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An investigation of finger pull strengths

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This paper describes a study to investigate the nature of pull strength with the fingers. Three types of pulls, distinguished by the type of pinch grip used, were investigated. The experiment was performed in two stages, using different subjects (36 male adults in Stage I and 34 in Stage II). The results indicated that finger pull strength depended on the type of pinch grip used but not on the direction of pull (in the saggital plane) nor on hand laterality. Pull forces with the lateral pinch grip were 1·6 times as strong as with the chuck pinch grip, which was, in turn, 1·5 times as strong as with the pulp pinch grip. Ergonomic design applications suggest a larger pinch handle and workspace to accommodate the lateral grip. Finger pull strength could not be predicted very accurately from pure pinch strengths or anthropometric dimensions accurately enough to be of value to designers, even though there were many statistically significant pairwise correlations.

1. Introduction

Most studies on the strength of the hand have concentrated on handgrip. In ergonomics handgrip has been perceived as one of the most important hand functions—as in using a pair of pliers; or, as in gripping an object in conjunction with twisting, rotating, lifting, lowering, pressing down, pushing, or pulling. However, other types of functions of the hand are also important to the ergonomist, both in occupational activities and in activities of daily living. Two of these are pinching and pulling with the fingers. Few ergonomic studies exist for pinching; Imrhan and Loo (1989) discuss these. Apart from Imrhan (1987), no data on pulling with the fingers could be found in the published literature.

The need to pull with the fingers is important where the object is too small to be gripped in the hand; and where the use of hand tools is inappropriate, either because of limited space for their manipulation or because the object cannot be properly grasped by available tools. Sometimes the use of hand tools is discouraged in order to prevent damage to sensitive equipment. Some tasks may require the exertion of strong finger pull forces—for example, tearing plastic or paper strips off cartons; removing plastic or metal caps off container lids; and tearing open vacuum packed plastic bags. Other tasks may require weaker finger pull forces which, by their repetitiveness, may be fatiguing or may even contribute to cumulative trauma disorders. Examples are peeling paint off metal sheets, and pulling on small machine parts to separate them from other parts, during maintenance. Armstrong *et al.* (1979) have reported that poultry workers repeatedly exert finger pull forces of about 6–7 kg on turkey carcasses during operations for separating meat from bone; and that this may have contributed to observed tendinitis and neuritis among the workers. Ivergard *et al.* (1978) and Berns *et al.* (1979) observed that consumers experience difficulties in generating enough finger pull strength on pull rings on containers; and that pull strips on cardboard containers were inadequately designed, leading to difficulties in opening such packages without mechanical aids. They also pointed out that elderly persons preferred packages that can be opened without mechanical aids over those that required mechanical aids.

In order to reduce or eliminate these problems, therefore, one must understand the nature of finger pull strength, and have available data on its distribution, for particular segments of the population. The purpose of this study was to investigate the nature of such pull strength.

The type of pinch used for a task is influenced significantly by the shape and surface area of the object available to the fingers for pinching, in addition to the task to be performed. For a small area of contact a pulp pinch with the index finger (pulp 2) is typical, while, for a larger area, a chuck or lateral pinch may be preferred. The biomechanical differences among these pinches are discussed in the next section.

2. Methods

The study was conducted in two stages. The objectives of Stage I were to determine whether the magnitude of the finger pull force was influenced significantly by (1) the type of pinch used; (2) the direction of pull (horizontal or oblique); and (3) hand laterality. The objectives of Stage II were (1) to determine the degree of association (correlation) between finger pull strength and other person related variables which are much easier to measure, such as age, sex, anthropometric dimensions, pinch strengths, and handgrip strength; and (2) to determine the effect of a small increase in the surface area of finger contact or pull strength, for the pulp 2 and chuck pinches.

2.1. *Stage I*

2.1.1. *Subjects:* The sample can best be described as a volunteer sample of 36 male college students between the ages of 22·0 and 40·4 yr (table 1). Eighteen were Americans and the remainder from the Middle East, Far East, Asia, and Africa. All were right-handed.

Table 1. Anthropometric characteristics of subjects in Stage I experiment ($n = 36$).

Variable	Mean	Standard deviation	Range
Age (yr)	27·0	5·8	22·0–40·4
Body weight (kg)	75·6	14·6	53·4–125·5
Stature (cm)	174·2	7·3	151·4–187·7
Hand length (cm)	19·1	0·8	18·1–20·5
Hand breadth (cm)	8·9	0·5	7·6–9·8

2.1.2. *Apparatus:* A load cell of 450 N capacity was connected to a digital force meter to measure and display pull forces. One side of the cell was attached to a small handle and the other side to a rectangular strip of rough fabric. The strip was 65 mm long and 25 mm wide, and of negligible extensibility. The digital force monitor displayed readings in increments of 0·1 N and held peak force, for easy recording.

2.1.3. *Strength tests and experimental design:* Three general types of pull tear strength were tested. Each was characterized by the type of finger pinch used in holding the fabric strip. The pinches corresponded to the types people usually employ in the industrial workplace and for other activities, like pulling and tearing objects such as strips of metal, paper, plastic, etc., on packages to open them. They were:

1. Lateral pinch–pull (LPP): The fabric strip was pinched with the pad of the thumb and the radial lateral aspect of the index finger with the other three fingers acting as a buttress to the index finger (figure 1b).
2. Chuck pinch–pull (CPP): The fabric strip was pinched with the pads of the index and middle fingers on one side and with the pad of the thumb on the other side. No attempt was made to restrict the distal interphalangeal joints to either a flexed or a hyperextended position (figure 1a).
3. Pulp pinch–pull (PPP): The fabric strip was pinched with the pads of the thumb and the index finger. Again, subjects were free to maintain either flexed or hyperextended distal interphalangeal joints.

In all cases subjects stood while pulling. The load cell was first held firmly and stabilized with one hand. The fabric was then pinched firmly with the fingers of the other hand and pulled with a maximal volitional effort (MVC). Subjects built up maximum gradually in about 1–2 s and held it for about a further 3 s.

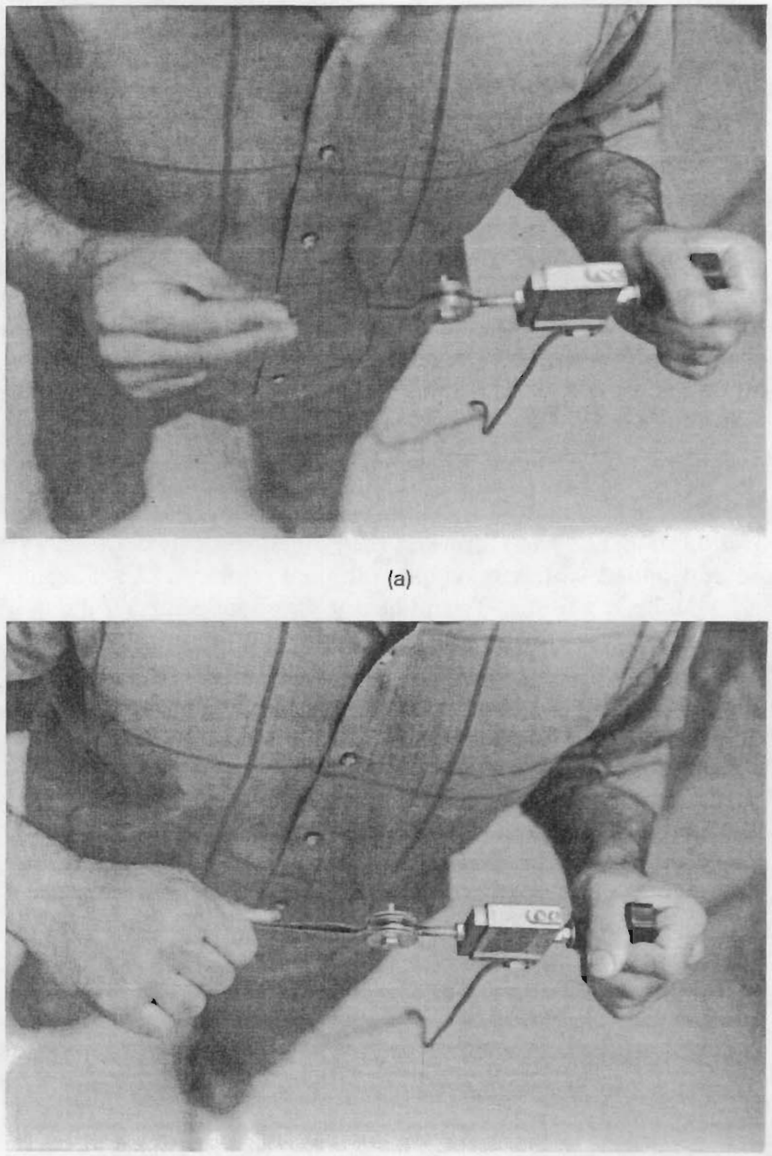
2.1.4. *Pull direction:* Two directions of pull were tested—horizontal and oblique. For the horizontal pull, subjects held the load cell just below the chest and pulled horizontally and approximately parallel to the coronal plane of the body. For the oblique pull, subjects held the load cell at about waist height and pulled towards the shoulder, on the opposite side of the body, approximately parallel to the coronal plane. A 3 (type of pull) × 2 (hand laterality) × 2 (direction of pull) complete factorial design was used to achieve the required variable combinations for measurements. Two repetitions per measurement (variable combination) were performed, at random. If the two were not within 10% of each other, the measurement was repeated, at random. Only the larger value, representing the subject's MVC strength, was used for data analysis.

2.1.5. *Procedure:* Subjects were tested in groups of 4 or 5. The waiting time between successive trials for any individual was long enough (approximately 2–3 min) to minimize fatigue effects. Competition among subjects was eliminated by not providing feedback on strength scores. Before final testing, subjects were given a demonstration of the various tests and were allowed to practice a few pulls to familiarize themselves with the tests.

2.2. *Stage II*

2.2.1. *Subjects:* A volunteer sample of 34 male college students participated in this stage (table 2). None of the subjects from Stage I was in this sample. Eighteen were Americans and the remainder from the Middle East, Far East, Asia, and South America. All were right-handed.

2.2.2. *Strength tests and experimental design:* The same types of finger pull strengths and anthropometric variables, as in Stage I, were tested. There was a slight difference



(a)

(b)

Figure 1. A sample of two pulls showing the positions of the hands and fingers. The chuck pinch–pull (CPP) is shown in (a); and lateral pinch–pull (LPP) in (b), for the horizontal pull direction.

in the pulp and chuck pinch grips; the pad(s) of the distal segment(s) of the finger(s) opposing the thumb were allowed to make greater contact with the fabric (figure 2).

In addition, handgrip and pinch strengths were measured. Handgrip was measured in the standard way. The pinches were of three types, lateral, chuck and pulp 2 (Imrhan and Loo 1989) corresponding to the three types of pinch grips used during the pulls. Figure 2 shows examples of the chuck and pulp pinches.

Table 2. Anthropometric characteristics of subjects in Stage II experiment ($n=34$).

Variable	Mean	Standard deviation	Range
Age (yr)	26·8	3·9	22·0–39·0
Body weight (kg)	75·1	11·9	52·0–107·8
Stature (cm)	175·1	7·0	161·0–188·0
Hand length (cm)	19·0	0·9	17·8–21·0
Inner hand breadth (cm)	9·4	0·6	7·9–10·7
Outer hand breadth (cm)	10·6	0·5	9·6–11·6
Wrist circumference (cm)	7·2	1·1	5·1–12·4

2.2.3. *Apparatus:* The load cell, fabric pull strip, and stabilizing handle were the same ones used in Stage I. The data recording system was different. The load cell was connected to an analog-to-digital converter board in an IBM PC computer, to enhance signals amplification and data acquisition. The 'Labtech Notebook' software was used to acquire the digitized voltage (load) signals from the load cell, at the rate of 10 Hz. The time history of the pull contraction (5–6 s) was displayed graphically on the computer screen to enable the investigator to observe the shape of the MVC curve and ensure that the MVC contraction was performed properly (Kroemer and Marras 1981).

2.2.4. *Data analysis methods:* The data for Stages I and II were analysed separately using the Statistical Analysis System (SAS) on an IBM 4381 mainframe computer. Statistical methods used included Analysis of Variance (ANOVA: followed by Duncan's multiple range test, where appropriate), correlation analysis, and regression analysis, with a level of significance of $\alpha=0·05$, arbitrarily chosen.

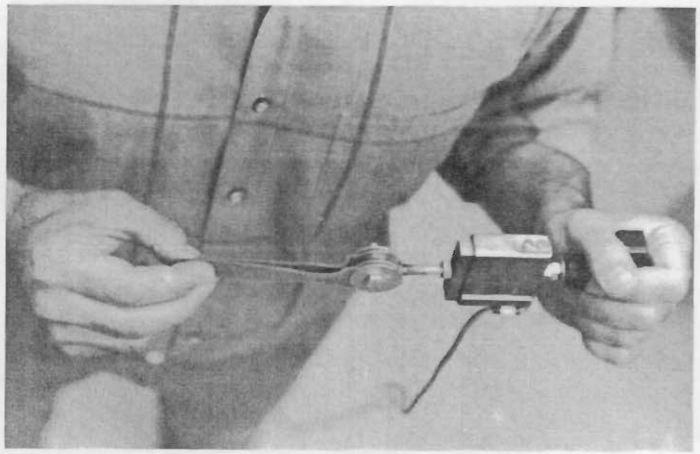
3. Results

3.1. *Stage I*

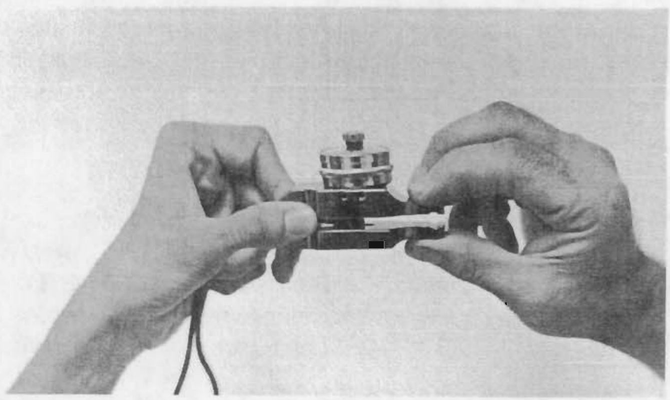
Age and anthropometric summary data were shown in table 1. General body size (stature and body weight) and hand size (length and breadth) of the subjects are only slightly smaller (by 4·8 cm in stature and 1·3 kg in weight) than those of 40 adult males in a study of pinch strength by Imrhan and Loo (1989). Hand strength comparisons between these two studies have, therefore, been considered appropriate.

The finger pinch–pull forces are summarized in table 3, according to the different factor combinations to illustrate relationships clearly. The table shows that differences in forces due to either direction of pull or hand laterality were very small, but the differences due to type of pinch used were great. Left hand finger pulls were 97% as strong as right hand ones. ANOVA followed by Duncan's multiple range test (at $\alpha=0·05$) confirmed that lateral pinch–pull force (LPP) was significantly greater than chuck pinch–pull force (CPP) which was, in turn, greater than pulp pinch–pull force (PPP). ANOVA also confirmed that there were no significant interaction effects among the factors; that is, the magnitude of the differences among LPP, CPP, and PPP were the same, regardless of which hand pulled or in which direction the pull was exerted.

The data for the different directions and hand laterality were therefore combined



(a)



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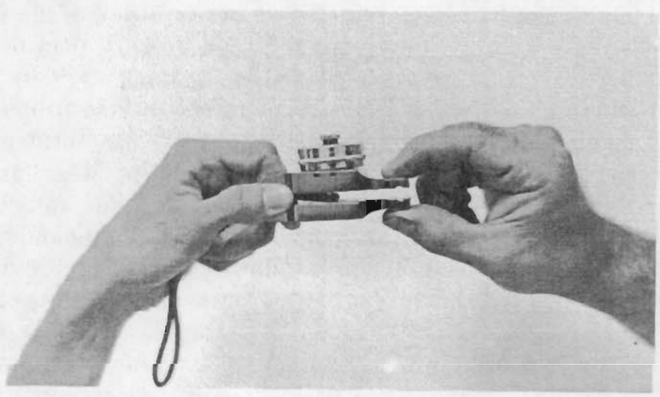

(c)

Figure 2. The positions of the hands and fingers during CPP (a); chuck pinch (CP) (b); and pulp pinch (PP) (c). Note that for CPP, the three fingers make a greater area of contact with the pull strip than in figure 1a (Stage I).

Table 3. Pinch–pull MVC force means (N; $n=36$), in different pull directions for each hand, Stage I experiment. The number in parenthesis represents the standard error of the mean ($n=36$).

Direction	Type of pull	Left hand	Right hand
	LPP	92·0(3·9)	94·8(4·9)
Horizontal	CPP	52·8(2·1)	57·2(2·9)
	PPP	36·5(1·9)	37·5(2·1)
	LPP	97·7(4·9)	95·9(4·2)
Oblique	CPP	53·2(2·8)	57·7(2·6)
	PPP	37·0(1·8)	37·0(1·9)

and averaged across the three types of pinch–pull. The means ($n=144$) were LPP=95·1 N; CPP=55·2 N; and PPP=37·2 N. There was some overlap in the tails of the distributions of the different pinches.

A comparison of the means of the ratios of these pulls showed that, to a close approximation, LPP was one-and-three-quarter times as strong as CPP which, in turn, was one-and-a-half times as strong as PPP.

The anthropometric dimensions—stature, body weight, hand length, and hand breadth—were all correlated significantly with the strongest pinch–pull (LPP); but only body weight was significantly correlated with CPP, and only age with PPP. Significant Pearson Product Moment correlation coefficients ranged from $r=0{\cdot}35$ to $r=0{\cdot}66$, with p-values ranging from 0·04 to 0·0001.

3.2. *Stage II*

Tables 2 and 4 show summary data for anthropometric and strength variables, respectively. Mean body dimensions of the subjects were comparable to those in Stage I experiment and to those in the adult group of Imrhan and Loo (1989).

ANOVA and Duncan's Multiple Range Test confirmed again that, the average force (n=34) of LPP (99·5 N) was significantly greater than that of CPP (65·8 N), which in turn was greater than that of PPP (45·2 N). The pinch forces were, likewise, significantly different from each other (mean LP=103·6 N; mean CP=98·4 N and mean PP=72·7 N). Handgrip strength was considerably greater than the pulls or the pinches, averaging 531·6 N. There was some overlap in the tails of the distributions, among the pulls and among the pinches.

3.3. *Correlations—strength and anthropometry*

Pearson's product-moment correlation coefficients (r) indicated strong associations among the various types of strengths. This was expected because similar muscle groups were used. Pairwise correlations among the pulls ($r=0{\cdot}73$–$0{\cdot}86$) were comparable in magnitude to those among the pure pinches ($r=0{\cdot}69$–$0{\cdot}76$). The level of significance, as indicated by the p-values was $p<0{\cdot}0001$, in all cases (table 5).

Strong correlations also existed between the pulls and two pinches (pulp and lateral). Pearson's r varied from 0·54 to 0·60, with $p<0{\cdot}0001$ to $p<0{\cdot}0002$. The chuck pinch was more weakly correlated with the pulls ($r=0{\cdot}32$–$0{\cdot}46$) with one value, 0·32, having a non-significant p value ($p<0{\cdot}06$). This difference, between the chuck and the other two pinches, was difficult to interpret.

Table 4. Pinch–pull, pinch and handgrip mean ($n=34$) strength (N, Stage II experiment. The number in parenthesis represents the standard error of the mean.

Variable	Mean
Type of pull	
LPP	99·5(3·0)
CPP	65·8(1·3)
PPP	45·2(1·1)
Type of pinch	
Lateral (LP)	103·6(2·2)
Chuck (CP)	98·4(1·8)
Pulp II (PP)	72·7(1·8)
Handgrip	531·6(10·9)

The pull strengths (LPP, CPP, and PPP) were not correlated significantly with age ($r=0{\cdot}02$–$0{\cdot}13$), but were correlated significantly with all other anthropometric variables measured—stature, body weight, hand length, and hand breadth ($r=0{\cdot}36$–$0{\cdot}58$; with $p<0{\cdot}0003$ to $p<0{\cdot}037$).

Significant correlations between all the pure pinches (LP, CP, and PP) and anthropometric variables existed for body weight and hand breadth ($r=0{\cdot}41$–$0{\cdot}63$; with $p<0{\cdot}0001$ to $p<0{\cdot}04$). There were no significant correlations with age. Handgrip strength was significantly correlated with all pulls ($r=0{\cdot}58$–$0{\cdot}69$; $p<0{\cdot}0001$ to $p<0{\cdot}0003$) and pulp pinches ($r=0{\cdot}53$–$0{\cdot}60$; $p<0{\cdot}0002$ to $p<0{\cdot}001$).

4. Discussion

Pure pinches (LP, CP, and PP) and anthropometric dimensions did not provide strong enough associations with any of the three pulls (LPP, CPP, and PP). Multiple regression analysis produced predictive models in which R^2 values were only 0·68 (for pulp pinch–pull as the response variable), 0·62 (for chuck pinch–pull) and 0·47 (for lateral pinch–pull). Therefore, the results of this study indicate that finger pull strength cannot be predicted accurately enough from pure pinches and anthropometric dimensions, to be of value to ergonomists and designers. It is important to note that the final regression models contained no anthropometric variables. All contained handgrip strength and one or more pinch strengths.

The proportional relationship between the strength of pull using a particular type of pinch and the strength of that pinch measured separately provides some insight into the contribution of the shoulder muscles for the pulls. Stage II results indicated that these ratios were: LPP/LP=0·97; CPP/CP=0·67, and PPP/PP=0·62 (table 6). The differences in these ratios suggest that the shoulder muscles may have contributed much more force (45–56%) when using the lateral pinch grip (LPP) than the other two pinch grips. The similarity of the ratios for the chuck and pulp pinch grips (0·67 and 0·62) may be explained by the observation that these two grips were identical, except that the chuck pinch used two fingers (index and middle) in opposing the action of the thumb, whereas the pulp pinch used one finger (index). All subjects, in a post-test interview, agreed that they felt greater strain in the shoulder area, when using the lateral pinch, compared with the chuck or pulp pinch, to pull; and they felt greater strain in the fingers when using the chuck or pulp pinch compared with the lateral pinch.

Table 5. Pearson correlation coefficients among strength and anthropometric variables (Stage II, $n=34$).

	LPP	CPP	PPP	HG	LP	CP	PP	AGE	ST	BWT	HL	HB
LPP	1·00 (0·000)	0·86 (0·000)	0·73 (0·000)	0·58 (0·001)	0·55 (0·000)	0·46 (0·006)	0·56 (0·001)	0·02 (0·910)	0·39 (0·021)	0·46 (0·006)	0·36 (0·036)	0·38 (0·027)
CPP			0·83 (0·000)	0·69 (0·000)	0·59 (0·000)	0·39 (0·023)	0·58 (0·000)	0·04 (0·769)	0·58 (0·000)	0·55 (0·001)	0·48 (0·004)	0·49 (0·003)
PPP				0·58 (0·000)	0·60 (0·000)	0·32 (0·064)	0·54 (0·002)	0·13 (0·478)	0·50 (0·003)	0·50 (0·002)	0·36 (0·037)	0·44 (0·004)
HG					0·55 (0·001)	0·60 (0·000)	0·53 (0·001)	0·18 (0·31)	0·72 (0·000)	0·53 (0·001)	0·61 (0·000)	0·52 (0·002)
LP						0·69 (0·000)	0·76 (0·000)	0·21 (0·229)	0·25 (0·151)	0·54 (0·001)	0·34 (0·051)	0·46 (0·006)
CP							0·76 (0·000)	0·25 (0·15)	0·35 (0·043)	0·50 (0·003)	0·49 (0·004)	0·35 (0·041)
PP								0·21 (0·241)	0·35 (0·041)	0·63 (0·000)	0·44 (0·009)	0·44 (0·009)
AGE									−0·08 (0·647)	0·04 (0·818)	0·09 (0·609)	−0·03 (0·915)
ST										0·41 (0·015)	0·68 (0·000)	0·39 (0·024)
BWT											0·58 (0·000)	0·74 (0·000)
HL												0·54 (0·002)

HG represents handgrip strength.

Table 6. Proportional relationships among pinch-pull, pinch, and handgrip strengths.

Type of strengths	Mean ratio	Range of ratios
Stage I ($n=34$)		
LPP/CPP	1·73	1·08–2·10
CPP/PPP	1·49	0·85–1·94
Stage II ($n=36$)		
LPP/CPP	1·51	1·22–1·70
CPP/PPP	1·47	1·23–1·76
LP/CP	1·06	0·66–1·27
CP/PP	1·36	1·18–1·68
LP/HG	0·19	0·14–0·24
PP/HG	0·14	0·10–0·18
LPP/LP	0·97	0·70–1·14
CPP/CP	0·67	0·44–0·95
PPP/PP	0·62	0·47–0·99

For the pulls, there was one aspect that was different in the two stages of this study, by design; that is, a greater area of the pads of the index and middle fingers was allowed to contact the pull strip (fabric). The results indicated that the slight increase in contact area produced greater pull forces (CPP=55·2 N in Stage I and 65·8 N in Stage II; and PP=37·0 N and 45·2 N, respectively); the increases were of the same order—19% for CPP and 18% for PPP. While it may be argued that these increases are not directly comparable because of two different samples of males, one must note that LPP strength, where the pull conditions in the two stages were identical, showed only a very small non-significant increase (95·1 N to 99·5 N, or 4%). Pooling the LPP data for the two experiments ($n=70$) gave 58 N, 94 N, and 139 N for the 5th, 50th, and 95th percentile values. There is no other reason, therefore, for the large increases in CPP and PPP, other than the increase in the area of contact between the fingers and pull strip. The practical implication here is that, whenever possible, allowing for a little more contact area on the object (either through pull strip design or workspace for the hand) to make greater area contact with the fingers can produce significantly greater pull forces, or reduce muscular strain for a required level of force.

For the separate pinch forces, LP was as strong as CP (LP/CP=1·06), and CP 1·36 times as strong as PP. These figures are close to those in Imrhan and Loo (1989), which were 1·00 and 1·28, respectively. In comparison, the ratios among the pulls, for corresponding pinch grips, were very different for the lateral pinch grip; LPP was 1·51 as strong as CPP (table 5), but CPP was 1·47 as strong as PPP. Again the influence of the greater effort of the shoulder muscles seems to be evident here. One cannot therefore assume that finger pinch strengths bear the same relationship to finger pull strengths; and ergonomic designs for pinch pull strength should not use pure pinch strength data in a proportional manner.

5. Conclusions

These two experiments indicate that when objects must be pulled with the fingers, the tasks and objects should be designed to take advantage of the more powerful lateral pinch grip. This means that a sufficiently large surface area of contact (pinch handle) must be provided, otherwise the person may resort to the index finger pinch, which requires less area of contact but generates much weaker forces and, hence, imparts greater mechanical stress on the hand musculoskeletal system. In fact, a larger area may even enhance the chuck and pulp–pinch pulls, if it encourages a greater area of the pads of the fingers to make contact.

Data on pinch strengths, though not as rare as finger pull strengths, should not be used without caution by designers of tasks or objects requiring finger pull strengths. Quantitative relationships among pure pinches are not the same as among finger pulls. The best strategy for determining design parameters for finger pull strengths may be the development of descriptive data of the specific measurements. Recourse to predictive methods, such as regression analysis, using variables that are easier to measure, such as anthropometric measurements, and pinch and handgrip strengths, are not recommended at this stage.

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