 - 216.50
	f	5	96.10	12.53	84.00 - 114.10	5	103.20	13.42	91.80 - 126.30	5	97.24	17.20	78.50 - 123.20
16 – 20	m	14	168.39	34.89	98.80 - 234.30	14	176.40	39.19	102.60 - 230.00	14	202.36	56.17	96.00 - 307.40
	f	5	113.84	39.32	63.90 - 164.30	5	122.42	27.96	87.80 - 158.30	5	136.80	44.31	73.20 - 198.20
21 - 30	m	7	178.74	39.62	110.30 - 223.10	7	174.17	14.88	155.00 - 193.40	7	182.53	11.36	159.60 - 195.30
	f	9	139.27	24.36	103.80 - 179.30	9	128.03	26.04	101.30 - 161.60	9	153.03	29.15	122.50 - 209.00
31 – 50	m	7	216.04	45.24	167.40 - 285.40	7	219.61	40.57	161.70 - 281.60	7	233.40	52.36	179.00 - 311.70
	f	8	150.39	33.32	100.80 - 198.20	8	147.00	39.04	82.50 - 192.00	8	157.49	35.35	89.90 - 204.70
51 – 60	m	4	185.83	21.05	167.50 - 207.20	4	198.10	45.66	162.40 - 262.20	4	214.40	22.93	183.40 - 234.20
	f	5	124.48	27.26	92.60 - 162.10	5	125.96	34.69	107.30 - 187.80	5	136.46	44.67	77.80 - 181.60
61 – 70	m	4	158.65	55.03	80.70 - 209.20	4	145.30	44.43	87.10 - 192.80	4	155.63	45.79	90.30 - 187.60
	f	15	116.41	43.55	69.50 - 259.70	15	112.10	36.73	67.40 - 226.90	15	125.05	48.32	62.00 - 237.70
71 – 80	m	9	136.42	22.03	104.10 - 170.90	9	134.76	26.18	88.40 - 167.40	9	162.56	49.72	111.00 - 262.60
	f	14	90.49	27.25	49.10 - 144.40	14	93.35	27.03	41.50 - 133.90	14	101.50	32.05	53.70 - 154.20
81 – 90	m	2	131.15	59.18	89.30 - 173.00	2	126.35	45.47	94.20 - 158.50	2	185.00	90.51	121.00 - 249.00
	f	8	73.25	17.47	51.70 - 92.90	8	70.33	19.37	36.70 - 102.10	8	82.23	16.30	62.70 - 115.90

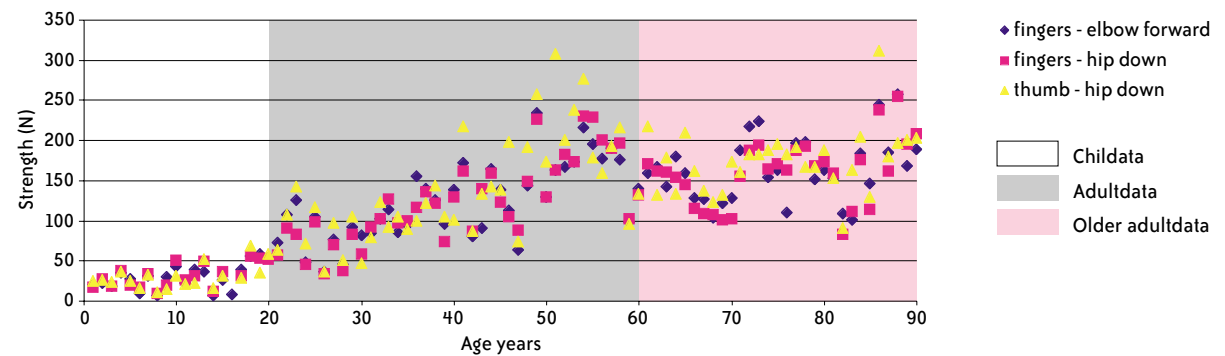
Mean maximum push strength with the thumb or 2 or more fingers (males)



Mean maximum push strength with the thumb or 2 or more fingers (females)



Maximum push strength when pushing with thumb or two or more fingers



3 Push with the shoulder

Description

Maximum static pushing force when pushing with the shoulder, at or near shoulder height and at 90% of shoulder height, in Newtons (N).

Method

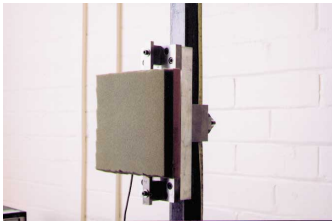
The subject stands in front of the measuring device and adopts a free posture. A static pushing force is exerted with the shoulder on a force plate. Subjects are stood behind a line on the floor, level with the bar. The force plate is positioned at shoulder at 90% and at 100% of the subject's shoulder height. Subjects are instructed to build up their maximum strength in the first few seconds and to maintain maximum strength for a further few seconds.

Pad type and size

A force plate (200mm x 200mm) covered with 25mm thick foam.

Button type and size

A plastic cube (50mm x 50mm).



Foam pad for measuring push with the shoulder



Measuring push with the shoulder at 90% of shoulder height

Subject numbers

152/140 subjects were tested

Push at 100% of shoulder height			
Age (Years)	Male	Female	Total
2-5	8	9	17
6-10	5	8	13
11-15	7	5	12
16-20	14	4	18
21-30	7	9	16
31-50	7	8	15
51-60	4	5	9
61-70	4	15	19
71-80	9	14	23
81-90	2	8	10
Total	67	85	152

Push at 90% of shoulder height			
Age (Years)	Male	Female	Total
2-5	9	8	17
6-10	5	8	13
11-15	7	5	12
16-20	7	5	12
21-30	7	6	13
31-50	9	8	17
51-60	4	4	8
61-70	5	14	19
71-80	9	13	22
81-90	2	5	7
Total	64	76	140

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

Analysis

Effect of sex

Males were significantly stronger than females when pushing at 100% of shoulder height from age 11 to 70, except at ages 31-50. When pushing at 90% of shoulder height, the only significant differences between the sexes were found in the 11 to 20 and 51 to 60 age groups (Appendix 3b).

Effect of age

As with the other measurements, strength generally increases in children, peaks in adulthood and declines in older adults. When pushing with the shoulder at both heights, those aged between 6 and 90 years were found to be significantly stronger than the 2 to 5 year olds. When pushing with the shoulder at 100% of shoulder height: 11 to 50 year olds were found to be significantly stronger than 2 to 10 year olds; 11 to 15 year olds were found to be significantly stronger than 71 to 90 year olds. 11-60 year olds were found to be significantly stronger than 71 to 90 year olds when pushing with the shoulder at 90% of shoulder height. (Appendix 3c).

Effect of the height at which people were pushing with the shoulder

Subjects were found to be able to yield a significantly higher mean strength when pushing with the shoulder at 90% of shoulder height when compared to pushing at 100% of shoulder height (Appendix 3d). Correlation coefficients for all measurements can be found in Appendix 3e.

Results

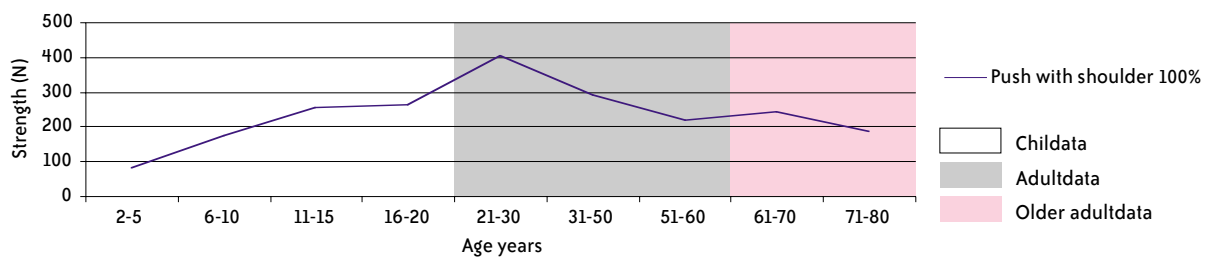
Pushing strength with the shoulder at 100% of shoulder height

100% of shoulder height (N)					
Age (years)	Sex	No.	Mean	SD	Range
2-5	m	8	79.78	35.02	51.58 -157.98
	f	9	72.39	12.85	47.33 - 94.14
6-10	m	5	172.45	48.11	98.40 -226.07
	f	8	130.85	42.68	64.35 - 196.28
11-15	m	7	255.25	35.30	213.30 - 298.42
	f	5	152.87	18.89	136.70 - 179.26
16-20	m	14	262.25	58.06	192.03 -413.33
	f	4	181.39	30.79	145.24 -209.05
21-30	m	7	401.77	86.51	238.84- 498.44
	f	9	201.48	37.09	136.70 -277.14
31-50	m	7	290.52	70.89	204.79 -392.05
	f	8	253.73	162.45	94.14 -630.37
51-60	m	4	216.50	33.76	187.77 -260.12
	f	5	152.02	17.70	132.44 - 175.00
61-70	m	4	242.03	44.96	204.79 -306.93
	f	15	169.33	58.92	89.89 - 349.49
71-80	m	9	186.82	63.33	102.65 -285.65
	f	14	136.40	63.29	60.10 -315.44
81-90	m	2	151.60	75.23	98.40 -204.79
	f	8	101.59	37.22	77.12 -187.77

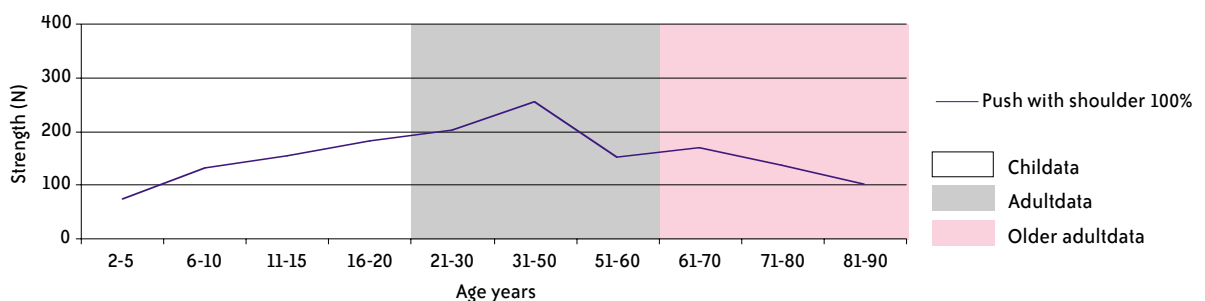
Pushing strength with the shoulder at 90% of shoulder height

90% of shoulder height (N)					
Age (years)	Sex	No.	Mean	SD	Range
2-5	m	9	105.96	46.56	51.58 - 179.26
	f	8	99.46	21.31	64.35 - 123.93
6-10	m	5	215.01	82.45	136.70 - 353.74
	f	8	237.24	119.62	106.91 - 460.14
11-15	m	7	432.78	76.12	349.49 - 528.23
	f	5	247.35	90.43	140.96 - 362.26
16-20	m	7	595.72	39.50	532.49 - 651.65
	f	5	312.04	111.68	217.56 - 455.88
21-30	m	7	620.04	100.35	511.21 - 749.53
	f	6	504.12	102.87	358.00 - 587.81
31-50	m	9	645.98	267.85	349.49 - 1102.76
	f	8	469.71	170.77	170.75 - 638.88
51-60	m	4	497.38	136.95	426.09 - 707.22
	f	4	281.40	39.47	226.07 - 319.70
61-70	m	5	510.36	157.04	387.79 - 783.58
	f	14	273.80	80.27	170.75 - 451.63
71-80	m	9	339.09	100.60	170.75 - 494.19
	f	13	228.36	70.27	102.65 - 336.72
81-90	m	2	281.40	18.06	268.63 - 294.16
	f	5	167.34	76.21	89.89 - 294.16

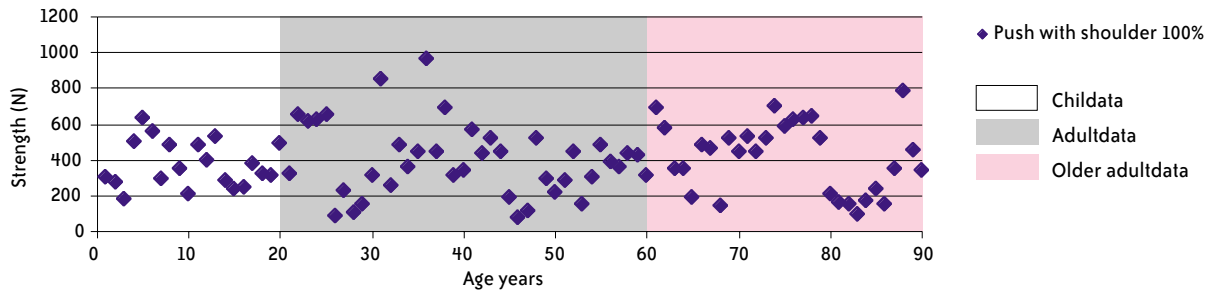
Mean maximum pushing strength with the shoulder at 100% of shoulder height (males)



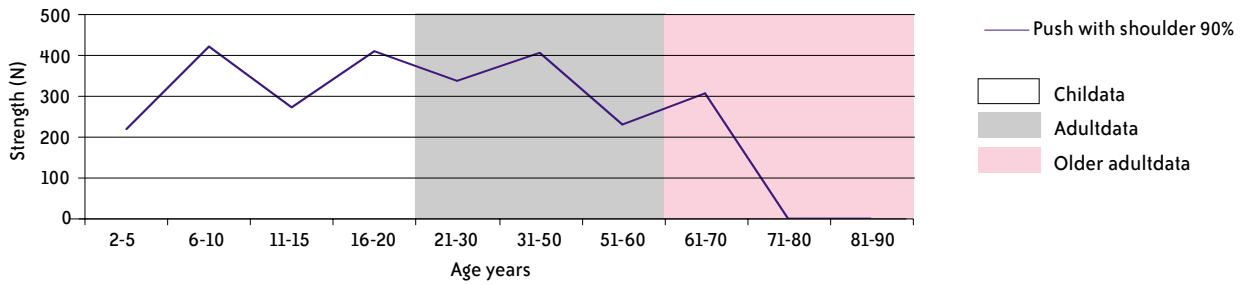
Mean maximum pushing strength with the shoulder at 100% of shoulder height (females)



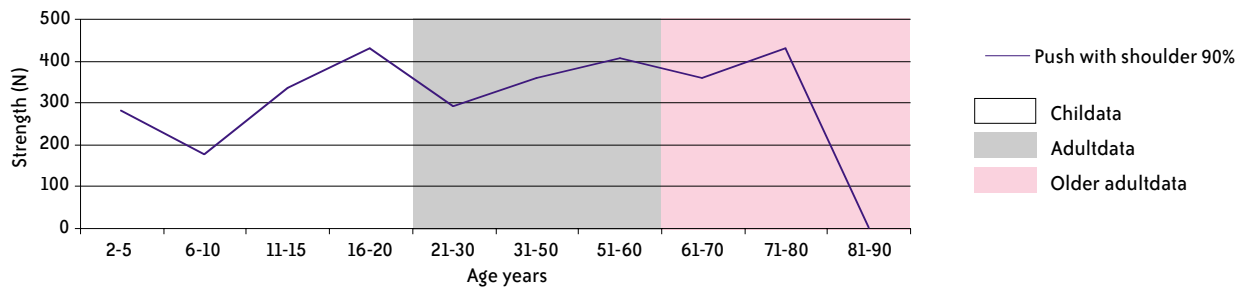
Maximum pushing strength with the shoulder at 100% of shoulder height



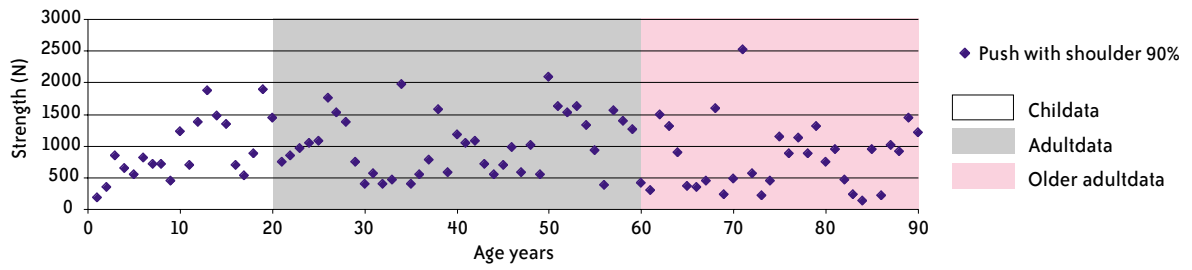
Mean maximum pushing strength with the shoulder at 90% of shoulder height (males)



Mean maximum strength for pushing with the shoulder at 90% of shoulder height (females)



Maximum pushing strength with the shoulder at 90% of shoulder height



4 Pull with different grips

Description

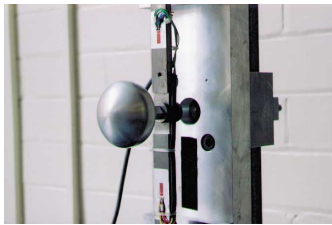
Maximum static pulling force on two different handle types, in Newtons (N).

Method

The subject stands in front of the measuring device and adopts a free posture. A maximum static pulling force is exerted on two different handle types (an under-hand grip handle and a round door knob). Subjects are instructed to build up their maximum strength in the first few seconds and to maintain maximum strength for a further few seconds.

Handle type and size

Two handles positioned at elbow height: a round door knob (55mm diameter) and an under-hand grip handle (140mm long, 25mm/40mm high at the front/back, 20mm deep, 5mm thickness of metal).



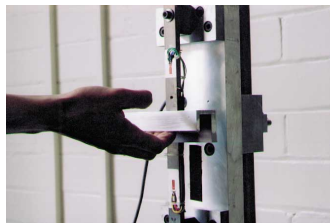
55mm door knob



Pulling on 55mm knob



Underhand grip handle



Pulling with an underhand grip

Subject numbers

152 subjects were measured

Age (Years)	Male	Female	Total
2-5	6	3	9
6-10	5	8	13
11-15	7	5	12
16-20	14	5	19
21-30	6	9	15
31-50	7	8	15
51-60	4	4	8
61-70	4	15	19
71-80	8	14	22
81-90	2	8	10
Total	63	79	142

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

Analysis

Effect of sex

Males were found to be significantly stronger than females when using the under-hand grip handle with 1 hand, between the ages of 16-20, 31-60 and 71-80 years, and when using the round handle with 2 hands between the ages 21-50. Otherwise there were no significant differences (Appendix 4b).

Effect of age

Pulling with different grips generally increases with age throughout childhood, it peaks in adulthood and then decreases with age from around 50 years old. Some significant difference was found between the age groups (Appendix 4c).

Effect of the number of hands used and the handle type

Significant differences were found between the force exerted with the under-hand grip handle and the round handle, and between using one or two hands. The highest mean maximum forces were exerted with two hands. The forces exerted with the round handle were significantly higher than with the under-hand grip handle (Appendix 4d). Correlation coefficients for all measurements can be found in Appendix 4e.

Results

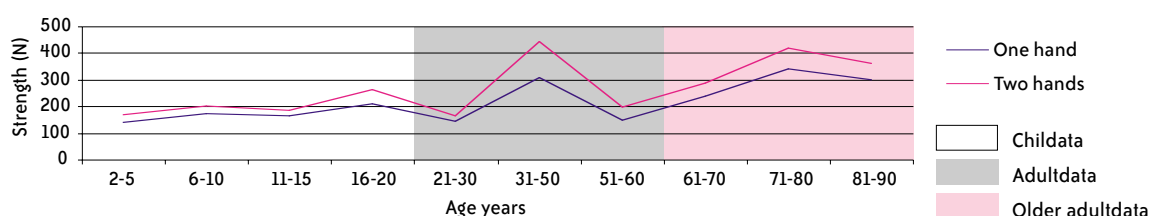
Pulling with different grips - one handed strength

		Underhand grip handle (N)				55mm round handle (N)			
Age (yrs)	Sex	No.	Mean	SD	Range	No.	Mean	SD	Range
2 – 5	m	6	9.75	8.90	0.44 - 24.19	6	140.91	42.08	65.13 - 184.54
	f	3	9.75	5.34	3.62 - 13.33	3	140.02	85.82	78.09 - 237.99
6 – 10	m	5	39.23	14.48	16.57 - 55.42	5	172.63	97.47	100.75 - 304.74
	f	8	48.80	26.50	24.19 - 101.40	8	205.02	57.51	110.46 - 273.62
11 – 15	m	7	109.42	60.23	10.09 - 202.35	7	163.63	54.69	87.80 - 267.68
	f	5	85.05	16.66	65.76 - 101.40	5	224.87	84.48	123.42 - 315.19
16 – 20	m	14	159.83	39.02	71.61 - 214.23	14	210.04	130.72	39.23 - 428.02
	f	5	101.49	35.44	42.47 - 137.03	5	175.99	72.53	94.28 - 291.43
21 - 30	m	6	153.32	42.55	103.99 - 214.23	6	142.09	99.17	19.81 - 285.50
	f	9	120.28	24.95	95.46 - 166.72	9	260.11	123.17	110.46 - 487.41
31 – 50	m	7	182.97	51.76	125.15 - 255.80	7	308.23	83.17	129.89 - 374.58
	f	8	123.16	24.89	87.80 - 160.78	8	208.12	94.55	65.76 - 338.94
51 – 60	m	4	145.94	21.95	125.15 - 172.66	4	145.94	21.95	125.15 - 172.66
	f	4	85.59	40.22	26.28 - 113.27	3	78.34	45.95	26.28 - 113.27
61 – 70	m	4	141.16	48.28	97.51 - 196.41	4	239.67	209.56	77.64 - 546.80
	f	15	121.14	74.45	48.95 - 243.92	15	329.48	170.15	59.82 - 606.19
71 - 80	m	8	112.53	38.81	59.82 - 160.78	8	341.91	269.82	30.13 - 624.00
	f	14	63.39	26.52	26.28 - 110.46	14	342.04	221.89	65.76 - 707.14
81 – 90	m	2	86.55	71.39	36.07 - 137.03	2	297.37	159.57	184.54 - 410.21
	f	8	50.01	20.04	23.04 - 77.64	8	210.93	121.57	24.19 - 379.21

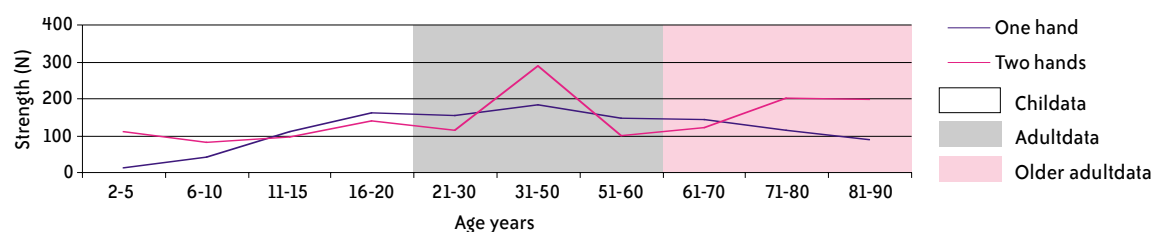
Pulling with different grips – two handed strength

Age (yrs)	Sex	Underhand grip handle (N)				55mm round handle (N)			
		No.	Mean	SD	Range	No.	Mean	SD	Range
2 – 5	m	6	109.52	60.99	45.71 - 226.11	6	169.70	46.39	94.28 - 237.99
	f	3	108.88	66.27	35.99 - 165.51	3	152.97	75.38	94.28 - 237.99
6 – 10	m	5	78.73	10.59	68.37 - 94.28	5	201.12	83.72	136.37 - 333.88
	f	8	139.16	41.02	68.37 - 184.54	8	265.01	87.18	136.37 - 368.64
11 – 15	m	7	93.08	54.41	35.99 - 196.41	7	183.83	96.97	97.51 - 392.39
	f	5	103.41	21.13	83.58 - 137.03	5	229.73	73.62	136.37 - 327.07
16 – 20	m	14	136.40	94.28	12.30 - 303.30	14	264.07	177.71	42.01 - 612.13
	f	5	95.40	38.74	36.00 - 137.00	5	186.78	76.53	100.75 - 303.31
21 - 30	m	6	111.78	93.30	3.62 - 232.05	6	161.97	104.09	26.28 - 315.19
	f	9	182.67	119.45	48.95 - 422.09	9	322.79	149.95	142.97 - 606.19
31 – 50	m	7	286.33	81.35	107.23 - 344.88	7	441.66	127.46	184.94 - 582.43
	f	8	137.20	72.32	30.13 - 273.62	8	270.54	170.30	83.58 - 594.31
51 – 60	m	4	98.40	125.84	12.30 - 285.50	4	197.87	201.47	42.00 - 493.35
	f	4	73.70	35.80	26.30 - 113.30	4	112.29	58.64	26.31 - 154.84
61 – 70	m	4	120.24	95.54	59.82 - 261.74	4	288.44	222.90	113.32 - 612.13
	f	15	186.49	126.02	29.52 - 457.72	15	405.50	193.24	172.04 - 760.59
71 - 80	m	8	200.13	169.11	18.25 - 416.15	8	416.94	303.22	59.76 - 748.72
	f	14	187.87	148.23	29.52 - 463.66	14	401.62	267.94	81.27 - 909.06
81 – 90	m	2	196.41	50.39	160.78 - 232.05	2	359.69	155.37	249.91 - 469.60
	f	8	107.09	72.83	0.44 - 208.29	7	274.43	104.86	160.78 - 433.96

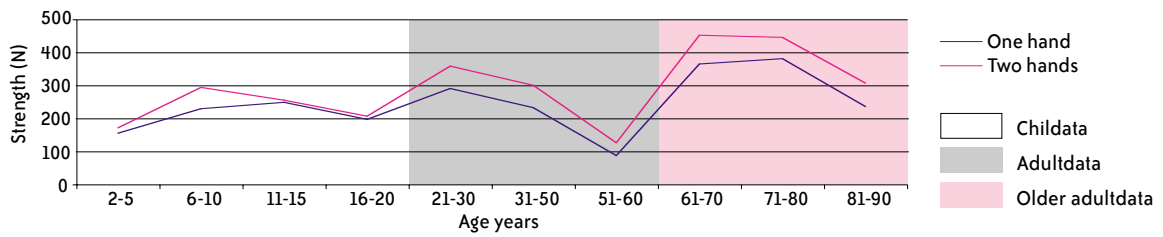
Mean maximum pulling strength on the round handle (males)



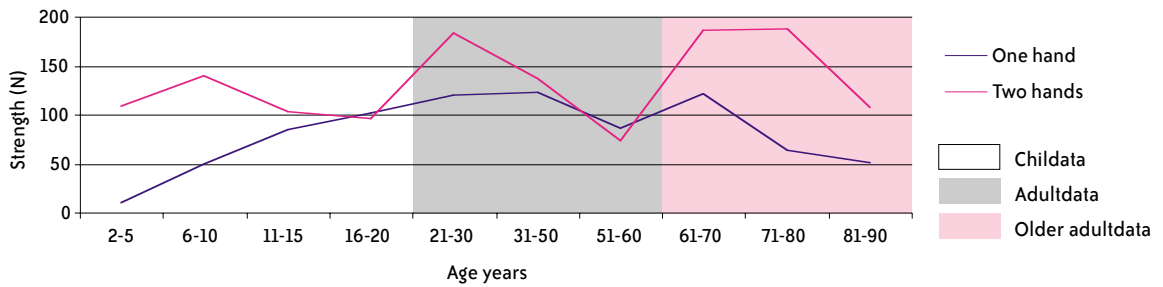
Mean maximum pulling strength on the under-hand grip handle (males)



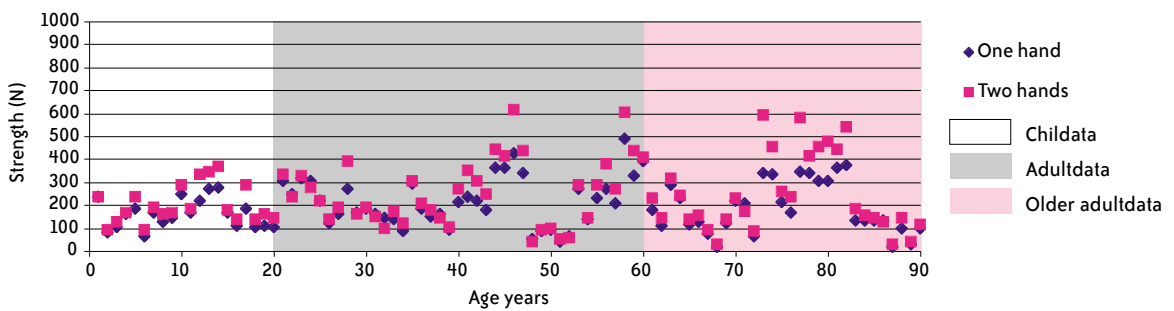
Mean maximum pulling strength on the round handle (females)



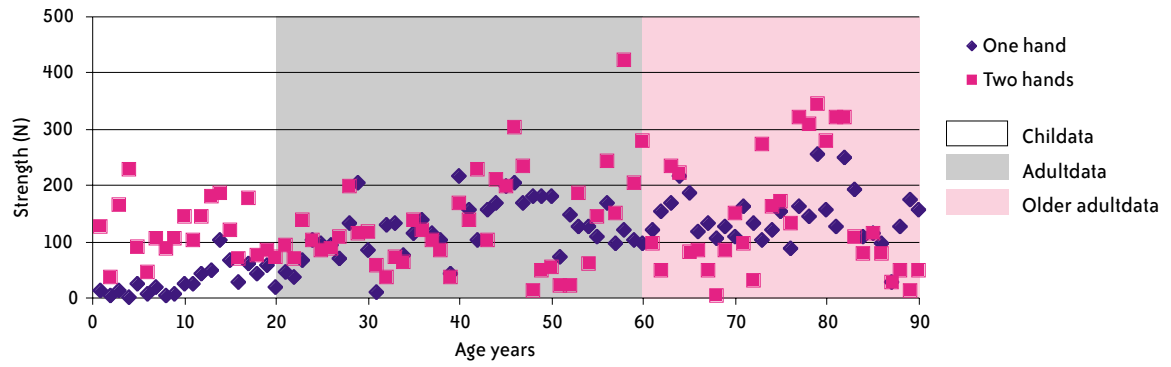
Mean maximum pulling strength on the under-hand grip handle (females)



Maximum pulling strength on the round handle



Maximum pulling strength on the under-hand grip handle



5 Wrist twisting and push-and-turn strength

Description

Maximum static torque (clock-wise) on two different handle types, in Newton-metres (Nm).

Method

The subject stands in front of the measuring device and adopts a free posture. A maximum static twisting force is exerted using one (dominant) hand on two types of handle: a circular knob and push and turn knob. Subjects are instructed to build up their maximum strength in the first few seconds and to maintain maximum strength for a further few seconds.

Handle type and size

Three handles positioned vertically and horizontally:

- i) a round knob, 20mm diameter and 20 mm depth
- ii) a ridged push-and-turn knob of 40mm diameter with a ridge 15mm deep, 10mm wide, with a push resistance of 10 Newtons
- iii) as ii) with a push resistance of 20 Newtons.



Push and turn knob



Measuring twist force on the push and turn knob



20 mm knob



Measuring twist force on the 20 mm knob

Subject numbers

142 subjects were measured:

Age (Years)	Male	Female	Total
2-5	9	7	16
6-10	5	8	13
11-15	6	6	12
16-20	7	5	12
21-30	6	7	13
31-50	8	8	16
51-60	4	4	8
61-70	4	14	18
71-80	9	12	21
81-90	5	8	13
Total	63	79	142

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

Analysis

Effect of sex

Males were significantly stronger than females in wrist twisting strength using the push and turn knob across nearly all ages (16-80 years). When using the round knob, few significant differences between the sexes were found, the only exception being in the age groups 21-30 and 61-70 (vertical knob only) and 71-80 (horizontal knob only) (Appendix 5b).

Effect of age

Maximum strength for both vertical and horizontal wrist twisting increases generally throughout childhood (2-15 years), it peaks in adulthood, and then decreases with age from around 50 years. Some significant differences were found between the age groups but not consistently, except for ages 2-10 where all older age groups were significantly stronger (Appendix 5c).

Effect of handle type and orientation

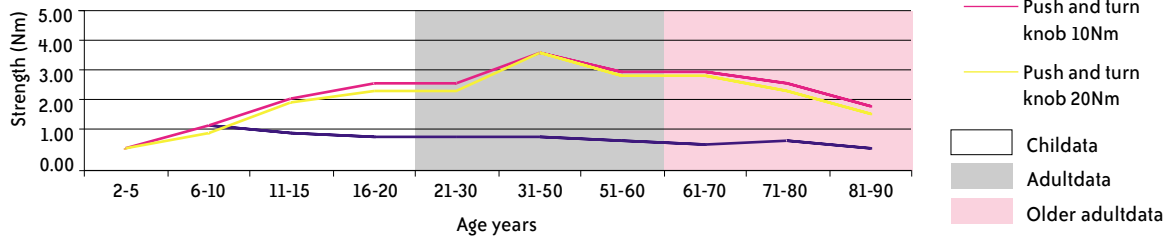
The handle type appears to significantly effect maximum strength, as significant differences were found between the circular knob and the ridged knob (10 & 20 Newtons) in both the horizontal and the vertical orientation. As expected, the push and turn knobs allowed a better grip and so generated higher forces than the circular knob, which had a smooth surface. Generally a significance difference was found between resistance of the two push-and-turn knobs (10 & 20N) with a higher force being generated on the knob with least resistance in both the horizontal and the vertical orientation (Appendix 5d). Correlation coefficients for all measurements can be found in Appendix 5e.

Results

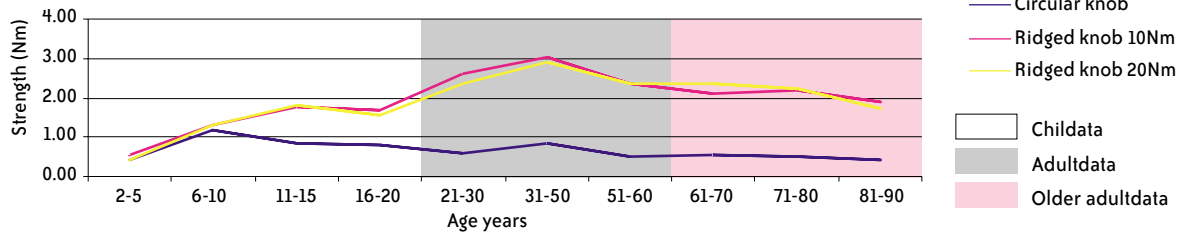
Wrist twisting strength

Age (yrs)	Sex	Orientation	Circular 20mm knob (Nm)				Push and turn knob - 10N resistance (Nm)				Push and turn knob - 20N resistance (Nm)			
			No.	Mean	SD	Range	No.	Mean	SD	Range	No.	Mean	SD	Range
2 – 5	m	Vertical	9	0.50	0.28	0.05 - 0.88	8	0.51	0.25	0.20 - 1.01	7	0.41	0.18	0.18 – 0.64
		Horizontal		0.51	0.37	0.04 - 1.29		0.54	0.25	0.25 - 0.93		0.54	0.27	0.23 – 0.88
	f	Vertical	7	0.60	0.28	0.60 - 1.00	7	0.44	0.21	0.18 - 0.74	7	0.40	0.26	0.16 – 0.89
		Horizontal		0.44	0.33	0.15 - 0.94		0.53	0.33	0.16 - 0.98		0.41	0.18	0.17 – 0.69
6 – 10	m	Vertical	5	1.06	0.43	0.56 - 1.75	5	1.04	0.54	0.36 - 1.71	5	0.96	0.53	0.48 – 1.58
		Horizontal		1.31	0.53	0.72 - 2.02		1.33	0.43	0.74 - 1.80		1.10	0.52	0.56 – 1.67
	f	Vertical	8	1.12	0.30	0.61 - 1.69	8	1.22	0.37	0.63 - 1.73	8	1.21	0.38	0.65 – 1.73
		Horizontal		1.17	0.57	0.62 - 2.07		1.32	0.51	0.55 - 2.13		1.32	0.53	0.57 – 1.95
11 – 15	m	Vertical	6	0.87	0.48	0.35 - 1.78	6	2.18	0.62	1.54 - 3.22	6	2.09	0.62	1.35 – 2.80
		Horizontal		1.14	0.63	0.30 - 1.98		2.51	0.69	1.43 - 3.21		2.36	0.76	1.37 – 3.66
	f	Vertical	6	0.74	0.26	0.49 - 1.13	6	1.72	0.51	0.76 - 2.16	6	1.89	0.29	1.51 – 2.28
		Horizontal		0.86	0.26	0.40 - 1.07		1.78	0.34	1.35 - 2.34		1.79	0.21	1.54 – 2.13
16 – 20	m	Vertical	7	0.87	0.31	0.48 - 1.35	7	2.95	0.73	2.27 - 4.26	7	2.60	0.69	1.73 – 3.84
		Horizontal		0.95	0.40	0.57 - 1.53		3.08	0.42	2.37 - 3.56		2.83	0.89	1.69 – 4.43
	f	Vertical	5	0.66	0.32	0.35 - 1.21	5	1.69	0.34	1.27 - 2.16	5	1.50	0.35	1.20 – 2.02
		Horizontal		0.79	0.48	0.42 - 1.62		1.67	0.47	1.34 - 2.47		1.56	0.30	1.25 – 1.95
21 – 30	m	Vertical	6	0.83	0.26	0.52 - 1.15	6	3.18	0.54	2.18 - 3.66	6	3.11	0.29	2.66 – 3.47
		Horizontal		0.97	0.46	0.44 - 1.59		3.15	0.61	2.10 - 3.64		2.84	0.35	2.22 – 3.15
	f	Vertical	7	0.51	0.13	0.36 - 0.70	7	2.29	0.30	1.75 - 2.66	7	2.09	0.32	1.53 – 2.46
		Horizontal		0.58	0.20	0.34 - 0.89		2.59	0.31	2.27 - 3.11		2.35	0.23	1.93 – 2.68
31 – 50	m	Vertical	8	1.02	0.27	0.68 - 1.49	8	3.86	0.78	2.93 - 5.33	8	3.85	1.08	2.34 – 5.91
		Horizontal		0.96	0.34	0.63 - 1.69		4.35	0.93	3.46 - 5.69		4.30	0.79	3.41 – 5.45
	f	Vertical	8	0.82	0.24	0.47 - 1.15	8	2.41	0.59	1.03 - 2.89	8	2.45	0.60	1.18 – 3.11
		Horizontal		0.84	0.42	0.22 - 1.60		3.03	0.55	2.20 - 3.89		2.92	0.50	2.09 – 3.44
51 – 60	m	Vertical	4	0.74	0.10	0.62 - 0.85	4	3.00	0.75	2.20 - 4.01	4	2.87	0.40	2.41 – 3.37
		Horizontal		0.75	0.28	0.34 - 0.96		3.49	0.58	2.91 - 4.28		3.34	0.29	2.94 – 3.64
	f	Vertical	4	0.52	0.15	0.40 - 0.74	4	1.95	0.35	1.56 - 2.30	4	1.91	0.58	1.31 – 2.60
		Horizontal		0.51	0.04	0.47 - 0.56		2.36	0.06	2.27 - 2.42		2.35	0.28	1.96 – 2.60
61 – 70	m	Vertical	4	0.70	0.10	0.62 - 0.84	4	2.37	0.40	2.14 - 2.96	4	2.38	0.84	1.74 – 3.60
		Horizontal		0.68	0.06	0.60 - 0.74		3.57	0.78	2.50 - 4.26		3.35	0.84	2.43 – 4.37
	f	Vertical	14	0.49	0.10	0.30 - 0.64	14	1.64	0.41	0.94 - 2.54	14	1.58	0.46	0.85 – 2.67
		Horizontal		0.53	0.17	0.24 - 0.81		2.11	0.49	1.33 - 3.09		2.37	0.63	1.61 – 3.39
71 – 80	m	Vertical	9	0.66	0.26	0.32 - 1.03	9	2.47	0.56	1.51 - 3.20	9	2.24	0.64	1.21 – 3.24
		Horizontal		0.71	0.28	0.36 - 1.23		3.05	0.51	1.89 - 3.63		2.84	0.36	2.22 – 3.39
	f	Vertical	12	0.55	0.25	0.14 - 1.14	12	1.72	0.36	1.01 - 2.10	12	1.50	0.43	0.84 – 2.11
		Horizontal		0.49	0.18	0.23 - 0.89		2.20	0.44	1.61 - 2.79		2.24	0.50	1.50 – 2.91
81 – 90	m	Vertical	5	0.63	0.36	0.30 - 1.24	5	1.74	0.69	1.23 - 2.93	5	1.80	0.72	1.15 – 2.94
		Horizontal		0.45	0.13	0.31 - 0.63		2.11	0.88	1.28 - 3.53		1.81	1.11	0.40 – 3.35
	F	Vertical	8	0.51	0.33	0.22 - 1.24	8	1.36	0.31	0.90 - 1.71	8	1.29	0.38	0.80 – 1.89
		Horizontal		0.41	0.13	0.24 - 0.63		1.88	0.44	1.28 - 2.35		1.72	0.44	1.09 – 2.36

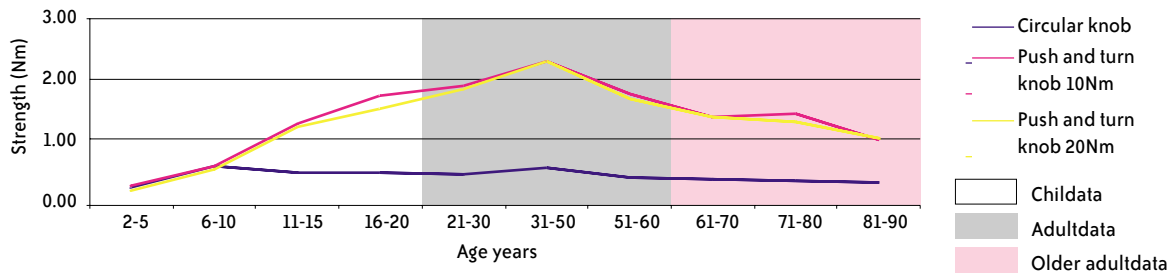
Mean maximum horizontal wrist twisting strength (males)



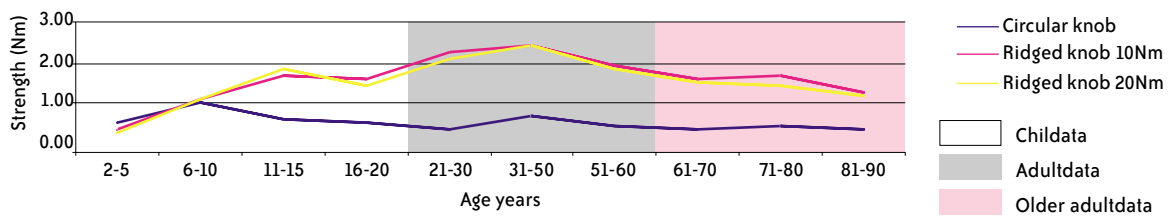
Mean maximum horizontal wrist twisting strength (females)



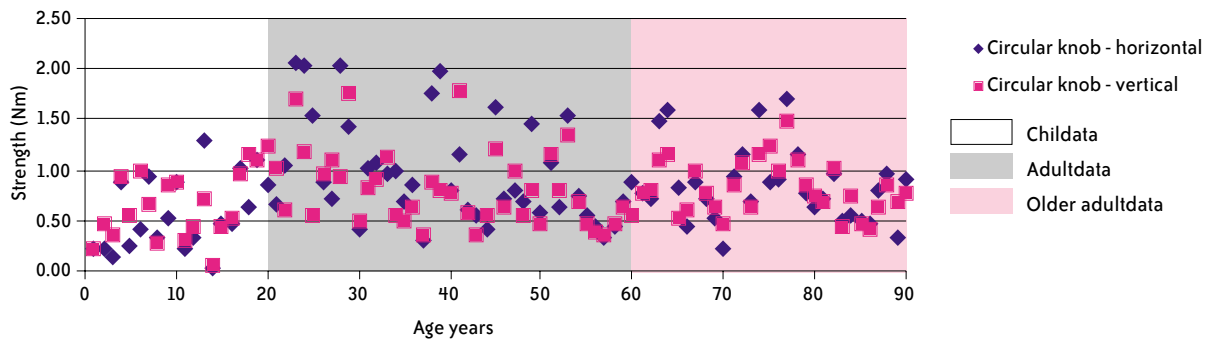
Mean maximum vertical wrist twisting strength (males)



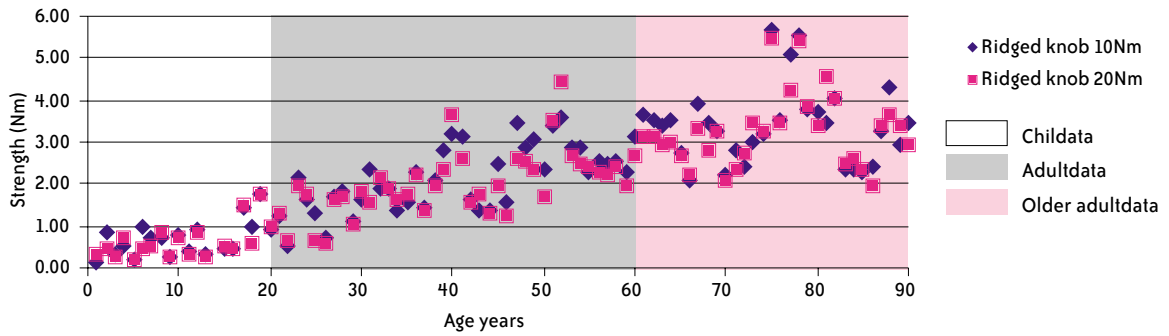
Mean maximum vertical wrist twisting strength (females)



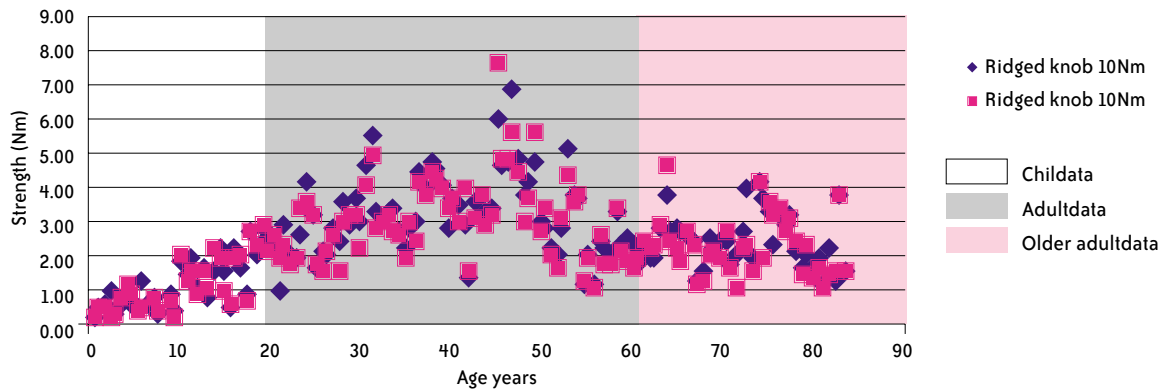
Maximum wrist twisting strength with circular knob



Maximum wrist twisting strength with the push and turn knob with resistances of 10N and 20N in horizontal position



Maximum wrist twisting strength with the push and turn knob with resistances of 10N and 20N in vertical position



6 Pull force on a can ring-pull

Description

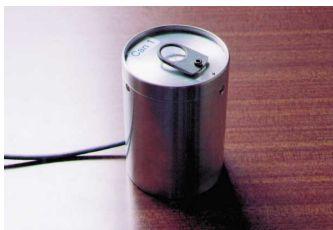
Maximum static pull strength when opening a can ring-pull, in Newtons (N).

Method

The subject stands in front of the measuring device and adopts a free posture. A maximum static pulling force is exerted using one hand on the ring-pull on a can (ie the ring pull doesn't move). The ring-pull is in two positions. The subjects can hold the can in any hand, and in any orientation. Subjects are instructed to build up their maximum strength in the first few seconds and to maintain maximum strength for a further few seconds.

Can type and size

Two custom-made replica cans, 100mm high and 75mm diameter, with a ring-pull 35mm long and 23mm (maximum) diameter. On can 1 the ring-pull is in the starting position, a space of 5mm between the ring-pull and the top of the can. On can 2 the ring-pull is at 75° angle to the top of the can.



Can 1



Measuring pulling force on can 1



Can 2



Measuring pulling force on can 2

Subject numbers

139 subject were measured

Age (Years)	Male	Female	Total
2-5	9	7	16
6-10	6	8	14
11-15	6	6	12
16-20	6	5	11
21-30	6	7	13
31-50	8	8	16
51-60	4	4	8
61-70	4	14	18
71-80	9	12	21
81-90	2	8	10
Total	60	79	139

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

Analysis

Effect of sex

In adults aged 16 years and over, males were generally found to be significantly stronger than females. No significant differences were found in pull force on the can ring-pull (vertical and horizontal) between males and females in children from 2-15 years and adults ages 71-90 (Appendix 6b).

Effect of age

Maximum strength for both ring-pulls generally increases throughout childhood (2-15 years), it peaks in adulthood, and then decreases with age from around 50 years. Some significant differences were found between the age groups for both horizontal and vertical conditions, although 2-5 year olds were significantly weaker than all other age groups on both ring-pulls (Appendix 6c).

Effect of orientation of can ring-pull.

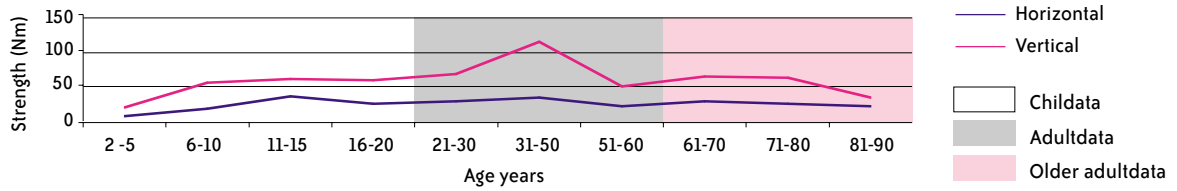
The orientation of the handles appears to significantly effect maximum strength for both males and females with the higher strength forces being exerted when the can ring-pull was in the vertical orientation (Appendix 6d). Correlation coefficients for all measurements can be found in Appendix 6e.

Results

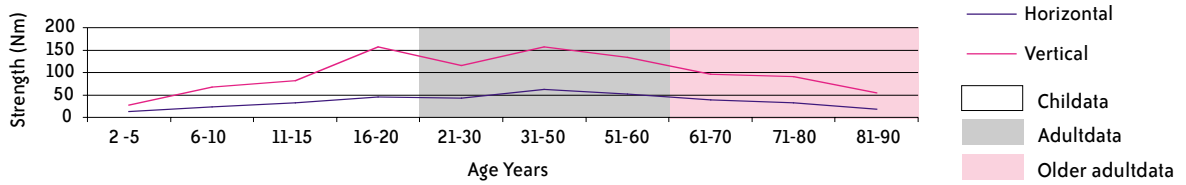
Pull strength on a can ring-pull

Age (yrs)	Sex	Horizontal ring-pull (N)				Vertical ring-pull (N)			
		No.	Mean	SD	Range	No.	Mean	SD	Range
2 – 5	m	9	12.38	6.17	5.57 - 23.27	9	27.08	14.33	6.84 - 47.14
	f	7	7.66	1.19	5.96 - 9.30	7	19.50	11.58	5.11 - 38.50
6 – 10	m	6	23.02	8.49	17.43 - 38.34	6	68.02	27.62	29.06 - 95.50
	f	8	17.36	9.17	9.45 - 38.64	8	53.95	31.37	21.34 - 103.56
11 – 15	m	6	32.59	16.43	10.07 - 48.77	6	82.24	44.40	23.76 - 153.54
	f	6	34.54	13.85	20.32 - 59.85	6	59.81	18.88	34.47 - 87.21
16 – 20	m	6	45.69	14.67	25.20 - 68.43	6	157.34	53.35	59.92 - 199.14
	f	5	24.67	15.26	8.37 - 49.48	5	57.80	47.62	30.67 - 141.56
21 - 30	m	6	42.51	11.42	29.11 - 56.51	6	115.08	23.27	82.84 - 149.62
	f	7	28.57	4.87	19.57 - 34.47	7	66.99	8.72	53.70 - 79.38
31 – 50	m	8	62.03	30.60	34.11 - 111.74	8	156.78	87.75	2.23 - 277.79
	f	8	32.36	10.91	17.88 - 48.08	8	111.93	66.95	42.76 - 254.18
51 – 60	m	4	51.89	20.69	25.20 - 71.17	4	133.33	42.45	70.05 - 160.68
	f	4	21.51	2.90	19.19 - 25.68	4	48.95	20.40	22.50 - 70.17
61 – 70	m	4	39.52	9.99	28.63 - 50.85	4	95.67	21.53	71.44 - 114.04
	f	14	27.08	9.65	8.28 - 46.89	14	62.20	18.68	28.83 - 94.81
71 - 80	m	9	32.31	9.27	16.21 - 42.21	9	91.37	42.21	49.21 - 177.49
	f	12	24.94	10.48	12.10 - 45.49	12	61.20	27.36	30.90 - 114.16
81 – 90	m	2	18.23	1.43	17.22 - 19.25	2	54.57	23.86	37.70 - 71.44
	f	8	20.43	9.12	5.16 - 32.35	8	33.75	5.42	28.25 - 40.92

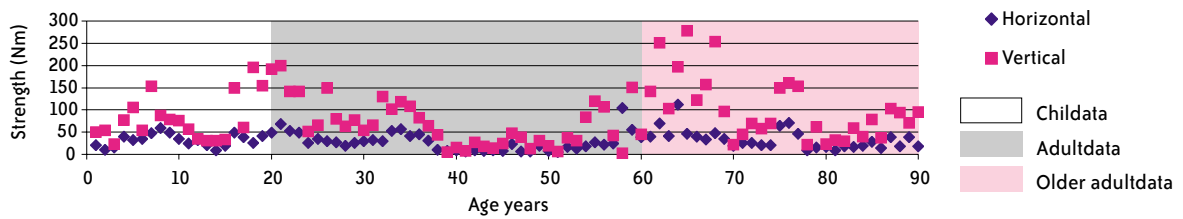
Mean maximum pulling strength on can ring-pull (males)



Mean maximum pulling strength on can ring-pull (females)



Maximum pulling strength on can ring-pull



7 Press and lift with the foot

Description

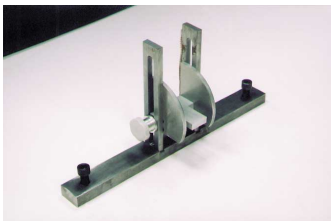
Maximum static pressing and lifting strength with the foot on a bar and a pedal, in Newtons (N).

Method

The subject stands in front of the measuring device and adopts a free posture. A maximum static pressing and lifting force is exerted with one (dominant) foot on a bar and a pedal, placed at the subject's instep height (the highest point on the top of the foot). Subjects are instructed to build up their maximum strength in the first few seconds and to maintain maximum strength for a further few seconds.

Pedal type and size

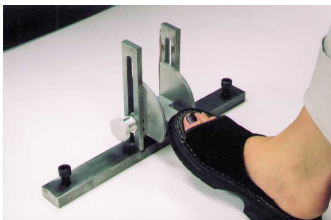
A pedal 400mm length and 30mm wide, placed inside a 55mm wide space to restrict the amount of the foot that can be placed onto the pedal. A bar, 250mm long and 20mm diameter. The pedals were designed to represent those used as brake pedals on pushchairs.



Pedal for measuring press and lift with the foot



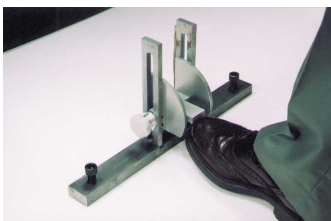
Bar for measuring press and lift with the foot



Measuring press strength on the pedal



Measuring press strength on the bar



Measuring lift strength on the pedal



Measuring lift strength on the bar

Subject numbers

140 subjects were measured

Age (Years)	Male	Female	Total
2 - 5	9	8	17
6 -10	5	8	13
11 - 15	7	5	12
16 - 20	7	5	12
21 - 30	7	6	13
31 - 50	9	8	17
51 - 60	4	4	8
61 - 70	5	14	19
71 - 80	9	13	22
81 - 90	2	5	7
Total	64	76	140

Anthropometric variables (stature, weight, elbow height, hand length and hand breadth) for all subjects can be found in Appendix 7a.

Analysis

Effect of sex

Males were found to be significantly stronger than females between ages 16 to 20 and in most conditions from 31 to 70 years (Appendix 7b).

Effect of age

For both the pressing and lifting of the bar and pedal maximum strength generally increases from childhood (2-15 years) peaking in adulthood and begins decreasing from around 50 years. Some significant differences were found between the age groups (Appendix 7c).

Effect of pressing or lifting with the foot on pedal and bar type

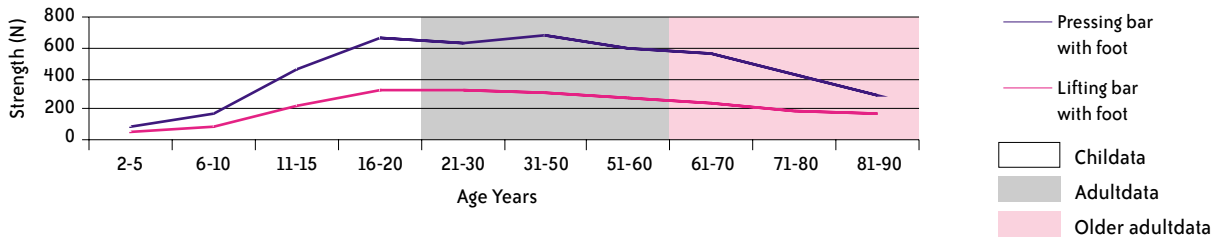
A significant difference was found between pressing and lifting with the foot on the pedal and the bar. Pressing on both the bar and the pedal gave higher mean maximum forces than lifting for both males and females. Also the bar yielded higher mean maximum forces than the pedal for both pressing and lifting for males and females (Appendix 7d). Correlation coefficients for all measurements can be found in Appendix 7e.

Results

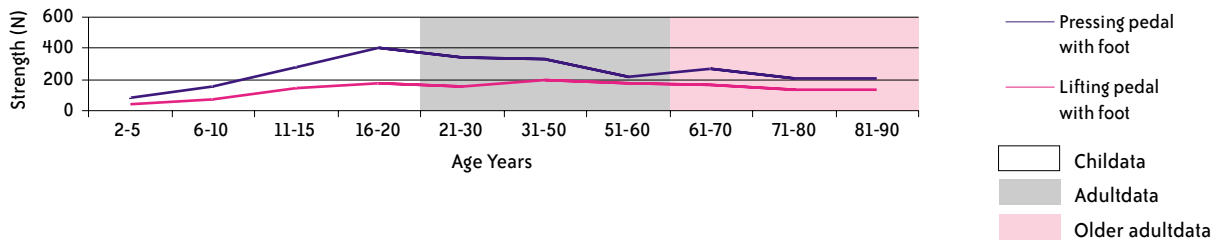
Press and lift strength with the foot

Age (years)	Sex	Condition	Bar (N)				Pedal (N)			
			No.	Mean	SD	Range	No.	Mean	SD	Range
2 – 5	m	Lift	9	46.43	15.55	18.20 - 63.00	9	42.57	12.32	23.20 - 58.10
		Press		93.49	29.48	44.30 - 137.00		79.17	35.39	18.50 - 126.70
	f	Lift	8	48.69	16.92	18.20 - 63.00	8	33.15	13.02	23.20 - 63.00
		Press		84.84	33.43	44.30 - 147.30		80.31	33.59	39.10 - 131.80
6 – 10	m	Lift	5	89.96	35.35	58.10 - 142.80	5	72.02	24.26	48.10 - 102.90
		Press		169.90	40.48	100.90 - 203.90		151.36	38.90	106.10 - 198.70
	f	Lift	8	133.41	41.64	73.00 - 192.60	8	97.95	36.33	43.10 - 147.80
		Press		232.86	124.73	95.80 - 466.50		162.71	64.07	75.20 - 276.00
11 – 15	m	Lift	7	223.94	69.03	117.90 - 342.10	7	142.77	45.94	48.10 - 197.60
		Press		466.44	125.98	250.20 - 636.40		280.40	78.38	147.30 - 384.10
	f	Lift	5	178.66	50.52	147.80 - 267.40	5	118.86	44.19	83.00 - 182.60
		Press		428.38	26.66	394.40 - 466.50		197.72	107.59	111.20 - 373.80
16 – 20	m	Lift	7	327.14	56.45	242.40 - 416.80	7	172.69	52.02	117.90 - 252.40
		Press		657.69	129.04	476.80 - 898.90		407.61	177.69	167.80 - 667.20
	f	Lift	5	180.64	80.23	102.90 - 302.20	5	98.90	35.13	63.00 - 152.70
		Press		403.64	116.68	296.60 - 590.00		216.26	128.59	85.50 - 415.00
21 – 30	m	Lift	7	320.04	99.37	147.80 - 441.80	7	155.59	33.65	107.90 - 212.50
		Press		632.67	178.44	399.50 - 873.20		341.44	137.94	147.30 - 564.30
	f	Lift	6	228.32	49.56	142.80 - 277.30	6	136.13	31.47	83.00 - 177.70
		Press		469.02	64.62	389.20 - 528.20		227.05	66.33	167.80 - 332.60
31 – 50	m	Lift	9	309.42	49.20	247.40 - 391.90	9	200.36	39.40	157.70 - 282.30
		Press		672.96	137.85	461.30 - 873.20		329.18	129.99	173.00 - 579.70
	f	Lift	8	210.65	59.26	127.80 - 312.20	8	129.70	24.42	92.90 - 167.70
		Press		519.24	189.74	209.00 - 754.80		237.99	106.80	121.50 - 435.60
51 - 60	m	Lift	4	279.80	78.71	197.60 - 386.90	4	176.43	31.89	137.80 - 202.60
		Press		592.60	162.50	435.60 - 811.40		215.45	41.04	162.70 - 260.50
	f	Lift	4	145.28	42.40	102.90 - 202.60	4	109.13	31.60	78.00 - 152.70
		Press		351.93	92.91	245.10 - 466.50		243.78	45.15	193.60 - 291.40
61 – 70	m	Lift	5	245.44	42.07	207.60 - 317.20	5	160.72	21.60	142.80 - 197.60
		Press		559.12	126.11	451.00 - 770.20		267.74	66.40	173.00 - 342.90
	f	Lift	14	155.59	39.31	112.90 - 252.40	14	120.71	22.01	78.00 - 147.80
		Press		337.39	94.73	106.10 - 512.80		183.29	57.68	70.00 - 276.00
71 – 80	m	Lift	9	182.63	53.43	73.00 - 242.40	9	131.14	38.61	63.00 - 197.60
		Press		417.86	112.80	296.60 - 605.50		205.02	95.68	85.50 - 399.50
	f	Lift	13	139.71	38.80	38.10 - 182.60	13	128.58	25.64	92.90 - 162.70
		Press		357.15	71.56	214.20 - 481.90		214.98	67.87	111.20 - 378.90
81 – 90	m	Lift	2	162.70	49.36	127.80 - 197.60	2	132.80	70.43	83.00 - 182.60
		Press		296.55	72.76	245.10 - 348.00		211.65	91.00	147.30 - 276.00
	f	Lift	5	117.86	33.27	63.00 - 147.80	5	107.88	52.13	48.10 - 187.60
		Press		256.40	106.96	157.60 - 430.40		151.40	25.57	126.70 - 193.60

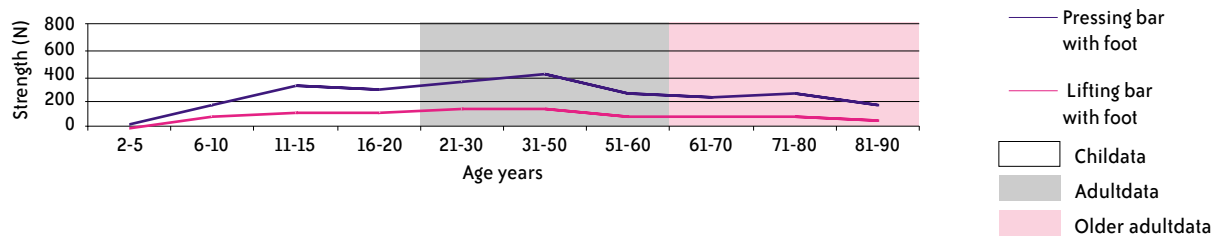
Mean maximum pressing and lifting strength with the foot on the bar (males)



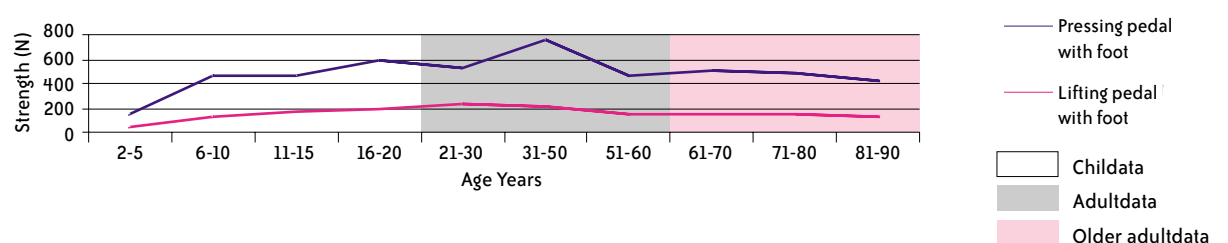
Mean maximum pressing and lifting strength with the foot on the pedal (males)



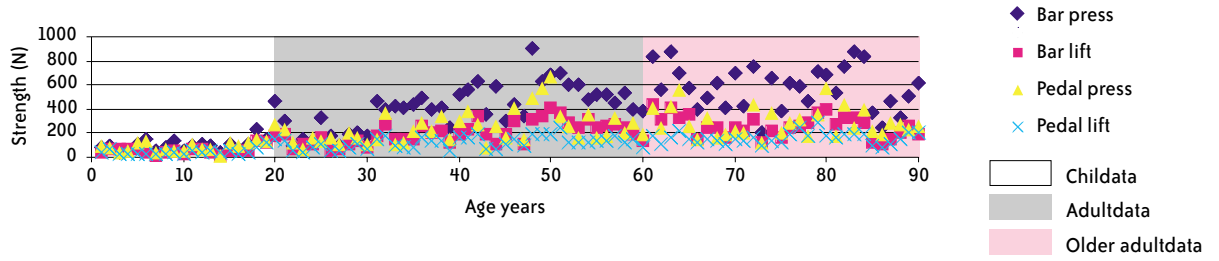
Mean maximum pressing and lifting strength with the foot on the bar (females)



Mean maximum pressing and lifting strength with the foot on the pedal (females)



Maximum pressing and lifting strength with the foot



8 Pull on 20mm knob

Description

Maximum static pulling strength using one and two hands on a small round knob, in Newtons (N).

Method

The subject stands in front of the measuring device and adopts a free posture. A maximum static pulling force is exerted using both one (dominant) hand and both hands on the knob. Subjects are instructed to build up their maximum strength in the first few seconds and to maintain maximum strength for a further few seconds.

Handle type and size

A round knob, 20mm diameter and 20mm depth.



20 mm knob



Experimental trial: pulling on the 20mm knob

Subject numbers

140 subjects were measured:

Age (Years)	Male	Female	Total
2 - 5	9	8	17
6 -10	5	8	13
11 - 15	7	6	13
16 - 20	8	4	12
21 - 30	7	6	13
31 - 50	9	8	17
51 - 60	4	4	8
61 - 70	5	14	19
71 - 80	9	13	22
81 - 90	2	4	6
Total	65	75	140

Anthropometric variables (stature, weight, elbow height, hand length and hand breadth) for all subjects can be found in Appendix 8a.

Analysis

Effect of sex

No significant difference in pulling strength was found between males and females except at ages 16-20 and 21-30 (this latter group with 1 hand only) (Appendix 8b).

Effect of age

Strength generally increases in females up to age group 31 to 50, then gradually decreases with age from around 50 years, although with a slight decrease in the 16 to 20 age group. Strength gradually increases in males through childhood, peaks in the 16 to 20 age group and then gradually decreases. This decrease could be due to finger size and difficulty with manipulation of the knob. The only significant differences were between children 2-15 years and the older age groups (Appendix 8c).

Effect of the number of hands used

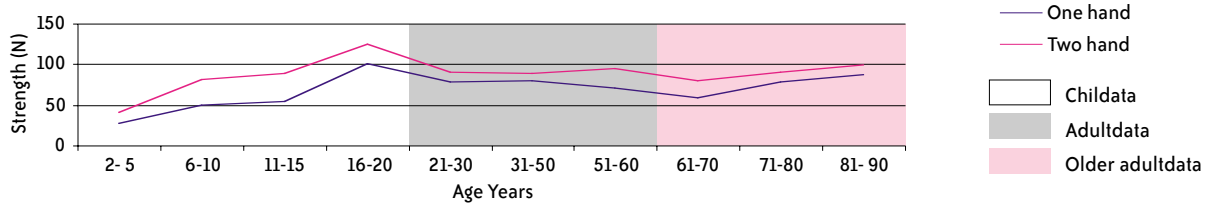
The number of hands used appears to significantly affect maximum strength, with two hands generating higher forces for both males and females (Appendix 8d). Correlation coefficients for all measurements can be found in Appendix 8e.

Results

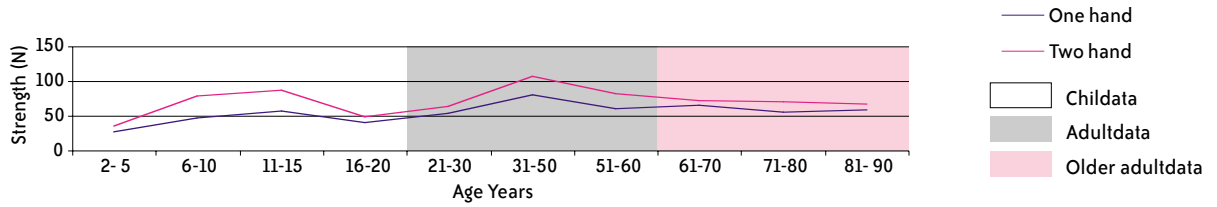
Pull strength on 20mm knob

Age (yrs)	Sex	Pull on 20mm knob with one hand (N)				Pull on 20mm knob with two hands (N)			
		No.	Mean	SD	Range	No.	Mean	SD	Range
2 – 5	m	9	27.61	10.37	15.40 - 51.80	9	41.20	19.00	16.10 - 74.70
	f	8	26.93	10.77	15.20 - 42.60	8	35.63	8.51	22.30 - 49.90
6 – 10	m	5	49.62	8.89	41.10 - 63.10	5	80.64	18.66	59.30 - 109.10
	f	8	46.26	9.14	25.60 - 53.40	7	78.63	19.65	44.80 - 102.50
11 – 15	m	7	53.26	16.54	36.70 - 85.40	7	88.63	37.23	47.80 - 161.20
	f	6	56.57	12.04	46.00 - 72.90	6	86.68	38.30	56.90 - 161.50
16 – 20	m	8	100.50	27.41	53.90 - 137.70	8	125.03	36.65	56.70 - 167.90
	f	4	39.68	15.64	20.10 - 54.40	4	48.78	14.91	27.40 - 60.50
21 - 30	m	7	77.73	15.33	62.30 - 103.80	7	89.57	47.41	58.40 - 195.00
	f	6	54.05	12.85	44.20 - 74.40	6	63.13	15.34	51.30 - 86.20
31 – 50	m	9	80.07	42.10	42.00 - 163.50	9	87.80	44.86	41.40 - 188.90
	f	8	80.53	34.77	44.80 - 140.40	8	106.01	41.47	44.70 - 187.60
51 – 60	m	4	70.23	22.57	45.10 - 100.00	4	94.58	7.68	87.90 - 103.80
	f	4	59.98	14.08	39.00 - 69.30	4	81.00	27.02	47.70 - 113.80
61 – 70	m	5	58.26	14.34	47.70 - 83.30	5	78.76	25.87	50.90 - 105.00
	f	14	64.44	28.02	34.10 - 144.00	14	72.28	33.09	21.10 - 151.20
71 - 80	m	9	77.68	36.18	28.50 - 138.80	9	89.32	32.42	54.20 - 156.70
	f	13	55.17	16.73	35.10 - 84.80	13	70.57	22.08	38.50 - 105.20
81 – 90	m	2	87.35	25.24	69.50 - 105.20	2	99.20	83.01	40.50 - 157.90
	f	4	58.05	21.45	37.90 - 87.30	5	67.24	9.01	58.30 - 79.90

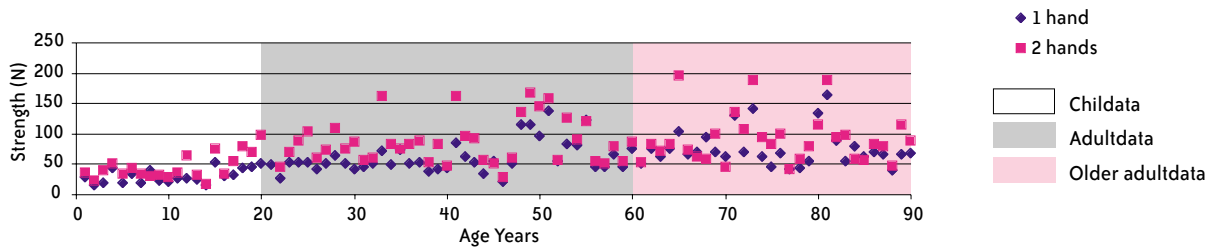
Mean maximum pulling strength on the 20mm knob (males)



Mean maximum pulling strength on the 20mm knob (females)



Maximum pulling strength on the 20mm knob with one hand and two hands



Appendix 1 – Push and pull strength

1a - Anthropometric characteristics of subjects

Age (years)	Sex	No.	Stature		Weight		Elbow height		Hand length		Hand Breadth	
			Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
2-5	m	7	1062.86	98.27	18.54	3.10	844.29	84.82	106.29	10.27	52.71	1.89
	f	8	1008.75	44.54	15.50	1.96	806.25	42.74	114.00	8.40	51.63	4.21
6-10	m	4	1297.50	118.71	27.60	7.09	1067.50	103.08	137.50	15.67	61.25	6.03
	f	9	1356.67	95.00	30.71	8.98	1104.44	82.02	142.78	12.67	63.67	5.34
11-15	m	7	1653.57	55.43	50.83	6.20	1383.57	52.58	171.57	10.01	75.86	6.74
	f	6	1590.00	102.57	50.37	11.29	1321.67	85.19	164.50	9.33	69.00	4.52
16-20	m	14	1762.86	67.30	63.80	10.84	1460.00	59.36	181.43	5.61	81.57	5.29
	f	5	1680.00	60.83	60.00	16.09	1416.00	86.20	168.00	7.18	72.20	6.83
21-30	m	6	1876.67	76.33	79.02	13.63	1540.00	44.72	187.83	6.68	82.33	5.13
	f	8	1617.50	157.91	66.21	12.34	1350.00	127.28	170.00	5.66	70.38	4.34
31-50	m	9	1746.67	201.00	81.20	11.29	1501.11	76.72	188.89	8.55	85.22	2.73
	f	9	1662.22	83.33	74.29	27.42	1385.56	69.84	165.89	15.78	75.22	4.76
51-60	m	4	1802.50	34.03	243.70	311.39	1492.50	5.00	195.50	6.35	85.00	3.56
	f	5	1656.00	48.27	66.12	8.48	1378.00	54.50	177.40	6.88	79.00	5.39
61-70	m	5	1798.00	55.41	80.36	8.44	1506.00	55.05	195.60	11.33	86.60	3.13
	f	14	1623.57	51.38	61.71	10.66	1347.14	54.13	173.64	9.56	76.50	4.01
71-80	m	9	1748.89	42.85	81.00	7.20	1452.22	48.93	190.11	6.97	86.67	2.87
	f	13	1613.08	64.82	68.57	9.99	1348.85	54.70	176.00	9.05	77.38	4.27
81-90	m	2	1800.00	28.28	71.20	7.92	1505.00	21.21	182.00	2.83	83.50	0.71
	f	7	1595.71	78.07	59.77	10.63	1330.00	86.22	170.86	12.93	78.00	3.37

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

Push

Age (years)	Sex	No.	Horizontal push 1 hand			Vertical push 1 hand			Horizontal push 2 hands			Vertical push 2 hands		
			t	df	Sig	t	df	Sig	t	df	Sig	t	df	Sig
2-5	m	7	-0.188	10.513	0.854	0.006	9.958	0.995	-0.503	9.767	0.626	-0.383	8.269	0.711
	f	8												
6-10	m	4	0.140	11.000	0.891	-0.273	11.000	0.790	1.193	3.058	0.317	-0.136	11.000	0.894
	f	9												
11-15	m	6	-1.206	10.000	0.256	-2.251	10.000	0.048*	-1.765	10.000	0.108	-2.063	10.000	0.066
	f	6												
16-20	m	14	-0.911	17.000	0.375	-1.161	17.000	0.262	-0.937	17.000	0.362	-1.372	17.000	0.188
	f	5												
21-30	m	6	-0.026	12.000	0.979	-0.082	12.000	0.936	0.159	12.000	0.877	0.398	12.000	0.698
	f	8												
31-50	m	9	2.067	16.000	0.055	1.955	16.000	0.068	2.313	16.000	0.034*	2.123	16.000	0.050
	f	9												
51-60	m	4	1.610	7.000	0.151	-0.797	7.000	0.452	2.271	7.000	0.057	-0.547	5.148	0.607
	f	5												
61-70	m	5	1.846	17.000	0.082	1.672	17.000	0.113	1.521	4.296	0.198	2.175	17.000	0.044*
	f	14												
71-80	m	8	0.568	19.000	0.577	1.301	19.000	0.209	0.654	19.000	0.521	1.115	19.000	0.279
	f	13												
81 to 90	m	2	-0.490	7.000	0.639	-0.296	7.000	0.776	-0.051	7.000	0.961	-0.236	7.000	0.820

Pull

Age (years)	Sex	No.	Horizontal push 1 hand			Vertical push 1 hand			Horizontal push 2 hands			Vertical push 2 hands		
			t	df	Sig	t	df	Sig	t	df	Sig	t	df	Sig
2-5	m	7	-0.247	10.622	0.809	0.216	13.000	0.832	-0.565	8.735	0.586	-0.496	9.908	0.631
	f	8												
6-10	m	4	0.642	11.000	0.534	-0.035	11.000	0.972	0.755	11.000	0.466	-0.282	11.000	0.783
	f	9												
11-15	m	6	-1.279	10.000	0.230	-1.480	10.000	0.170	-0.843	10.000	0.419	-1.072	10.000	0.309
	f	6												
16-20	m	14	0.389	17.000	0.702	0.634	17.000	0.534	0.839	17.000	0.413	0.815	17.000	0.426
	f	5												
21-30	m	6	0.291	12.000	0.776	0.220	12.000	0.829	0.501	12.000	0.626	0.124	12.000	0.903
	f	8												
31-50	m	9	3.376	12.089	0.005*	2.951	16.000	0.009*	2.651	13.627	0.019*	3.077	16.000	0.007*
	f	9												
51-60	m	4	1.329	6.200	0.231	-0.307	5.313	0.770	0.525	7.000	0.616	-0.524	4.534	0.625
	f	5												
61-70	m	5	2.530	17.000	0.022*	2.301	17.000	0.034*	2.817	17.000	0.012*	2.655	17.000	0.017*
	f	14												
71-80	m	8	-0.805	20.000	0.430	-0.548	20.000	0.590	-1.164	20.000	0.258	-0.586	20.000	0.564
	f	13												
81 to 90	m	2	-0.500	7.000	0.633	-0.317	7.000	0.761	-0.393	7.000	0.706	-0.245	7.000	0.813
	f	7												

Key:

t = value from t-test

df = degrees of freedom

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

1c – 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		* not vpush 1 vpush2 hpush1 hpull1 hpush2 hpull2	X	X	X	* not vpull1 hpull2 vpull2	X	X	X	X
6-10			* not vpush1 vpush1 vpush2 hpush1 hpull1 hpull2	*	X	*	*	X	* not vpull1	X
11-15				X	X	* not vpull1 hpull2 vpull2	X	X	X	X
16-20					X	* not vpush 1 vpull1 vpull2 hpull1 hpush2 hpull2	X	X	X	X
21-30						* not vpull1 vpull2 hpull1 hpull2	X	X	X	X
31-50							X	* not hpull2	* not vpull1 vpull2 vpush2 hpull1 hpush2 hpull2	* not vpull1 vpush2 hpull1 hpush2 hpull2
51-60								X	X	X
61-70									X	X
71-80										X

Key:

* = significant difference at 0.05 level

X = no significant difference between age groups

vpush1 = Vertical push on a cylindrical bar with one hand

vpush2 = Vertical push on a cylindrical bar with two hands

vpull1 = Vertical pull on a cylindrical bar with one hand

vpull2 = Vertical pull on a cylindrical bar with two hands

hpush1 = Horizontal push on a cylindrical bar with one hand

hpush2 = Horizontal push on a cylindrical bar with two hands

hpull1 = Horizontal pull on a cylindrical bar with one hand

hpull2 = Horizontal pull on a cylindrical bar with two hands

1d – Differences between orientation of handle and number of hands used (Paired samples test)

Action	t	df	Sig
hpush1 - hpush2	-4.856	149	0.000*
hpush1 - vpush2	-8.119	149	0.000*
hpush1 - hpull2	6.953	149	0.000*
hpush1 - vpull1	6.430	149	0.000*
hpush1 - hpull2	6.264	149	0.000*
hpush2 - vpull2	4.503	149	0.000*
vpush1 - hpush2	-4.858	149	0.000*
vpush1 - vpush2	-11.868	149	0.000*
vpush1 - hpull1	6.550	149	0.000*
vpush1 - vpull1	6.626	149	0.000*
vpush1 - vpull2	5.890	149	0.000*
vpush1 - vpull2	4.506	149	0.000*
hpush2 - vpush2	-3.169	149	0.002*
hpush2 - hpull1	8.683	149	0.000*
hpush2 - vpull1	8.412	149	0.000*
hpush2 - hpull2	8.216	149	0.000*
hpush2 - vpull2	6.963	149	0.000*
vpush2 - hpull1	11.816	149	0.000*
vpush2 - vpull1	11.965	149	0.000*
vpush2 - hpull2	10.844	149	0.000*
vpush2 - vpull2	10.043	149	0.000*
hpull1 - vpull2	-2.652	150	0.009*
vpull1 - vpull2	-4.202	150	0.000*
hpull1 - vpull2	-3.311	150	0.001*

Key:

vpush1 = Vertical push on a cylindrical bar with one hand

vpush2 = Vertical push on a cylindrical bar with two hands

vpull1 = Vertical pull on a cylindrical bar with one hand

vpull2 = Vertical pull on a cylindrical bar with two hands

hpush1 = Horizontal push on a cylindrical bar with one hand

hpush2 = Horizontal push on a cylindrical bar with two hands

hpull1 = Horizontal pull on a cylindrical bar with one hand

hpull2 = Horizontal pull on a cylindrical bar with two hands

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)

	Horizontal push one hand	Vertical push one hand	Horizontal push two hands	Vertical push two hands	Horizontal pull one hand	Vertical pull one hand	Horizontal pull two hands	Vertical pull two hands
Horizontal push one hand	1.00	0.93**	0.92**	0.91**	0.87**	0.82**	0.81**	0.80**
Vertical push one hand	0.93**	1.00	0.90**	0.96**	0.84**	0.84**	0.79**	0.81**
Horizontal push two hands	0.92**	0.90**	1.00	0.92**	0.84**	0.81**	0.80**	0.79**
Vertical push two hands	0.91**	0.96**	0.92**	1.00	0.87**	0.86**	0.81**	0.83**
Horizontal pull one hand	0.87**	0.84**	0.84**	0.87**	1.00	0.92**	0.93**	0.90**
Vertical pull one hand	0.82**	0.84**	0.81**	0.86**	0.92**	1.00	0.91**	0.96**
Horizontal pull two hands	0.81**	0.79**	0.80**	0.81**	0.93**	0.91**	1.00	0.93**
Vertical pull two hands	0.80**	0.81**	0.79**	0.83**	0.90**	0.96**	0.93**	1.00

* Correlation is significant at the 0.05 significant level

** Correlation is significant at the 0.01 significant level

Appendix 2 - Push with the thumb or 2 or more fingers

2a - Anthropometric characteristics of subjects

Age (years)	Sex	No.	Stature		Weight		Elbow height		Hand length		Hand Breadth	
			Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
2-5	m	9	1061.11	81.62	18.24	2.81	633.33	62.45	108.89	10.72	52.56	2.24
	f	8	1007.50	60.18	15.58	2.00	611.25	47.34	113.75	8.08	53.63	6.14
6-10	m	5	1340.00	116.62	29.37	6.16	865.00	74.77	141.00	13.67	62.50	4.37
	f	8	1353.75	93.34	30.55	9.58	850.00	70.31	142.75	13.54	62.88	5.74
11-15	m	7	1648.57	63.62	51.03	6.18	1052.86	39.46	171.14	11.58	76.00	6.68
	f	5	1618.00	104.26	52.32	11.43	1040.00	70.71	165.80	9.81	70.40	3.29
16-20	m	14	1766.43	68.57	65.04	11.73	1102.14	52.21	180.86	180.86	81.36	5.15
	f	5	1628.00	75.96	59.28	16.45	1040.00	52.44	168.40	7.02	72.60	6.88
21-30	m	7	1877.14	69.69	77.67	12.94	1166.67	33.27	187.14	6.36	82.43	4.69
	f	9	1682.22	44.94	65.52	11.73	1060.00	43.87	170.78	5.78	71.22	4.79
31-50	m	7	1798.57	91.91	81.29	11.29	1150.00	57.45	188.00	8.14	85.43	2.99
	f	8	1655.00	95.34	76.88	28.33	1058.57	53.18	170.13	13.90	75.88	1.52
51-60	m	4	1802.50	20.62	83.95	20.07	1137.50	29.86	195.50	6.35	85.00	3.56
	f	5	1672.00	35.64	64.92	8.50	1050.00	33.91	178.20	3.83	75.80	2.28
61-70	m	4	1780.00	38.30	76.50	4.46	1125.00	20.82	193.75	12.09	88.50	2.65
	f	15	1632.67	87.22	63.84	13.27	1032.00	64.94	176.00	11.70	77.20	4.81
71-80	m	9	1745.56	51.99	81.11	7.50	1102.22	36.67	189.11	7.20	86.56	3.71
	f	14	1615.71	66.76	68.29	9.66	1031.43	52.46	175.93	8.70	76.86	4.55
81-90	m	2	1810.00	14.14	71.20	7.92	1140.00	0.00	182.00	2.83	83.50	0.71
	f	8	1640.00	105.02	59.77	10.63	1012.50	54.97	171.00	11.98	76.88	3.91

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

Age (years)	Sex	No.	Push with fingers forward			Push with fingers down			Push with thumb		
			t	df	Sig	t	df	Sig	t	df	Sig
2-5	m	9	1.162	15.000	0.264	1.678	14.000	0.115	0.513	14.000	0.616
	f	8									
6-10	m	5	-0.765	11.000	0.460	-0.903	11.000	0.386	-0.828	11.000	0.425
	f	8									
11-15	m	7	2.170	10.000	0.055	0.997	10.000	0.342	1.282	10.000	0.229
	f	5									
16-20	m	14	2.910	17.000	0.010*	2.811	17.000	0.012*	2.347	17.000	0.031*
	f	5									
21-30	m	7	2.462	14.000	0.027*	4.168	14.000	0.001*	2.517	14.000	0.025*
	f	9									
31-50	m	7	3.230	13.000	0.007*	3.529	13.000	0.004*	3.332	13.000	0.005*
	f	8									
51-60	m	4	3.689	7.000	0.008*	2.704	7.000	0.030*	3.144	7.000	0.016*
	f	5									
61-70	m	4	1.640	17.000	0.119	1.544	17.000	0.141	1.135	17.000	0.272
	f	15									
71-80	m	9	4.235	21.000	0.000*	3.628	21.000	0.002*	3.598	21.000	0.002*
	f	14									
81 to 90	m	2	1.369	1.044	0.395	2.926	8.000	0.019*	1.599	1.016	0.353
	f	8									

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	*
16-20					X	X	X	* not fingf	*	*
21-30						* not fingf thumd	X	*	*	*
31-50							X	*	*	*
51-60								* not fingf thumd	*	*
61-70									X	* not thumd
71-80										* not fingf thumd

Key:

* = significant difference at 0.05 level

X = no significant difference between age groups

fingf = Pushing forward with fingers

fingd = Pushing down with fingers

thumd = Pushing down with thumb

2d – Differences between age groups (t-test)

Action	t	df	Sig
fingf – thumd	-4.764	151.000	0.000*
fingd – thumd	-5.416	151.000	0.000*

Key:

fingf = Pushing forward with fingers

fingd = Pushing down with fingers

thumd = Pushing down with thumb

t = value from t-test

df = degrees of freedom

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

2e - Correlation between measurements (Pearson Correlation)

Action	Push with fingers downwards	Push with fingers downward	Push with thumb down
Push with fingers forwards	1.00	0.96	0.89 **
Push with fingers down	0.96**	1.00	0.89 **
Push with thumb down	0.89**	0.89**	1.00

* Correlation is significant at the 0.05 significant level

** Correlation is significant at the 0.01 significant level

Appendix 3 – Push with the shoulder

3a - Anthropometric characteristics of subjects

Age (years)	Sex	No.	Stature		Weight		Shoulder height	
			Mean	SD	Mean	SD	Mean	SD
2-5	m	8	1062.50	87.14	18.53	2.87	853.75	86.84
	f	9	1012.22	58.05	15.62	1.87	805.00	57.76
6-10	m	5	1335.00	109.22	28.48	6.45	1084.00	89.05
	f	8	1353.75	93.34	28.48	6.45	1084.00	89.05
11-15	m	7	1648.57	63.62	51.03	6.18	1387.14	44.61
	f	5	1618.00	104.26	52.32	11.43	1340.00	82.76
16-20	m	14	1766.43	68.57	65.04	11.73	1457.14	71.30
	f	5	1628.00	75.96	59.28	16.45	1342.00	46.58
21-30	m	7	1877.14	69.69	77.67	12.94	1537.14	41.52
	f	9	1682.22	44.94	65.52	11.73	1398.89	53.49
31-50	m	7	1798.57	91.91	81.29	11.29	1481.43	78.19
	f	8	1655.00	91.03	76.88	28.33	1367.50	68.40
51-60	m	4	1802.50	20.07	83.95	20.07	1507.50	35.94
	f	5	1672.00	35.64	64.92	8.50	1384.00	43.93
61-70	m	15	1780.00	38.30	76.50	4.46	1482.50	42.72
	f	4	1632.67	87.22	63.84	13.27	1358.00	78.94
71-80	m	9	1745.56	51.99	81.11	7.50	1458.89	42.56
	f	14	1615.71	66.76	68.29	9.66	1340.00	54.63
81-90	m	2	1810.00	14.14	71.20	7.92	1495.00	21.21
	f	8	1602.50	71.66	59.77	10.63	1347.50	54.45

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

Push with shoulder at 100% of shoulder height

Age (years)	Sex	No.	t	df	Sig
2-5	m	8	0.592	15.000	0.563
	f	9			
6-10	m	5	1.632	11.000	0.131
	f	8			
11-15	m	7	5.860	10.000	0.000*
	f	5			
16-20	m	14	2.641	16.000	0.018*
	f	4			
21-30	m	7	5.730	7.719	0.001*
	f	9			
31-50	m	7	0.553	13.000	0.590
	f	8			
51-60	m	4	3.721	7.000	0.007*
	f	5			
61-70	m	4	2.278	17.000	0.036*
	f	15			
71-80	m	9	1.865	21.000	0.076
	f	14			
81 to 90	m	2	1.444	8.000	0.187
	f	8			

Push with shoulder at 90%

Age (years)	Sex	No.	t	df	Sig
2-5	m	8	0.377	11.485	0.713
	f	9			
6-10	m	5	-0.363	11.000	0.724
	f	8			
11-15	m	7	3.855	10.000	0.003*
	f	5			
16-20	m	7	5.442	4.722	0.003*
	f	5			
21-30	m	7	2.053	11.000	0.065
	f	6			
31-50	m	9	1.593	15.000	0.132
	f	8			
51-60	m	4	3.031	6.000	0.023*
	f	4			
61-70	m	5	1.601	17.000	0.128
	f	14			
71-80	m	9	2.026	20.000	0.056
	f	13			
81 to 90	m	2	1.986	5.000	0.104
	f	5			

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)

Push with shoulder at 100% of shoulder height

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	X	X	X
11-15				X	*	X	X	X	*	*
16-20					X	X	*	*	*	*
21-30						X	*	*	*	*
31-50							X	X	X	*
51-60								X	X	*
61-70									X	*
71-80										X

Push with shoulder at 90% of shoulder height

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	X
11-15				X	*	*	X	X	*	*
16-20					X	X	X	*	*	*
21-30						X	*	*	*	*
31-50							X	*	*	*
51-60								X	*	*
61-70									X	*
71-80										X

Key:

* = significant difference at 0.05 level

X = no significant difference between age groups

3d – Differences between pushing at 100% and 90% of shoulder height (Paired samples test)

Action	t	df	Sig
Push 100% shoulder height – Push 90% shoulder height	10.316	139	0.000*

Key:

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)

Action	Push at 100% shoulder height	Push at 90% shoulder height
Push at 100% shoulder height	1.00	0.48 **
Push at 90% shoulder height	0.48 **	1.00

* Correlation is significant at the 0.05 significant level

** Correlation is significant at the 0.01 significant level

Appendix 4 – Pull with different grips

4a - Anthropometric characteristics of subjects

Age (years)	Sex	No.	Stature		Weight		Elbow height		Hand length		Hand Breadth	
			Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
2-5	m	6	1101.67	56.36	19.53	2.55	660.00	51.77	112.17	2.04	53.50	1.97
	f	3	1060.00	26.46	17.00	0.69	646.67	37.86	116.33	5.13	52.67	5.51
6-10	m	5	1314.00	109.22	28.48	6.45	850.00	72.80	138.60	13.79	61.80	4.49
	f	8	1353.75	93.34	30.55	9.58	850.00	70.31	142.75	13.54	62.88	5.74
11-15	m	7	1648.57	63.62	51.03	6.18	1052.86	39.46	171.14	11.58	76.00	6.68
	f	5	1618.00	104.26	52.32	11.43	1040.00	70.71	165.80	9.81	70.40	3.29
16-20	m	14	1766.43	68.57	65.04	11.73	1102.14	52.21	180.86	5.05	81.36	5.15
	f	5	1628.00	75.96	59.28	16.45	1040.00	52.44	168.40	7.02	72.60	6.88
21-30	m	6	1878.33	76.27	76.75	13.92	1170.00	35.78	186.67	6.83	82.00	4.98
	f	9	1682.22	44.94	65.52	11.73	1060.00	43.87	170.78	5.78	71.22	4.79
31-50	m	7	1795.00	91.91	81.29	11.29	1150.00	57.45	188.00	8.14	85.43	2.99
	f	8	1655.00	91.03	76.88	28.33	1060.00	53.18	170.13	13.90	75.88	4.88
51-60	m	4	1802.50	20.62	83.95	20.07	1137.50	29.86	195.50	6.35	85.00	3.56
	f	4	1662.50	33.04	66.90	8.37	1045.00	36.97	177.50	4.04	76.25	2.36
61-70	m	4	1780.00	38.30	76.50	4.46	1125.00	20.82	193.75	12.09	88.50	2.65
	f	15	1632.67	87.22	63.84	13.27	1032.00	64.94	176.00	11.70	77.20	4.81
71-80	m	8	1747.50	55.23	81.10	8.02	1103.75	38.89	189.75	7.42	86.75	3.92
	f	14	1615.71	66.76	68.29	9.66	1031.43	52.46	175.93	8.70	76.86	4.55
81-90	m	2	1810.00	14.14	71.20	7.92	1140.00	0.00	182.00	2.83	83.50	0.71
	f	8	1640.00	105.02	59.77	10.63	1012.50	54.97	171.00	11.98	76.88	3.91

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

Age (years)	Sex	No.	Underhand handle - 1 hand			Underhand handle - 2 hands			Round handle - 1 hand			Round handle - 2 hands		
			t	df	Sig	t	df	Sig	t	df	Sig	t	df	Sig
2-5	m	6	0.006	7.000	0.995	0.014	7.000	0.989	0.021	7.000	0.984	0.420	7.000	0.687
	f	3												
6-10	m	5	-0.734	11.000	0.478	-3.961	8.410	0.004	-0.673	5.775	0.527	-1.304	11.000	0.219
	f	8												
11-15	m	7	0.869	10.000	0.405	-0.399	10.000	0.698	-1.534	10.000	0.156	-0.887	10.000	0.396
	f	5												
16-20	m	14	2.931	17.000	0.009*	1.340	16.334	0.199	0.547	17.000	0.592	0.928	17.000	0.366
	f	5												
21-30	m	6	1.907	13.000	0.079	-1.222	13.000	0.244	-1.955	13.000	0.072	-2.274	13.000	0.041*
	f	9												
31-50	m	7	2.788	8.382	0.023*	3.760	13.000	0.002	2.162	13.000	0.050	2.175	13.000	0.049*
	f	8												
51-60	m	4	2.634	6.000	0.039*	0.378	6.000	0.719	0.558	6.000	0.597	0.816	6.000	0.446
	f	4												
61-70	m	4	0.504	17.000	0.621	-0.972	17.000	0.345	-0.898	17.000	0.382	-1.046	17.000	0.310
	f	15												
71-80	m	8	3.534	20.000	0.002*	0.177	20.000	0.861	-0.001	20.000	0.999	0.123	20.000	0.903
	f	14												
81 to 90	m	2	0.717	1.040	0.600	1.604	8.000	0.147	0.861	8.000	0.414	0.731	1.274	0.576
	f	8												

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)

Age (years)	2-5	6-10	11-15	16-20	21-30	31-50	51-60	61-70	71-80	81-90
2-5		* not u2 r1	* not u2 r1 r2	* not u2 r1 r2	* not u2 r1 r2	*	* not u2 r1 r2	* not u2	*	* not u2 r1
6-10			* not u2 r1 r2	* not u2 r1 r2	* not u2 r1 r2	* not r1	* not u2 r1 r2	* not u2	*	X
11-15				* not u2 r1 r2	* not u2 r1 r2	* not r1	X	* not u2 r1 r2	* not u1	* not u2 r1, r2
16-20					X	* not u1, r1 r2	X	* not u1 u2	* not u2	* not u2 r1, r2
21-30						X	X	X	* not u2 r1, r2	* not u2
31-50							* not u1	X	* not u2, r1 r1, r2	* not r1 not u2
51-60								* not u1, u2	*	* not u2, r1
61-70									* not u2, r1, r2	* not u2 r1, r2
71-80										X

Key:

* = significant difference at 0.05 level

X = no significant difference between age groups

u1 = Pulling underhand handle with one hand

u2 = Pulling underhand handle with two hands

r1 = Pulling round handle with one hand

r2 = Pulling round handle with two hands

4d – Differences between grip/handle used and number of hands used (Paired samples test)

Action	t	df	Sig
u1 – u2	-5.01	141.00	0.00*
u1 – r1	-10.35	141.00	0.00*
u1 – r2	-12.12	140.00	0.00*
u2 – r1	-14.23	141.00	0.00*
u2 – r2	-16.71	140.00	0.00*
r1 – r2	-10.11	140.00	0.00*

Key:

u1 = Pulling underhand handle with one hand

u2 = Pulling underhand handle with two hands

r1 = Pulling round handle with one hand

r2 = Pulling round handle with two hands

t = value from t-test

df = degrees of freedom

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

4e - Correlation between measurements (Pearson Correlation)

Action	Underhand grip 1 hand	Underhand grip 2 hands	Round handle 1 hand	Round handle 2 hands
Underhand grip 1 hand	1.00	0.28 **	0.18 *	0.23 **
Underhand grip 2 hands	0.28 **	1.00	0.90 **	0.91 **
Round handle 1 hand	0.18 *	0.90 **	1.00	0.96 **
Round handle 2 hands	0.23 **	0.91 **	0.96 **	1.00

* Correlation is significant at the 0.05 significant level

** Correlation is significant at the 0.01 significant level

Appendix 5 - Wrist-twisting and push-and-turn strength

5a - Anthropometric characteristics of subjects

Age (years)	Sex	No.	Stature		Weight		Elbow height		Hand length		Hand Breadth	
			Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
2-5	m	9	1060.00	88.88	18.53	2.87	638.89	70.61	108.22	9.69	54.22	4.09
	f	7	1002.86	44.61	15.17	1.87	15.17	29.92	112.86	8.38	50.57	3.21
6-10	m	5	1314.00	109.22	28.48	6.45	836.00	73.69	138.60	13.79	61.80	61.80
	f	8	1351.25	98.91	30.45	9.57	853.75	66.32	143.00	13.65	64.00	5.98
11-15	m	6	1651.67	60.47	48.20	7.64	1041.67	47.50	172.17	10.83	76.33	7.26
	f	6	1591.67	101.47	50.37	11.29	1053.33	52.03	164.50	9.33	69.00	4.52
16-20	m	7	1788.57	45.25	61.74	6.67	1117.14	34.98	183.71	8.73	82.14	5.70
	f	5	1642.00	29.50	54.40	5.61	1076.00	28.81	162.80	2.95	69.60	3.97
21-30	m	6	1876.67	76.33	79.02	13.63	1155.00	48.48	187.83	6.68	82.33	5.13
	f	7	1615.71	170.48	67.93	12.26	1077.14	40.30	170.00	6.11	70.43	4.69
31-50	m	8	1735.00	211.59	82.65	11.20	1137.50	43.01	188.38	9.05	84.75	2.71
	f	8	1657.50	87.95	76.43	28.70	1068.75	60.58	165.63	16.54	75.50	4.87
51-60	m	4	1802.50	34.03	83.95	20.07	1140.00	45.46	195.50	6.35	85.00	3.56
	f	4	1670.00	42.43	65.85	9.76	1060.00	35.59	175.00	4.97	76.75	2.22
61-70	m	4	1795.00	63.51	79.95	9.69	1135.00	59.72	193.50	11.90	85.75	2.87
	f	14	1624.29	51.25	61.71	10.66	1020.71	41.60	173.64	9.56	76.50	4.01
71-80	m	9	1748.89	42.85	81.00	7.20	1092.22	27.28	190.11	6.97	86.00	3.64
	f	12	1625.42	57.74	69.77	9.41	1047.50	41.15	176.17	9.43	77.67	4.33
81-90	m	5	1800.00	28.28	71.20	7.92	1115.00	21.21	182.00	2.83	83.50	0.71
	f	8	1598.75	72.79	59.77	10.63	1030.00	56.57	171.00	11.98	77.38	3.58

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

Circular Knob

Age (years)	Sex	No.	Circular knob horizontal			Circular knob vertical		
			t	df	Sig	t	df	Sig
2-5	m	9	0.388	14.000	0.704	-0.755	14.000	0.463
	f	7						
6-10	m	5	0.450	11.000	0.662	-0.264	11.000	0.797
	f	8						
11-15	m	6	1.014	10.000	0.335	0.593	10.000	0.566
	f	6						
16-20	m	7	0.849	10.000	0.416	1.145	10.000	0.279
	f	5						
21-30	m	6	1.905	6.524	0.101	2.841	11.000	0.016 *
	f	7						
31-50	m	8	0.661	14.000	0.519	1.550	13.790	0.144
	f	8						
51-60	m	4	1.726	6.000	0.135	2.423	6.000	0.052
	f	4						
61-70	m	4	1.735	16.000	0.102	3.833	16.000	0.001 *
	f	14						
71-80	m	9	2.269	19.000	0.035 *	0.951	19.000	0.353
	f	12						
81 to 90	m	2	0.775	8.000	0.460	-0.125	8.000	0.904
	f	8						

Push and turn knob

Age (years)	Sex	No.	Horizontal knob 10N resistance			Horizontal knob 20N resistance			Vertical knob 10N resistance			Vertical knob 20N resistance		
			t	df	Sig	t	df	Sig	t	df	Sig	t	df	Sig
2-5	m	9	0.043	13.000	0.966	1.052	13.000	0.312	0.572	13.000	0.577	0.106	12.000	0.917
	f	7												
6-10	m	5	0.029	11.000	0.977	-0.722	11.000	0.485	-0.692	11.000	0.503	-0.990	11.000	0.343
	f	8												
11-15	m	6	2.310	10.000	0.044*	1.765	10.000	0.108	1.413	10.000	0.188	0.716	7.101	0.497
	f	6												
16-20	m	7	5.519	10.000	0.000*	3.048	10.000	0.012*	3.562	10.000	0.005	3.264	10.000	0.009*
	f	5												
21-30	m	6	2.122	11.000	0.057	3.059	11.000	0.011*	3.785	11.000	0.003*	5.978	11.000	0.000*
	f	7												
31-50	m	8	3.468	11.353	0.005*	4.203	14.000	0.001*	4.215	14.000	0.001*	3.197	14.000	0.006*
	f	8												
51-60	m	4	3.898	6.000	0.008*	4.862	6.000	0.003*	2.513	6.000	0.046*	2.750	6.000	0.033*
	f	4												
61-70	m	4	4.619	16.000	0.000*	2.560	16.000	0.021*	3.177	16.000	0.006*	2.572	16.000	0.020*
	f	14												
71-80	m	9	4.068	19.000	0.001*	3.055	19.000	0.007*	3.774	19.000	0.001*	3.177	19.000	0.005*
	f	12												
81 to 90	m	2	0.703	1.053	0.605	0.107	1.022	0.932	0.836	1.033	0.553	0.900	1.048	0.528
	f	8												

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		*	*	*	*	*	*	*	*	*
					not cv		not cv, ch	not cv, ch	not cv, ch	not cv, ch
6-10			*	*	*	*	*	*	*	*
			not cv, ch	not cv, ch		not cv, ch				not r10v, r20v
11-15				X	*	*	*	*	*	*
					not cv, ch	not cv, ch	not cv, ch r10v r20v	not cv, ch	not cv, r10h r10v r20v	not cv, r10h r20h r10v
16-20					X	*	X	*	*	*
						not cv, ch r10v		not r10h r20h, r20v	not cv, r10h r20h, r10v r20v	not cv, r10h r20h
21-30						*	X	*	*	*
						not ch r10v, r20v		not cv, ch r10h, r20h	not cv, ch r10h, r20h	not cv
31-50							not ch, r10h r20h, r10v, r20v	*	*	*
51-60								*	*	*
								not cv, ch, r10h, r20h	not ch, cv, r10h, r20h r10v	not cv
61-70									X	*
										not cv, r10h r10v, r20v
71-80										*
										not ch, cv, r20v

Key:

* = significant difference at 0.05 level

X = no significant difference between age groups

ch = circular knob in horizontal position

cv = circular knob in vertical position

r10h = ridged push and turn knob, 10N resistance, in horizontal position

r20h = ridged push and turn knob, 20N resistance, in horizontal position

r10v = ridged push and turn knob, 10N resistance, vertical position

r20v = ridged push and turn knob, 20N resistance, vertical position

5d – Differences between knob used and the resistance of the push and turn knob (Paired samples test)

Action	t	df	Sig
ch - r10h	-17.348	137	0.000*
ch- r20h	-16.153	137	0.000*
ch - r10v	-14.985	137	0.000*
ch - r20v	-13.892	136	0.000*
cv - r10h	-18.103	137	0.000*
cv - r20h	-17.012	137	0.000*
cv - r10v	-15.821	137	0.000*
cv - r20v	-14.673	136	0.000*
r10h - r20h	2.750	137	0.007*
r10h - r10v	8.932	137	0.000*
r10h - r20v	10.371	136	0.000*
r20h - r10v	6.020	137	0.000*
r10v - r20v	2.945	136	0.004*
r20h - r20v	7.645	136	0.000*

Key:

ch = circular knob in horizontal position

cv = circular knob in vertical position

r10h = ridged push and turn knob, 10N resistance, in horizontal position

r20h = ridged push and turn knob, 20N resistance, in horizontal position

r10v = ridged push and turn knob, 10N resistance, vertical position

r20v = ridged push and turn knob, 20N resistance, vertical position

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)

	Circular knob horizontal	Circular knob vertical	Push-turn knob 10N resistance horizontal	Push-turn knob 20N resistance horizontal	Push-turn knob 10N resistance vertical	Push-turn knob 20N resistance vertical
Circular knob horizontal	1.00	0.72 **	0.26 **	0.18 *	0.27 **	0.29**
Circular knob vertical	0.72**	1.00	0.30**	0.23**	0.32**	0.33**
Push-turn knob 10N resistance horizontal	0.26 **	0.30**	1.00	0.94**	0.91 **	0.89**
Push-turn knob 20N resistance horizontal	0.18 *	0.23 **	0.94 **	1.00	0.88**	0.86**
Push-turn knob 10N resistance vertical	0.27 **	0.32**	0.91**	0.88**	1.00	0.93**
Push-turn knob 20N resistance vertical	0.29 **	0.33 **	0.89**	0.86**	0.93**	1.00

* Correlation is significant at the 0.05 significant level

** Correlation is significant at the 0.01 significant level

Appendix 6 - Pull on a can ring-pull

6a - Anthropometric characteristics of subjects

Age (years)	Sex	No.	Stature		Weight		Hand length		Hand breadth	
			Mean	SD	Mean	SD	Mean	SD	Mean	SD
2-5	m	9	1060.00	88.88	18.53	46.50	107.89	9.48	54.22	4.09
	f	7	1002.86	44.61	15.17	1.87	112.86	8.38	50.57	3.21
6-10	m	6	1314.00	109.22	28.48	6.45	138.60	13.79	61.80	4.49
	f	8	1351.25	98.91	30.45	9.57	143.00	13.65	64.00	5.98
11-15	m	6	1651.67	60.47	48.20	7.64	172.17	10.83	76.33	7.26
	f	6	1591.67	101.47	50.37	11.29	172.17	10.83	76.33	7.26
16-20	m	6	1788.57	45.25	61.74	6.67	183.71	8.73	82.14	5.70
	f	5	1642.00	29.50	54.40	5.61	162.80	2.95	69.60	3.97
21-30	m	6	1876.67	76.33	79.02	13.63	187.83	6.68	82.33	5.13
	f	7	1615.71	170.48	67.93	12.26	170.00	6.11	70.43	4.69
31-50	m	8	1735.00	211.59	82.65	11.20	188.38	9.05	84.75	2.71
	f	8	1657.50	87.95	76.43	28.70	165.63	16.54	75.50	4.87
51-60	m	4	1802.50	34.03	83.95	20.07	195.50	6.35	85.00	3.56
	f	4	1670.00	42.43	65.85	9.76	175.00	4.97	76.75	2.22
61-70	m	4	1795.00	63.51	79.95	9.69	193.50	11.90	85.75	2.87
	f	14	1624.29	51.25	61.71	10.66	173.64	9.56	76.50	4.01
71-80	m	9	1748.89	42.85	81.00	7.20	190.11	6.97	86.00	3.64
	f	12	1625.42	57.74	69.77	9.41	176.17	9.43	77.67	4.33
81-90	m	2	1800.00	28.28	71.20	7.92	182.00	2.83	83.50	0.71
	f	8	1598.75	72.79	59.77	10.63	171.00	11.98	77.38	3.58

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

Age (years)	Sex	No.	Horizontal ring-pull			Vertical ring-pull		
			t	df	Sig	t	df	Sig
2-5	m	9	2.243	8.756	0.052	1.137	14.000	0.275
	f	7						
6-10	m	5	1.307	11.000	0.218	0.525	11.000	0.610
	f	8						
11-15	m	6	-0.222	10.000	0.829	1.139	10.000	0.281
	f	6						
16-20	m	7	2.580	10.000	0.027*	3.478	10.000	0.006*
	f	5						
21-30	m	6	2.780	6.549	0.029*	5.096	11.000	0.000*
	f	7						
31-50	m	8	2.582	8.752	0.030*	1.149	14.000	0.270
	f	8						
51-60	m	4	2.908	3.118	0.059	3.583	6.000	0.012*
	f	4						
61-70	m	4	2.258	16.000	0.038*	3.069	16.000	0.007*
	f	14						
71-80	m	9	1.675	19.000	0.110	1.989	19.000	0.061
	f	12						
81 to 90	m	2	-0.325	8.000	0.753	1.226	1.026	0.432
	f	8						

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)

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 v	*	*	*	X	* not v	* not v	X
11-15				X	X	* not h	X	X	X	*
16-20					X	X	X	* not h	X	*
21-30						* not h	X	X	X	*
31-50							X	*	*	*
51-60								X	X	* not h
61-70									X	*
71-80										*

Key:

* = significant difference at 0.05 level

X = no significant difference between age groups

v = vertical ring-pull

h = horizontal ring-pull

6d – Differences between the position of the ring-pull (Paired samples test)

Action	t	df	Sig
Horizontal ring pull – Vertical ring pull	-12.443	138	0.000*

Key:

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)

	Horizontal ring-pull	Vertical ring-pull
Horizontal ring-pull	1.00	0.61**
Vertical ring-pull	0.61**	1.00

** Correlation is significant at the 0.01 significant level

Appendix 7 – Press and lift with the foot

7a - Anthropometric characteristics of subjects

Age (years)	Sex	No.	Stature		Weight		Instep height		Foot length		Foot breadth	
			Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
2-5	m	9	1066.67	86.02	18.38	2.72	63.89	6.51	191.22	11.13	72.44	3.78
	f	8	1023.75	64.57	16.38	3.43	59.38	4.17	177.38	14.28	66.75	5.42
6-10	m	5	1314.00	109.22	28.48	6.45	77.00	4.47	236.40	21.30	83.20	6.18
	f	8	1353.75	101.13	30.55	9.58	81.88	15.10	221.50	14.87	78.00	3.51
11-15	m	7	1653.57	55.43	50.83	6.20	92.86	9.51	278.57	11.22	97.57	5.94
	f	5	1610.00	100.75	53.68	8.77	98.00	13.04	242.80	13.10	86.60	3.85
16-20	m	7	1788.57	45.25	66.03	8.10	101.43	8.52	298.29	4.68	108.29	6.63
	f	5	1646.00	36.47	60.32	16.58	91.60	10.74	245.00	21.42	91.80	10.92
21-30	m	7	1860.00	82.46	77.67	12.94	99.29	6.07	323.43	47.28	107.57	5.32
	f	6	1613.33	187.90	68.47	13.15	95.83	8.61	253.83	16.65	96.00	8.20
31-50	m	9	1746.67	201.00	81.20	11.29	97.78	13.25	293.33	9.46	104.33	4.95
	f	8	1656.25	87.00	76.15	28.93	95.00	13.89	255.13	20.68	255.13	14.47
51-60	m	4	1802.50	34.03	83.95	20.07	92.50	9.57	291.25	11.73	104.00	6.48
	f	4	1670.00	42.43	65.85	9.76	87.50	6.45	251.50	4.80	88.25	4.86
61-70	m	5	1798.00	55.41	80.36	8.44	100.00	0.00	277.00	46.66	100.60	8.44
	f	14	1623.57	51.38	61.71	10.66	88.57	6.63	251.50	14.74	84.93	9.20
71-80	m	9	1748.89	42.85	81.00	7.20	97.22	7.55	290.44	12.13	98.44	4.07
	f	13	1622.69	56.15	69.37	9.12	88.46	11.44	257.77	9.88	90.69	8.42
81-90	m	2	1800.00	28.28	71.20	7.92	102.50	3.54	282.50	0.71	93.00	5.66
	f	5	1618.00	75.96	60.08	7.72	75.00	16.20	252.60	5.55	87.40	5.59

7b – Differences between males and females (t-test)

Age (years)	Sex	No.	Press bar with foot			Lift bar with foot			Press pedal with foot			Lift pedal with foot		
			t	df	Sig	t	df	Sig	t	df	Sig	t	df	Sig
2-5	m	9	0.567	15.000	0.579	-0.286	15.000	0.779	-0.068	15.000	0.947	1.532	15.000	0.146
	f	8												
6-10	m	5	-1.321	9.106	0.219	-1.931	11.000	0.080	-0.354	11.000	0.730	-1.401	11.000	0.189
	f	8												
11-15	m	7	0.775	6.736	0.464	1.242	10.000	0.243	1.548	10.000	0.153	0.902	10.000	0.388
	f	5												
16-20	m	7	3.492	10.000	0.006*	3.736	10.000	0.004*	2.044	10.000	0.068	2.739	10.000	0.021*
	f	5												
21-30	m	7	2.260	7.759	0.055	2.045	11.000	0.066	1.848	11.000	0.092	1.070	11.000	0.308
	f	6												
31-50	m	9	1.928	15.000	0.073	3.755	15.000	0.002*	1.567	15.000	0.138	4.372	15.000	0.001*
	f	8												
51-60	m	4	2.572	6.000	0.042*	3.009	6.000	0.024*	-0.928	6.000	0.389	2.998	6.000	0.024*
	f	4												
61-70	m	5	4.133	17.000	0.001*	4.314	17.000	0.000*	2.709	17.000	0.015*	3.505	17.000	0.003*
	f	14												
71-80	m	9	1.549	20.000	0.137	2.189	20.000	0.041*	-0.287	20.000	0.777	0.188	20.000	0.853
	f	13												
81 to 90	m	2	0.475	5.000	0.655	1.447	5.000	0.208	0.922	1.064	0.518	0.529	5.000	0.619
	f	5												

Key:

t = value from t-test

df = degrees of freedom

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

7c – 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	*	* not bp, pp pl	X not pp, pl	X	* not bp, pp pl	* not pl
16-20					X	X	X	* not pl	* not pp, pl	* not pl
21-30						X	X	* not pl	* not pl	* not pl
31-50							X	*	*	*
51-60								X	X	* not pl
61-70									X	* not pp, pl
71-80										* not bl, pp pl

Key:

* = significant difference at 0.05 level

X = no significant difference between age groups

bp = pressing bar with foot

bl = lifting bar with foot

pp = pressing pedal with foot

pl = lifting pedal with foot

7d – Differences between the pedal/bar and lifting and pressing (Paired samples test)

Action	t	df	Sig
bp – bl	19.560	139.000	0.000*
bp – pp	14.345	139.000	0.000*
bp – pl	19.450	139.000	0.000*
bl – pp	-5.400	139.000	0.000*
bl – pl	11.747	139.000	0.000*
pp – pl	13.155	139.000	0.000*

Key:

bp = pressing bar with foot

bl = lifting bar with foot

pp = pressing pedal with foot

pl = lifting pedal with foot

t = value from t-test

df = degrees of freedom

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

7e - Correlation between measurements (Pearson Correlation)

	Press bar with foot	Lift bar with foot	Press pedal with foot	Lift pedal with foot
Press bar with foot	1.00	0.88**	0.71**	0.79**
Lift bar with foot	0.88**	1.00	0.75	0.82
Press pedal with foot	0.71**	0.75**	1.00	0.73**
Lift pedal with foot	0.79**	0.82**	0.73**	1.00

** Correlation is significant at the 0.01 significant level

Appendix 8 – Pull on 20mm knob

8a - Anthropometric characteristics of subjects

Age (years)	Sex	No.	Stature		Weight		Elbow height		Hand length		Hand breadth	
			Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
2-5	m	9	1066.67	86.02	18.38	2.72	596.67	171.83	107.67	9.55	53.22	1.92
	f	8	1023.75	64.57	16.38	3.43	631.25	45.18	116.63	5.97	51.50	4.07
6-10	m	5	1314.00	109.22	28.48	6.45	828.00	77.59	138.60	13.79	61.80	4.49
	f	8	1353.75	101.13	30.53	9.59	871.25	92.35	142.00	12.17	63.63	5.71
11-15	m	7	1653.57	55.43	50.83	6.20	1064.29	28.78	171.57	5.68	75.86	6.74
	f	6	1590.00	102.57	50.37	11.29	1056.67	56.45	164.50	8.32	72.33	9.33
16-20	m	8	1765.00	78.74	64.90	8.15	1132.50	51.20	181.25	11.35	79.75	8.58
	f	4	1657.50	29.86	61.15	19.02	1070.00	18.26	153.50	21.70	69.25	3.86
21-30	m	7	1860.00	82.46	77.67	12.94	1167.14	45.36	189.86	8.11	82.43	4.69
	f	6	1613.33	187.90	68.47	13.15	1083.33	38.82	173.00	5.18	72.83	4.96
31-50	m	9	1746.67	201.00	81.20	11.29	1154.44	38.12	188.89	8.55	85.22	2.73
	f	8	1656.25	87.00	76.15	28.93	1057.50	62.05	165.25	16.17	74.88	4.97
51-60	m	4	1802.50	34.03	83.95	20.07	1150.00	8.16	195.50	6.35	85.00	3.56
	f	4	1670.00	42.43	65.85	9.76	1070.00	36.51	175.00	4.97	76.75	2.22
61-70	m	5	1798.00	55.41	292.92	473.60	1144.00	42.78	195.60	11.33	86.60	3.13
	f	14	1623.57	51.38	61.71	10.66	1027.86	39.45	181.57	35.85	78.21	8.38
71-80	m	9	1748.89	42.85	81.00	7.20	1097.78	36.32	190.11	6.97	86.89	2.62
	f	13	1622.69	56.15	69.37	9.12	1038.46	35.32	176.08	9.03	77.08	4.66
81-90	m	2	1800.00	28.28	71.20	7.92	1105.00	21.21	1105.00	2.83	83.50	0.71
	f	4	1622.00	71.90	60.08	7.72	1044.00	51.28	170.60	14.33	77.40	2.30

8b – Differences between males and females (t-test)

Age (years)	Sex	No.	One hand			Two hands		
			t	df	Sig	t	df	Sig
2-5	m	9	0.134	15.000	0.895	0.795	11.358	0.443
	f	8						
6-10	m	5	0.651	11.000	0.529	0.178	10.000	0.862
	f	8						
11-15	m	7	-0.406	11.000	0.693	0.093	11.000	0.928
	f	6						
16-20	m	8	4.057	10.000	0.002*	3.924	10.000	0.003*
	f	4						
21-30	m	7	2.986	11.000	0.012*	1.302	11.000	0.220
	f	6						
31-50	m	9	-0.024	15.000	0.981	-0.865	15.000	0.400
	f	8						
51-60	m	4	0.770	6.000	0.470	0.966	6.000	0.371
	f	4						
61-70	m	5	-0.466	17.000	0.647	0.394	17.000	0.698
	f	14						
71-80	m	9	1.742	10.392	0.111	1.620	20.000	0.121
	f	13						
81 to 90	m	2	1.507	4.000	0.206	0.543	1.009	0.683
	f	5						

Key:

t = value from t-test

df = degrees of freedom

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

8c – 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	* not 2h	* not 2h	* not 2h	* not 2h	* not 2h	* not 2h	X
11-15				* not 2h	X	* not 2h	X	X	X	X
16-20					X	X	X	X	X	X
21-30						X	X	X	X	X
31-50							X	X	X	X
51-60								X	X	X
61-70									X	X
71-80										X

Key:

* = significant difference at 0.05 level

X = no significant difference between age groups

2h = two hands

8d – Differences between number of hands used (Paired samples test)

Action	t	df	Sig
One hand – two hands	-9.015	139	0.000*

Key:

t = value from t-test

df = degrees of freedom

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

8e - Correlation between measurements (Pearson Correlation)

	Pull with one hand	Pull with two hands
Pull with one hand	1.00	0.77**
Pull with two hands	0.77**	1.00

** Correlation is significant at the 0.01 significant level

Appendix 9 – Correlation between measurements

Appendix 9 - Correlation between measurements

		Push and pull strength							
		Horizontal push one hand	Vertical push one hand	Horizontal push two hands	Vertical push two hands	Horizontal pull one hand	Vertical pull one hand	Horizontal pull two hands	Vertical pull two hands
Push and pull strength	Horizontal push one hand	1.00	0.93**	0.92**	0.91**	0.87**	0.82**	0.81**	0.80**
	Vertical push one hand	0.93**	1.00	0.90**	0.96**	0.84**	0.84**	0.79**	0.81**
	Horizontal push two hands	0.92**	0.90**	1.00	0.92**	0.84**	0.81**	0.80**	0.79**
	Vertical push two hands	0.91**	0.96**	0.92**	1.00	0.87**	0.86**	0.81**	0.83**
	Horizontal pull one hand	0.87**	0.84**	0.84**	0.87**	1.00	0.92**	0.93**	0.90**
	Vertical pull one hand	0.82**	0.84**	0.81**	0.86**	0.92**	1.00	0.91**	0.96**
	Horizontal pull two hands	0.81**	0.79**	0.80**	0.81**	0.93**	0.91**	1.00	0.93**
	Vertical pull two hands	0.80**	0.81**	0.79**	0.83**	0.90**	0.96**	0.93**	1.00
Push with the thumb or 2 or more fingers	Push with fingers forwards	0.27**	0.24**	0.30**	0.23**	0.24**	0.17*	0.20*	0.16
	Push with fingers down	0.28**	0.24**	0.30**	0.23**	0.25**	0.18*	0.21*	0.16*
	Push with thumb down	0.24**	0.22**	0.28**	0.21*	0.19*	0.15	0.16*	0.12
Push with the Shoulder	Push 100%	0.19*	0.19*	0.18*	0.15	0.18*	0.11	0.15	0.10
	Push 90%	0.02	0.03	-0.03	0.03	0.02	-0.01	-0.01	-0.03
Pull with different grips	Underhand 1 hand	-0.01	0.01	0.03	0.01	0.07	0.04	0.04	0.03
	Underhand 2 hands	0.01	0.06	0.09	0.08	0.09	0.05	0.09	0.07
	Round handle 1 hand	-0.03	0.02	0.04	0.03	0.05	0.00	0.07	0.02
	Round handle 2 hands	0.00	0.05	0.09	0.07	0.08	0.02	0.08	0.04
Wrist twisting and push & turn strength	Circular knob horizontal	0.01	-0.05	-0.01	-0.03	0.01	0.03	0.02	0.05
	Circular knob vertical	0.00	0.00	0.03	0.00	0.04	0.07	0.03	0.08
	Push-turn knob 10N horizontal	0.02	-0.01	-0.02	-0.05	-0.02	-0.03	-0.04	-0.06
	Push-turn knob 20N horizontal	0.03	0.00	-0.03	-0.05	-0.05	-0.04	-0.05	-0.09
	Push-turn knob 10N vertical	0.05	0.01	0.00	-0.02	0.04	0.05	0.02	0.01
	Push-turn knob 20N vertical	0.04	-0.01	-0.02	-0.04	-0.01	0.02	-0.02	-0.02
Pull on can ring pull	Horizontal pull	0.04	0.04	-0.01	0.00	0.06	0.06	0.06	0.03
	Vertical pull	0.05	0.01	0.00	-0.01	0.07	0.07	0.08	0.02
Press & lift with the foot	Press bar with foot	0.12	0.12	0.07	0.06	0.10	0.15	0.08	0.09
	Lift bar with foot	0.11	0.12	0.10	0.07	0.12	0.15	0.08	0.09
	Press pedal with foot	0.09	0.06	0.05	0.03	0.06	0.09	0.02	0.04
	Lift pedal with foot	0.09	0.09	0.08	0.05	0.07	0.06	0.05	0.01
Pull on 20mm knob	Pull with one hand	0.05	0.05	0.04	0.04	0.02	0.03	0.05	0.04
	Pull with two hands	0.05	0.04	0.03	0.02	-0.02	-0.01	0.00	0.00

* Denotes significant correlation at 0.05 level

** Denotes significant correlation at 0.01 level

		Push with the thumb or 2 or more fingers		
		Push with fingers forwards	Push with fingers down	Push with thumb down
Push and pull strength	Horizontal push one hand	0.27 **	0.28 **	0.24 **
	Vertical push one hand	0.24 **	0.24**	0.22 **
	Horizontal push two hands	0.30**	0.30**	0.28 **
	Vertical push two hands	0.23**	0.23**	0.21 *
	Horizontal pull one hand	0.24**	0.25**	0.19 *
	Vertical pull one hand	0.17*	0.18*	0.15
	Horizontal pull two hands	0.20*	0.21*	0.16*
	Vertical pull two hands	0.16	0.16*	0.12
Push with the thumb or 2 or more fingers	Push with fingers forwards	1.00	0.96	0.89 **
	Push with fingers down	0.96**	1.00	0.89 **
	Push with thumb down	0.89**	0.89**	1.00
Push with the Shoulder	Push 100%	0.08	0.07	0.04
	Push 90%	-0.27 **	-0.26 **	-0.25 **
Pull with different grips	Underhand 1 hand	-0.08	-0.07	-0.09
	Underhand 2 hands	0.00	0.04	0.03
	Round handle 1 hand	0.02	0.04	0.05
	Round handle 2 hands	0.04	0.05	0.07
Wrist twisting and push & turn strength	Circular knob horizontal	0.04	0.07	0.03
	Circular knob vertical	0.07	0.10	0.05
	Push-turn knob 10N horizontal	0.00	0.03	-0.03
	Push-turn knob 20N horizontal	-0.03	-0.01	-0.07
	Push-turn knob 10N vertical	0.07	0.12	0.08
Pull on can ring pull	Push-turn knob 20N vertical	0.00	0.04	-0.01
	Horizontal pull	0.06	0.10	0.05
Press & lift with the foot	Vertical pull	0.04	0.09	0.09
	Press bar with foot	0.13	0.17	0.18 *
	Lift bar with foot	0.24 **	0.28 **	0.30 **
	Press pedal with foot	0.13	0.13	0.17 *
Pull on 20mm knob	Lift pedal with foot	0.11	0.14	0.15
	Pull with one hand	-0.18 **	-0.16	-0.14
	Pull with two hands	-0.17	-0.15	-0.12

* Denotes significant correlation at 0.05 level

** Denotes significant correlation at 0.01 level

		Push with the shoulder	
		Push 100%	Push 90%
Push and pull strength	Horizontal push one hand	0.19 *	0.02
	Vertical push one hand	0.19 *	0.03
	Horizontal push two hands	0.18 *	-0.03
	Vertical push two hands	0.15	0.03
	Horizontal pull one hand	0.18 *	0.02
	Vertical pull one hand	0.11	-0.01
	Horizontal pull two hands	0.15	-0.01
	Vertical pull two hands	0.10	-0.03
Push with the thumb or 2 or more fingers	Push with fingers forwards	0.08	-0.27 **
	Push with fingers down	0.07	-0.26 **
	Push with thumb down	0.04	-0.25 **
Push with the Shoulder	Push 100%	1.00	0.48 **
	Push 90%	0.48 **	1.00
Pull with different grips	Underhand 1 hand	0.35 **	0.59 **
	Underhand 2 hands	0.08	0.09
	Round handle 1 hand	0.03	0.00
	Round handle 2 hands	0.05	0.02
Wrist twisting and push & turn strength	Circular knob horizontal	-0.08	0.05
	Circular knob vertical	-0.02	0.14
	Push-turn knob 10N horizontal	-0.14	-0.04
	Push-turn knob 20N horizontal	-0.09	0.01
	Push-turn knob 10N vertical	-0.14	-0.07
	Push-turn knob 20N vertical	-0.11	-0.01
Pull on can ring-pull	Horizontal pull	-0.08	-0.03
	Vertical pull	-0.07	0.03
Press & lift with the foot	Press bar with foot	-0.15	0.02
	Lift bar with foot	-0.14	0.02
	Press pedal with foot	-0.11	-0.02
	Lift pedal with foot	-0.09	0.05
Pull on 20mm knob	Pull with one hand	0.02	0.17 *
	Pull with two hands	0.13	0.19 *

* Denotes significant correlation at 0.05 level

** Denotes significant correlation at 0.01 level

		Pull with different grips			
		Underhand 1 hand	Underhand 2 hands	Round handle 1 hand	Round handle 2 hands
Push and pull strength	Horizontal push one hand	-0.01	0.01	-0.03	0.00
	Vertical push one hand	0.01	0.06	0.02	0.05
	Horizontal push two hands	0.03	0.09	0.04	0.09
	Vertical push two hands	0.01	0.08	0.03	0.07
	Horizontal pull one hand	0.07	0.09	0.05	0.08
	Vertical pull one hand	0.04	0.05	0.00	0.02
	Horizontal pull two hands	0.04	0.09	0.07	0.08
	Vertical pull two hands	0.03	0.07	0.02	0.04
Push with the thumb or 2 or more fingers	Push with fingers forwards	-0.08	0.00	0.02	0.04
	Push with fingers down	-0.07	0.04	0.04	0.05
	Push with thumb down	-0.09	0.03	0.05	0.07
Push with the Shoulder	Push 100%	0.35 **	0.08	0.03	0.05
	Push 90%	0.59 **	0.09	0.00	0.02
Pull with different grips	Underhand 1 hand	1.00	0.28 **	0.18 *	0.23 **
	Underhand 2 hands	0.28 **	1.00	0.90 **	0.91 **
	Round handle 1 hand	0.18 *	0.90 **	1.00	0.96 **
	Round handle 2 hands	0.23 **	0.91 **	0.96 **	1.00
Wrist twisting and push and turn strength	Circular knob horizontal	0.00	-0.03	-0.06	-0.10
	Circular knob vertical	0.12	0.01	-0.07	-0.08
	Push-turn knob 10N horizontal	-0.10	-0.03	0.04	0.00
	Push-turn knob 20N horizontal	-0.05	0.01	0.09	0.05
	Push-turn knob 10N vertical	-0.12	-0.09	-0.05	-0.09
	Push-turn knob 20N vertical	-0.07	-0.11	-0.07	-0.11
Pull on can ring-pull	Horizontal pull	-0.05	-0.06	-0.03	-0.07
	Vertical pull	-0.05	-0.09	-0.08	-0.12
Press and lift with the foot	Press bar with foot	-0.16	-0.01	0.01	-0.02
	Lift bar with foot	-0.14	-0.08	-0.07	-0.10
	Press pedal with foot	-0.14	-0.14	-0.12	-0.13
	Lift pedal with foot	-0.12	0.02	0.05	0.02
Pull on 20mm knob	Pull with one hand	0.19 *	-0.04	-0.08	-0.08
	Pull with two hands	0.11	0.01	0.00	-0.03

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** Denotes significant correlation at 0.01 level

		Wrist twisting and push and turn strength					
		Circular knob horizontal	Circular knob vertical	Push-turn knob 10N resistance horizontal	Push-turn knob 20N resistance horizontal	Push-turn knob 10N resistance vertical	Push-turn knob 20N resistance vertical
Push and pull strength	Horizontal push one hand	0.01	0.00	0.02	0.03	0.05	0.04
	Vertical push one hand	-0.05	0.00	-0.01	0.00	0.01	-0.01
	Horizontal push two hands	-0.01	0.03	-0.02	-0.03	0.00	-0.02
	Vertical push two hands	-0.03	0.00	-0.05	-0.05	-0.02	-0.04
	Horizontal pull one hand	0.01	0.04	-0.02	-0.05	0.04	-0.01
	Vertical pull one hand	0.03	0.07	-0.03	-0.04	0.05	0.02
	Horizontal pull two hands	0.02	0.03	-0.04	-0.05	0.02	-0.02
	Vertical pull two hands	0.05	0.08	-0.06	-0.09	0.01	-0.02
Push with the thumb or 2 or more fingers	Push with fingers forwards	0.04	0.07	0.00	-0.03	0.07	0.00
	Push with fingers down	0.07	0.10	0.03	-0.01	0.12	0.04
	Push with thumb down	0.03	0.05	-0.03	-0.07	0.08	-0.01
Push with the Shoulder	Push 100%	-0.08	-0.02	-0.14	-0.09	-0.14	-0.11
	Push 90%	0.05	0.14	-0.04	0.01	-0.07	-0.01
Pull with different grips	Underhand 1 hand	0.00	0.12	-0.10	-0.05	-0.12	-0.07
	Underhand 2 hands	-0.03	0.01	-0.03	0.01	-0.09	-0.11
	Round handle 1 hand	-0.06	-0.07	0.04	0.09	-0.05	-0.07
	Round handle 2 hands	-0.10	-0.08	0.00	0.05	-0.09	-0.11
Wrist twisting and push and turn strength	Circular knob horizontal	1.00	0.72 **	0.26 **	0.18 *	0.27 **	0.29**
	Circular knob vertical	0.72**	1.00	0.30**	0.23**	0.32**	0.33**
	Push-turn knob 10N horiz	0.26 **	0.30**	1.00	0.94**	0.91**	0.89**
	Push-turn knob 20N horiz	0.18 *	0.23 **	0.94 **	1.00	0.88**	0.86**
	Push-turn knob 10N vertical	0.27 **	0.32**	0.91**	0.88**	1.00	0.93**
	Push-turn knob 20N vertical	0.29 **	0.33 **	0.89**	0.86**	0.93**	1.00
Pull on can ringipull	Horizontal pull	0.38**	0.43**	0.73**	0.72**	0.74**	0.75**
	Vertical pull	0.41**	0.44**	0.64**	0.61**	0.69**	0.60**
Press and lift with the foot	Press bar with foot	0.13	0.16	0.53**	0.52**	0.57**	0.54**
	Lift bar with foot	0.20 *	0.23**	0.51**	0.46 **	0.55**	0.51**
	Press pedal with foot	0.21 *	0.16	0.44**	0.38**	0.46**	0.44**
	Lift pedal with foot	0.10	0.13	0.56 **	0.53**	0.55**	0.53**
Pull on 20mm knob	Pull with one hand	-0.12	-0.12	-0.15	-0.11	-0.17	-0.17*
	Pull with two hands	-0.14	-0.16	-0.14	-0.09	-0.15	-0.16

* Denotes significant correlation at 0.05 level

** Denotes significant correlation at 0.01 level

		Pull on can ring-pull	
		Horizontal ring-pull	Vertical ring-pull
Push and pull strength	Horizontal push one hand	0.04	0.05
	Vertical push one hand	0.04	0.01
	Horizontal push two hands	-0.01	0.00
	Vertical push two hands	0.00	-0.01
	Horizontal pull one hand	0.06	0.07
	Vertical pull one hand	0.06	0.07
	Horizontal pull two hands	0.06	0.08
	Vertical pull two hands	0.03	0.02
Push with the thumb or 2 or more fingers	Push with fingers forwards	0.06	0.04
	Push with fingers down	0.10	0.09
	Push with thumb down	0.05	0.09
Push with the Shoulder	Push 100%	-0.08	-0.07
	Push 90%	-0.03	0.03
Pull with different grips	Underhand 1 hand	-0.05	-0.05
	Underhand 2 hands	-0.06	-0.09
	Round handle 1 hand	-0.03	-0.08
	Round handle 2 hands	-0.07	-0.12
Wrist twisting and push and turn strength	Circular knob horizontal	0.38 **	0.41 **
	Circular knob vertical	0.43 **	0.44 **
	Push-turn knob 10N horizontal	0.73 **	0.64**
	Push-turn knob 20N horizontal	0.72**	0.61**
	Push-turn knob 10N vertical	0.74**	0.69**
	Push-turn knob 20N vertical	0.75**	0.60**
Pull on can ring-pull	Horizontal pull	1.00	0.61**
	Vertical pull	0.61**	1.00
Press and lift with the foot	Press bar with foot	0.38**	0.45**
	Lift bar with foot	0.42**	0.46**
	Press pedal with foot	0.32**	0.43**
	Lift pedal with foot	0.44**	0.48**
Pull on 20mm knob	Pull with one hand	-0.19 *	-0.13
	Pull with two hands	-0.17*	-0.13

* Denotes significant correlation at 0.05 level

** Denotes significant correlation at 0.01 level

		Press and lift with the foot			
		Press bar with foot	Lift bar with foot	Press pedal with foot	Lift pedal with foot
Push and pull strength	Horizontal push one hand	0.12	0.11	0.09	0.09
	Vertical push one hand	0.12	0.12	0.06	0.09
	Horizontal push two hands	0.07	0.10	0.05	0.08
	Vertical push two hands	0.06	0.07	0.03	0.05
	Horizontal pull one hand	0.10	0.12	0.06	0.07
	Vertical pull one hand	0.15	0.15	0.09	0.06
	Horizontal pull two hands	0.08	0.08	0.02	0.05
	Vertical pull two hands	0.09	0.09	0.04	0.01
Push with the thumb or 2 or more fingers	Push with fingers forwards	0.13	0.24**	0.13	0.11
	Push with fingers down	0.17	0.28**	0.13	0.14
	Push with thumb down	0.18	0.30**	0.17*	0.15
Push with the Shoulder	Push 100%	-0.15	-0.14	-0.11	-0.09
	Push 90%	0.02	0.02	-0.02	0.05
Pull with different grips	Underhand 1 hand	-0.16	-0.14	-0.14	-0.12
	Underhand 2 hands	-0.01	-0.08	-0.14	0.02
	Round handle 1 hand	0.01	-0.07	-0.12	0.05
	Round handle 2 hands	-0.02	-0.10	-0.13	0.02
Wrist twisting and push and turn strength	Circular knob horizontal	0.13	0.20*	0.21*	0.10
	Circular knob vertical	0.16	0.23**	0.16	0.13
	Push-turn knob 10N horizontal	0.53**	0.51**	0.44**	0.56**
	Push-turn knob 20N horizontal	0.52**	0.46**	0.38**	0.53**
	Push-turn knob 10N vertical	0.57**	0.55**	0.46**	0.55**
	Push-turn knob 20N vertical	0.54**	0.51**	0.44**	0.53**
Pull on can ring-pull	Horizontal pull	0.38**	0.42**	0.32**	0.44**
	Vertical pull	0.45**	0.46**	0.43**	0.48**
Press and lift with the foot	Press bar with foot	1.00	0.88**	0.71**	0.79**
	Lift bar with foot	0.88**	1.00	0.75	0.82
	Press pedal with foot	0.71**	0.75**	1.00	0.73**
	Lift pedal with foot	0.79**	0.82**	0.73**	1.00
Pull on 20mm knob	Pull with one hand	-0.07	-0.05	-0.07	-0.06
	Pull with two hands	-0.10	-0.10	-0.10	-0.06

* Denotes significant correlation at 0.05 level

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		Pull on 20mm knob	
		Pull with one hand	Pull with two hands
Push and pull strength	Horizontal push one hand	0.05	0.05
	Vertical push one hand	0.05	0.04
	Horizontal push two hands	0.04	0.03
	Vertical push two hands	0.04	0.02
	Horizontal pull one hand	0.02	-0.02
	Vertical pull one hand	0.03	-0.01
	Horizontal pull two hands	0.05	0.00
	Vertical pull two hands	0.04	0.00
Push with the thumb or 2 or more fingers	Push with fingers forwards	-0.18	-0.17
	Push with fingers down	-0.16	-0.15
	Push with thumb down	-0.14	-0.12
Push with the Shoulder	Push 100%	0.02	0.13
	Push 90%	0.17*	0.19*
Pull with different grips	Underhand 1 hand	0.19*	0.11
	Underhand 2 hands	-0.04	0.01
	Round handle 1 hand	-0.08	0.00
	Round handle 2 hands	-0.08	-0.03
Wrist twisting and push & turn strength	Circular knob horizontal	-0.12	-0.14
	Circular knob vertical	-0.12	-0.16
	Push-turn knob 10N horizontal	-0.15	-0.14
	Push-turn knob 20N horizontal	-0.11	-0.09
	Push-turn knob 10N vertical	-0.17	-0.15
	Push-turn knob 20N vertical	-0.17*	-0.16
Pull on can ring pull	Horizontal pull	-0.19*	-0.17*
	Vertical pull	-0.13	-0.13
Press & lift with the foot	Press bar with foot	-0.07	-0.10
	Lift bar with foot	-0.05	-0.10
	Press pedal with foot	-0.07	-0.10
	Lift pedal with foot	-0.06	-0.06
Pull on 20mm knob	Pull with one hand	1.00	0.77**
	Pull with two hands	0.77**	1.00

* Denotes significant correlation at 0.05 level

** Denotes significant correlation at 0.01 level

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