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Isometric muscle strength of Chinese young males in Taiwan

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This paper represents the results of an anthropometric measurement of the isometric muscle strength of Chinese young males in Taiwan aged from 16 to 20 years. The study uses a sample of 120 male students and measures four types of muscle strength: (1) right arm strength in exerting pull, push, adduction, abduction, lift, and press directions with five elbow angles (60, 90, 120, 150 and 180°) in seated posture; (2) grip strength of both hands; (3) backlift strength; and (4) chest expanding strength. The obtained data are analysed and listed. Comparisons are made between the results of this study and those from domestic and foreign studies available in the literature. In general, their pattern is similar, but values obtained in this study are relatively smaller than those obtained in western countries.

1. Introduction

Anthropometric data are fundamental to the design of products and systems for human use; however, due to lack of a complete anthropometric database on the Chinese people, local designers have to adopt such data from foreign countries when designing products for local users. This trend is gradually changing; more and more static anthropometric data about body dimensions of people in Taiwan have been compiled and established. In addition, a very complete and comprehensive anthropometric survey on Taiwanese subjects is being conducted with government support. However, the measurements are limited to static body dimensions.

Broadly speaking, anthropometry should include not only measurements of structural and functional body dimensions, but also measurements of various bodily powers. Among them, muscle power has to be one of the most important bodily abilities.

The measurement of muscular powers can generally be classified as static or dynamic. Static measurement usually refers to isometric strength, which is the maximal force muscles can exert isometrically in a single voluntary effort. Another type of static measurement is endurance, which measures the strength people can maintain for an extended period of time. Dynamic measurement includes isoinertial muscular power under constant loading, such as load lifting and isokinetic muscular power under constant movement or speed. Another type of dynamic measurement of muscular power refers to the working capacity (hp) in performing a repetitive dynamic task, such as pedalling on a gymnasium cycling machine.

The measurement of muscular powers is much more complicated and involves more variables than the measurement of body dimensions. To date, no standardized method has been available and such data are scarcely complete even in countries that are advanced in the research of human factors, such as the USA and Japan (Chuang 1989). In Taiwan, investigations in this area have barely been reported. Among these scarce studies, Lin (1985) has measured grip strength, backlift strength, leglift strength, pulling strength of both hands in front of the chest (chest expanding strength) and pushing strength under the same condition for 125 male students, aged 16 – 20 years, as part of a set of variables to establish the physique index for Taiwanese young males. Wang (1984) has investigated the grip strength in five different wrist positions by measuring the grip strength of 21 college students in Taiwan.

In the application of anthropometric data, one has to be aware of the fact that such data vary considerably for different groups of people. This is especially true for measures of muscular strength among different ethnic populations. For instance, Guthrie *et al.* (1970) report that the 75th percentile of grip strength of the Vietnamese is about the 25th percentile of that of the Americans (in Chapanis 1975). Therefore, it is urgently needed to establish a database of muscle strength of the Chinese people, which can be applied to products and systems designed for the use of the local people. As the first attempt to fulfill this goal, this study will measure the isometric muscle strength of Chinese young males in Taiwan.

2. Method

2.1. *Subjects*

A total of 120 volunteer male students of ages 16 to 20 years (24 students in each age group) were recruited. Among the subjects, 8 of them were left-handed, the remaining 112 were right-handed. All subjects were well motivated and in good health. Each was paid NT$ 50 (about 2 US dollars) for every hour attending the measurement session in the ergonomics laboratory. All the measurement sessions lasted less than 3 h. No effects of fatigue and boredom were observed. Before the beginning of the measurement, subjects were introduced to the purpose of the research, the features and types of strength to be measured, and the apparatus and procedure to be used.

Out of convenience, subjects were recruited from the same junior college. Most of the students in this school are aged from 16 to 20 years. As this is the first study in measuring these kinds of muscle strengths in Taiwan, the authors began with measuring subjects in these age groups, and expect to finish a complete database by measuring other age groups step-by-step in the future.

2.2. *Apparatus*

For the measurement of anthropometric characteristics, a home scale, a stature gauge, a Martin-type anthropometer and a self-made height gauge were used. For the measurement of muscle strengths, a set of the TKK Versatile Muscular Power Measuring Device was utilized together with a versatile digital dynamometer and various attachments to be used in combination, including: an attachment for measuring tensile force, one for grip strength, one for back and leg muscle strength, and one for measuring pulling and pushing force, and a digital printer.

All pieces of apparatus were examined and calibrated before use and frequently checked while in use.

2.3. *Measurements and procedures*
The measurements consist of two major parts: anthropometric characteristics and muscle strengths. Although the latter is the main purpose of this survey, the former is also necessary for further analysis and description of the obtained data.

For the purpose of comparability, the definition of the measurements given below are generally based on those that are available in literature, such as Damon *et al*. (1966), Du and Li (1984) and Qiu-Wei (1988). Measurements were taken with respect to the right-hand side (if applicable and not otherwise indicated) and subjects wore only shorts during the measurement.

2.3.1. *Anthropometric characteristics:* Measurement of the following anthropometric characteristics were made.

(1) *Weight:* Subject, in shorts, stands naturally on a calibrated home scale.
(2) *Stature:* Vertical distance from floor to the top of the head; subject stands erect, looking straight ahead.
(3) *Sitting height:* Vertical distance from the sitting surface to the top of the head: subject sits erect, looking straight ahead, with knees and ankles forming right angles.
(4) *Shoulder-elbow length:* Distance from the top of the acromion process (at the uppermost point on the lateral edge of the shoulder) to the bottom of the elbow; subject sits erect, upper arm vertical at side and making a right angle with the forearm.
(5) *Forearm-hand length:* Distance from tip of elbow to tip of longest finger; subject sits erect, upper arm vertical at side, forearm, hand, and fingers extended horizontally.
(6) *Hand length:* Distance from the proximal edge of the navicular bone at the wrist (base of thumb) to middle fingertip; hand held straight and stiff.
(7) *Chest circumference:* Horizontal circumference at nipple level during normal breathing.
(8) *Waist circumference:* Horizontal circumference at level of the greatest lateral indentations of trunk.
(9) *Biceps circumference:* Maximum circumference of biceps with elbow bent at 90° and biceps maximally flexed.
(10) *Lower arm circumference:* The maximum circumference of lower arm, wherever found, with the upper arm horizontal, forearm vertical, and the elbow at 90°, muscles maximally tensed.

2.3.2. *Muscle strength:* For each of the following measurements, after some practice to get familiar with the measuring method, the subjects were asked to make three consecutive exertions (building up to a maximum for about 5 s) with a rest of about 10 s between two exertions. All the values of three exertions were recorded in a measurement recording sheet. Only the maximum value of each strength measurement was used for later statistics and analysis.

(1) *Arm strength:* The subject sat in the chair of the versatile muscular power measuring device with back rest adjusted properly and then fastened with seat belts girded over the shoulders and across the breast. The arm rest was adjusted with the right arm (in a horizontal position) and the elbow joint formed one of the following 5 angles: 60, 90, 120, 150, and 180° (figure 1). For each elbow angle, the strength in each of the following six directions was

measured by exerting maximum force on the vertical handgrip directly in front of the right hand. The six directions were: pull, push, adduction (or to the left with the right arm), abduction (or to the right with the right arm), lift, and press. For example, figure 2 shows the measurement of adduction force with an elbow angle of 120°. The directions and elbow angles selected here are all the same as those of Hunsicker's corresponding study of 1955 (in

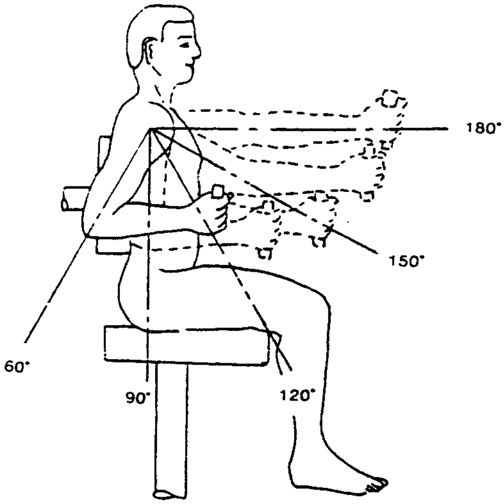

Figure 1. The five elbow angles used during measurement of arm strength.

Figure 2. Measurement of the arm strength—adduction with an elbow angle of 120°.

Saunders and McCormick (1987)); thus, the result of this measurement is expected to be comparable with Hunsicker's result for finding ethnic differences of arm strength between Taiwanese and American men.

(2) *Grip strength:* Subject assumed standing posture and exerted maximum force with the grip dynamometer (figure 3). Grip strength was measured with four different grip spans: 4, 5, 6, and 7 cm. For each grip span strengths of both hands were measured alternately. Here, the grip span is defined as the distance between the two grip bars of the grip dynamometer on which the subject's hand has to grasp tightly to exert its strength when in testing. The distance is adjustable by means of an adjusting screw on the dynamometer. Finally, the grip strength of each hand with the grip span continuously adjusted according to the subject's preference was also measured.

(3) *Backlift strength:* The subject assumed a posture with the back slightly bent forward, stood with both feet on the foot sign of the standing platform of the back and leg muscle dynamometer, adjusted the length of the chain properly so that the chain was stretched, and then exerted maximum lifting force with both hands grasping the handgrips of the T-shaped handle while keeping both knees and elbows straight (figure 4).

(4) *Chest expanding strength:* Subjects assumed a natural standing posture and exerted maximum pulling force with both hands holding the handgrips of the attachment for pulling and pushing force in front of and at the level of the breast (figure 5).

The measuring sequence of the above muscle strengths was as follows: grip strength first, then backlift strength, chest expanding strength, and finally arm strength. In measuring the grip strength, the right hand was measured before the left hand for each grip span, and the grip spans varied in the following order: 4 cm,

Figure 3. Measurement of the grip strength with a grip dynamometer.

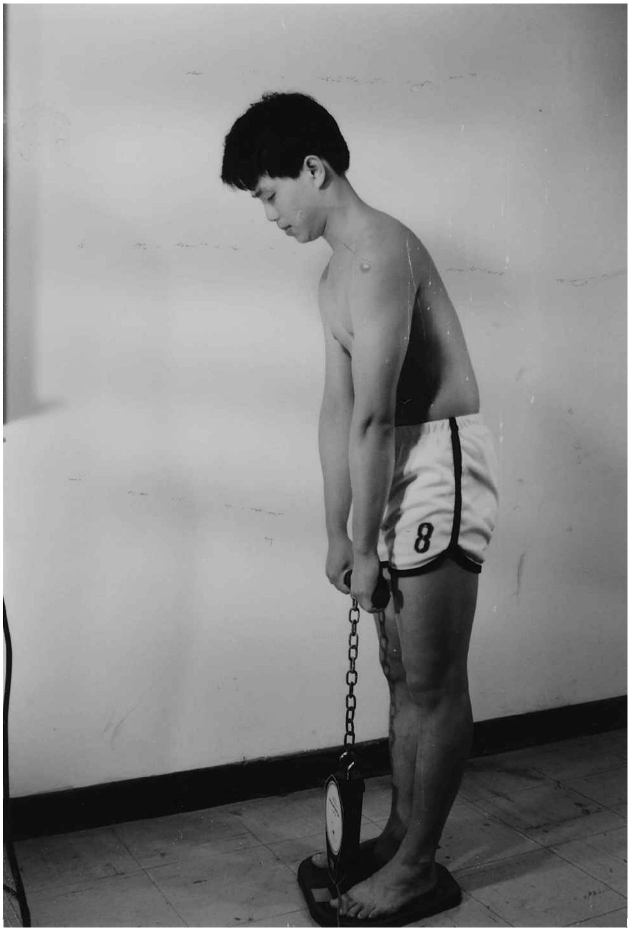

Figure 4. Measurement of the backlift strength.

5 cm, 6 cm, 7 cm, and the preferred span. In measuring the arm strength, half of the subjects were measured in the following order of the directions: push, adduction, lift, pull, abduction, and press; and the others were measured in reverse order. The elbow angles assumed an ascending order (from 60 to 180°) for each of the directions for half of the subjects, and a descending order for the other half. After each measurement, the subjects were allowed to take a rest of about 2 min.

2.4. *Pilot study*

Before the full-scale measurement, a sample of 30 subjects was used in a preliminary study. Results and experience obtained during the pilot study provided much help in the implementation and improvement of the present study; however, the results of the pilot study are not included in the present results.

3. Results

The results of this study are presented and discussed below. Owing to an occurrence of equipment breakdown during one of the measurement sessions, the affected values were treated as invalid and not used in the analysis. Some data that were smeared in the recording sheet were also left out of the analysis. Hence, some of the numbers of data used for analysis are slightly less than 120, the number of subjects used.

Table 1 lists the statistics of the measurements of the anthropometric characteristics of the 120 subjects.

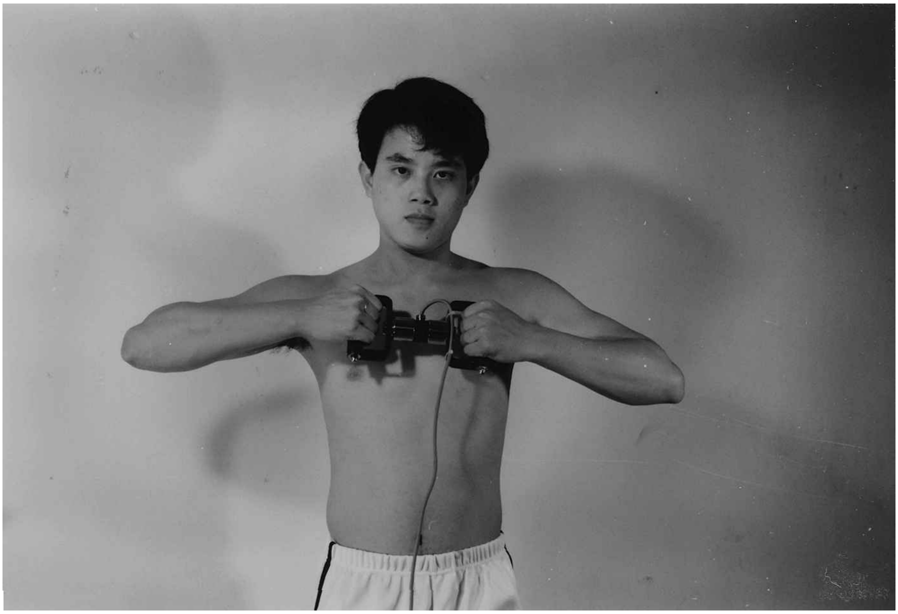

Figure 5. Measurement of the chest expanding strength.

Table 1. Basic body dimensions (cm) and weight (kg).

Item	*n*	Mean	SD	Min.	Max.	Range	P5	P50	P95
Weight	120	61·9	6·8	47·5	90·5	43·0	52·3	61·0	74·4
Stature	118	170·8	5·5	154·6	186·0	31·4	162·0	170·6	180·0
Sitting height	108	91·3	3·1	82·0	99·0	170·0	86·4	91·6	96·0
Shoulder-elbow length	120	35·7	2·0	30·6	44·2	13·6	32·0	35·7	38·5
Forearm-hand length	120	45·8	2·1	35·7	49·7	14·0	43·3	45·7	49·0
Hand length	120	18·4	0·9	15·2	21·2	6·0	17·0	18·5	19·8
Chest circumference	120	86·9	5·4	73·0	109·5	36·0	80·0	86·2	96·0
Waist circumference	120	72·0	4·7	63·5	100·2	36·7	66·3	71·5	79·7
Biceps circumference	120	29·4	3·6	24·3	60·0	35·7	25·9	29·4	32·5
Lower arm circumference	120	27·1	2·1	22·8	36·8	14·0	23·9	27·0	30·5

Table 2 shows the statistics of the measures of arm strength and figure 6 illustrates the relationships between the average results of the six directions (pull, push, adduction, abduction, lift, and press) at the five elbow angles (60, 90, 120, 150, and 180°).

Table 3 sums up the grip strength of both hands at different grip spans, where 'pref.' denotes the span that the subject adjusted at his preference. Table 4 lists the statistics of the length of the preferred grip spans of both hands.

The result of the measurements of backlift strength and chest expanding strength are listed in table 5.

4. Discussion

4.1. *Anthropometric characteristics*

From table 1 it can be seen that the measures of weight, stature, sitting height, and hand length are close to those measures on the Chinese youths as reported by Du and Li (1984). The measures of stature, weight, and chest circumference are also similar to those listed by the Ministry of Education of Taiwan (1986). As for the measures of shoulder-elbow length, forearm-hand length, waist circumference, and lower arm circumference, no comparison can be made due to lack of data from local

Table 2. Arm forces (N) exerted in different directions at various elbow angles.

Movement	Angle(°)	*n*	Mean	SD	Min.	Max.	Range	P5	P50	P95
Pull	60	120	320·5	69·5	134·4	567·8	433·4	210·4	320·2	432·0
	90	120	349·5	56·2	182·4	528·6	346·2	263·3	348·1	449·1
	120	120	392·9	60·2	226·5	560·0	333·5	301·6	392·3	489·8
	150	120	449·5	92·2	191·2	692·3	501·1	297·6	452·1	603·6
	180	120	547·9	108·2	196·1	767·9	571·8	347·6	547·2	709·0
Push	60	120	322·4	64·4	156·9	480·5	323·6	230·5	316·8	451·1
	90	120	316·8	63·7	160·8	525·6	364·8	221·6	313·8	433·0
	120	120	364·5	78·5	220·6	715·9	495·3	248·6	355·0	510·4
	150	120	429·3	96·6	215·7	755·1	539·4	278·5	419·2	601·6
	180	120	400·9	83·4	212·8	675·0	444·2	275·6	389·8	556·5
Adduction	60	108	163·1	33·9	93·2	280·5	187·3	110·8	158·9	224·6
	90	108	163·0	33·0	106·9	265·8	158·9	114·7	161·8	217·7
	120	108	160·5	36·7	88·3	326·6	238·3	107·9	156·4	221·6
	150	108	160·6	29·2	94·1	242·2	148·1	113·8	161·8	224·6
	180	108	144·0	35·9	53·9	269·7	215·8	95·1	141·7	205·0
Abduction	60	120	113·1	25·9	60·8	213·8	153·0	73·1	111·3	161·3
	90	120	104·0	22·3	57·9	175·5	117·6	70·1	104·4	139·7
	120	120	100·0	21·3	53·0	161·8	108·8	67·2	98·1	141·7
	150	120	101·6	22·4	53·9	179·5	125·6	69·6	98·6	137·3
	180	120	106·7	25·0	55·9	256·9	201·0	75·0	103·5	140·7
Lift	60	120	194·7	44·0	93·2	333·4	240·2	138·8	186·3	291·3
	90	120	192·3	41·0	98·1	343·2	245·1	139·3	188·3	270·2
	120	120	196·1	44·5	109·8	375·6	265·8	133·4	192·7	281·0
	150	120	184·8	46·1	78·5	301·1	222·6	117·7	176·0	270·2
	180	120	161·2	35·9	97·1	275·6	178·5	109·3	157·4	231·9
Press	60	120	136·6	33·0	71·6	273·6	202·0	93·7	129·0	201·0
	90	120	137·4	21·4	77·5	194·2	116·7	103·0	137·3	173·6
	120	120	154·6	24·1	87·3	227·5	140·2	111·8	154·0	193·2
	150	120	157·6	26·1	108·9	255·0	146·1	117·2	157·4	205·4
	180	120	140·8	25·6	83·4	231·4	148·1	100·5	140·2	180·0

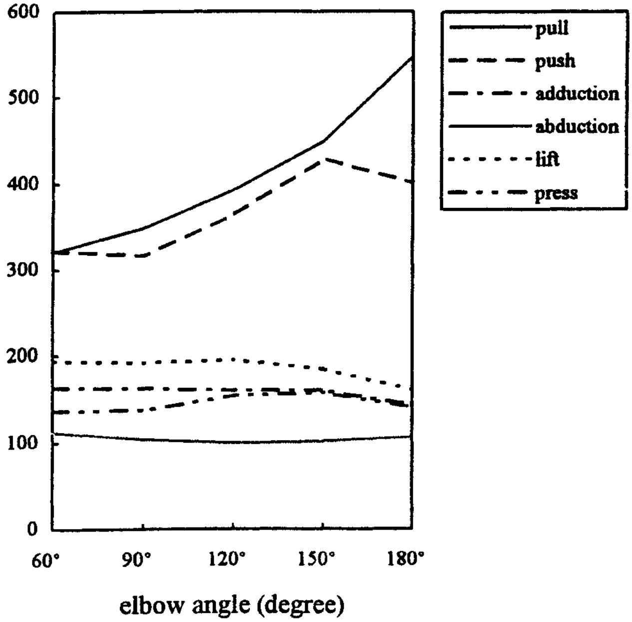

Figure 6. Arm strength of six directions at five elbow angles.

Table 3. Grip strength (N) of both hands at different grip spans.

Hand	Span (cm)	*n*	Mean	SD	Min.	Max.	Range	P5	P50	P95
Left	4	120	349·9	57·2	214·8	491·3	276·5	254·5	346·2	442·8
	5	120	368·3	54·9	242·2	510·9	268·7	276·1	370·7	463·9
	6	120	364·7	55·9	228·5	565·8	337·3	275·6	369·7	450·6
	7	120	342·4	53·4	212·8	492·3	279·5	254·0	339·3	429·5
	pref.	120	364·4	54·7	227·5	560·9	333·4	275·1	367·7	443·8
Right	4	120	380·0	64·6	215·7	600·2	384·5	281·9	375·1	492·3
	5	120	398·1	63·7	252·0	602·1	350·1	300·1	399·1	496·7
	6	120	394·5	63·4	238·3	584·5	346·2	283·9	397·2	491·8
	7	120	364·2	60·9	225·6	560·0	334·4	267·2	357·0	467·8
	pref.	120	390·7	58·2	264·8	604·1	339·3	290·3	390·8	483·5

pref. span that the subject adjusted at his preference.

literature. In conclusion, the present sample of subjects seems to be reasonably representative.

4.2. *Arm strength*

T-tests were conducted for the pairwise differences of mean strength of each direction at different angles and for each elbow angle with different directions. Table 6 summarizes the test results, where ' > ' denotes statistically greater than (with $p < 0{\cdot}01$). Variables in parentheses are not significantly different in value from one another, but those with greater values are placed toward the left-hand side.

Table 4. Preferred grip spans (cm) of both hands.

Hand span	*n*	Mean	SD	Min.	Max.	Range	P5	P50	P95
Left hand	120	5·40	0·58	4·20	7·50	3·30	4·50	5·45	6·40
Right hand	120	5·41	0·59	4·20	7·50	3·30	4·50	5·40	6·40

Table 5. Backlift strength and chest expanding strength (N).

Item	*n*	Mean	SD	Min.	Max.	Range	P5	P50	P95
Backlift strength	120	1284·0	181·4	902·2	1804·4	902·2	1000·3	1279·8	1618·1
Chest expanding	120	355·5	76·0	181·4	524·7	343·3	220·6	353·0	486·4

Table 6. Summaries of *t*-tests.

Movement	Pull	180°> 150°> 120°> 90°> 60°
	Push	150°> 180°> 120°> (60°, 90°)
	Adduction	(60°, 90°, 150°, 120°)> 180°
	Abduction	60°> (180°, 90°, 150°, 120°)
	Lift	(120°, 60°, 90°, 150°)> 180°
	Press	(150°, 120°)> (180°, 90°, 60°)
Angle (°)	60	(push, pull)> lift> adduction> press> abduction
	90	pull> push> lift> adduction> press> abduction
	120	pull> push> lift> (adduction, press)> abduction
	150	(push, pull)> lift> (adduction, press)> abduction
	180	pull> push> lift> (adduction, press)> abduction

> denotes statistically greater than (with $P < 0{\cdot}01$).

From figure 6 and table 6, it is obvious that the forces exerted pulling and pushing are consistently and significantly higher than those exerted in other directions, with pulling being higher than pushing. The force exerted in abduction direction is lower than all other directions in general, and upward direction is in the middle range through all the angles. When elbow angles are of concern, it is noted that the forces exerted with the elbow at angles of 180 and 150° are higher than the others, while the forces exerted with the elbow in angles of 90 and 60° are lower than the others. For pulling force, a positive correlation can be observed with an increase of elbow angle, registering a maximum force while the elbow is fully extended. As for pushing, no significant difference is observed between 60 and 90°, and at 150° maximum force occurs. For other directions, it seems that the changes of elbow angle do not significantly affect the amount of force exerted.

The results agree in pattern to those obtained by Hunsicker as published in Sanders and McCormick (1987), but the values here are relatively smaller than those from Hunsicker. A possible explanation of such differences may be that the samples of these two studies are from two ethnic groups of different body-builds, in addition to the fact that the subjects in the present study are comparatively younger than those in Hunsicker's study (aged 17 – 25 years). It is mentioned that strength reaches a maximum by the middle to late 20s (Damon *et al.* 1966). This may partly explain the lower values of strength in the present study.

4.3. *Grip strength*

4.3.1. *Grip span and grip strength:* From table 4, it can be noted that the relative dispersion of the preferred grip spans of both hands is only about 10%, thus the preferred grip span does not vary much among subjects.

It is noted that, for either the right hand or the left hand, the grip strengths at grip spans of 5 and 6 cm and at the preferred span do not significantly differ with one another, but each is significantly greater than those at 4 and 7 cm, and that the grip force yielded at the grip span of 7 cm is significantly less than forces yielded at all other spans. Since for both hands, the mean grip forces at 5 cm are maximal and are highly correlated with forces at other grip spans, later on, the grip forces at the grip span of 5 cm will be used to denote the grip strengths.

Although the preferred grip span is determined by the subject, it does not always produce the maximal grip force. Contrary to expectation, the maximum grip force is exerted at the grip span of 5 cm; however, the discrepancies among grip forces at 5 cm, 6 cm and the preferred grip spans are not significant. The maximal grip force being not at the preferred grip span may simply be because people can not always easily determine an optimal grip span so that a maximum grip force can be generated, unless several trials or feedback of values are provided during the exertion. This is especially true for those who selected a preferred grip span in the lower or higher extreme percentiles, such as the 5th or the 95th percentiles (i.e. a preferred grip span less than 4·5 cm or more than 6·4 cm). Another explanation may be that the preferred span was determined after all pre-set spans had been tested, ending up with the effect of fatigue during the measurement. Further discussion of this point will be dealt with in a later section.

Greenberg and Chaffin (1977) report that the optimal grip span is between 6·4 and 8·9 cm with a maximum grip strength at around 7·6 cm. Hertzberg has used 3·81, 6·35, 10·16, and 12·70 cm (1·5, 2·5, 4, and 5 in) as grip spans on a Smedley dynamometer for grip strength evaluation and discovered that at the grip span of 6·35 cm a maximum grip force can be exerted (Van Cott and Kinkade 1972). Both values (7·6 and 6·35 cm) are greater than the result of this study (5 cm). It should be noted, however, that the definitions of the grip span in different studies may be different for different purposes. For example, Greenberg and Chaffin (1977), for the purpose of designing a pop-riveting gun, defined the grip span as the distance between the points near to the outside ends of two grip bars that are pivoted together in an 'A' shape. On the other hand, Ayoub and Lo Presti (1971) found that maximum grip strength on a cylindrical handle occurred when the diameter of the object was about 4·1 cm. This value is closer to the optimal grip span found in the present study, while the definition of the grip span in this situation is closer to that of the present study. Actually, the definition of grip span in the present study is similar to that of hand grasp span of cylindrical grasp defined by Jones (Eastman Kodak Company 1983). The median value of this grasp span is found to be about 5·5 cm, which is very close to the mean of preferred grip span found in this study. There should be many other factors that may affect the determination of the optimal grip span. For example, the shape of the hand grip may be an influential one. Another reason for the difference in optimal spans may be merely because the subjects differ in their hand dimensions. It may be interesting to study the relationship between the optimal grip spans and the hand dimensions of the subjects.

The grip strengths of either hand obtained here are lower than those from foreign data (Chuang 1989), but are comparable to those reported by local researchers (Wang 1984).

4.3.2. *Left hand versus right hand:* From table 4, it can be seen that the right hand is superior to the left hand in terms of exerting grip force at all different grip spans. On the average, the mean grip strength of the left hand is 8% less than that of the right hand. However, it may be the factor of 'handedness' that accounts for the strength difference rather than the 'side' of the hands.

Furthermore, strengths of the right hand are also highly correlated with those of the left hand at all corresponding grip spans (with r values around 0·84).

4.4. *Backlift strength and chest expanding strength*

As shown in table 5, the measures of the backlift strength are relatively smaller than data from both the USA and the UK (Damon *et al.* 1966), but are marginally larger than data from Japan (Kurata 1979). However, both backlift and chest expanding strengths are similar to the local data reported by Lin (1985).

4.5. *Correlation analysis*

Since some anthropometric measures (including measures of muscle strength) may be correlated with each other, it is expected that some measures in this study are correlated. To clarify this, the product moment correlation coefficients of all variables measured in this research has been computed. First, the measures of length are all clearly correlated with the measure of stature (with r ranging from 0·57 to 0·77), while the measure of weight is highly correlated with that of chest circumference ($r = 0·84$) and with that of waist circumference ($r = 0·79$).

Significant correlations were found between some muscle strengths too, although the degrees of significance are not as high as those between body dimensions. The arm strengths of the same exerting direction but at different elbow angles are significantly correlated. For instance, the pulling arm strengths at the elbow angle of 60, 90, 120, 150 and 180° are significantly correlated with each other with r values ranging from 0·44 to 0·75. The arm strengths of different exerting directions are correlated with each other too, although the correlations are less significant. For example, it shows that the correlations between arm strengths of different exerting directions of pulling, pushing, adduction, abduction, lift, and press, with elbow angle of 90° are all significant at the 0·01 significance level (r ranging from 0·27 to 0·60).

The arm strength (pulling, with 90° elbow angle as representative), grip strength (right hand, with 5 cm grip span), backlift strength and chest expanding strength are also significantly correlated to each other with r values ranging from 0·64 (between backlift strength and grip strength) to 0·33 (between backlift strength and chest expanding strength).

Finally, it shows that some muscle strengths are significantly correlated to some body dimensions, although the r values are not very high. For example, weight and chest circumference are correlated to all strengths measured with a significance level of 0·01 (r ranging from 0·27 to 0·49). Furthermore, both grip strength and backlift strength are significantly correlated to weight, stature, sitting height, shoulder-elbow length, forearm-hand length, hand length, chest circumference and lower arm circumference (with *r* ranging from 0·27 to 0·49).

4.6. *Effect of fatigue*

People can maintain their maximal muscular force only for a few seconds. This is due to the development of fatigue in the muscle while strength is exerted (Damon *et al.* 1966). In the measurement process used here, each muscle strength measure is taken successively three times, each with a relaxation interval of about 10 s. It is worthwhile to examine whether or not an effect of fatigue takes place during the three successive exertions. For each type of muscle strength (arm, grip, backlift, and chest expanding), the force measured in corresponding sequence positions (first, second, or third) are pooled together and averaged, then the differences between these means are tested with the ANOVA procedure. The results shows that except for the grip strength the means of the forces measured in different sequence positions in each of the other types of strength do not differ from one another at the 0·01 significance level. This implies that the effect of fatigue is not significant during the three successive exertions, except for the grip strength. Since there are smaller muscles involved in exerting grip strength than those on other types of muscle strength in this measurement, they may get tired more easily. This may partly explain why only exerting grip strength shows obvious fatigue in this study. Another possible effect of fatigue may occur during measuring different types of muscle strength, or during measuring the same type of strength but in different situations, with the previous one affecting the following. However, since the rest period between different measurements is much longer than that between successive exertions, this effect may even be less than that in successive exertions of identical conditions; hence, it was not further analysed in this study.

4.7. *Age and strength*

Another analysis deals with the effect of age on each type of muscle strength. ANOVA results show that, except for the backlift strength, the measured strengths of all other types, for instance, the arm strength (pulling force at elbow angle of 90°), the grip strength (right hand, with grip span of 5 cm), or the chest expanding strength, are not all equal among different age groups. However, the correlation of age with various types of muscle strength is not obvious; that is, those who belong to the group of older ages do not necessarily have greater strength. This result is not only against the authors experience but also disagrees with most previous studies of muscle strength. However, the difference in age is fairly small and may contribute to these confusing results. Also, as the differences of muscle strength between different age groups here are only small percentages, they may just be noise caused by sampling. Further studies may be needed before a clear conclusion on the relationship between age (in the range of 16 to 20 years) and muscle strength can be drawn.

5. Conclusions

The following conclusions can be made based on the analysis of the measurements observed in this study:

(1) The measures of arm strength, grip strength, backlift strength and chest expanding strength are, in parttern, all similar to data from other studies,

either domestic or abroad, but values are proportionally smaller than data from occidental countries.

(2) In terms of the six directions in arm strength, the magnitude of the forces can be ordered as: pull, push, lift, adduction, press, and abduction, with pulling strength being the highest and abduction the lowest.

(3) The maximum grip forces does not occur coincidentally at the grip span that the subjects prefer. This is especially true for those who selected a preferred grip span in the lower or the higher extreme percentile, the 5th or the 95th percentile (i.e. a preferred grip span less than 4·5 cm or more than 6·4 cm).

(4) Left-hand grip strength is about 8% less than that of the right hand, without regarding the handedness of the subjects.

(5) Many measurements of muscle strength are significantly but not very highly correlated to one another and muscle powers are also marginally correlated to some structural body dimensions and weight.

(6) No effect of fatigue is observed in the three successive exertions of each measurement in this study, except for grip strength.

(7) Muscle strength differs in different age groups (16–20 years), but those who belong to the group of older ages do not demonstrate greater strength, except for backlift strength. Further studies are needed to determine the relationship between age and muscle strength.

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