Effect of Grip Span on Lateral Pinch Grip Strength

Carrie L. Shivers, Gary A. Mirka, and **David B. Kaber,** North Carolina State University, Raleigh, North Carolina

Repetitive, high-force pinch grip exertions are common in many occupational activities. The goal of the current study was to quantify the relationship between lateral pinch grip span (distance between thumb and index finger) and lateral pinch grip strength. An experiment was conducted in which 40 participants performed maximal lateral pinch grip exertions at 11 levels of grip span distances (0, 10%, … 100% of maximum functional lateral pinch grip span distance). The results show a significant effect of lateral pinch grip span, with strength at the maximum functional lateral pinch grip span 40% higher than that found at the smallest lateral pinch grip span considered. Between these two endpoints, strength increased monotonically with increasing pinch grip span. The application of these results in pinch grip design criteria for both high-force and long-duration exertions is discussed. Potential applications of this research include the design of hand tools and controls for which significant force is applied by the user.

INTRODUCTION

Repetitive, awkward, high-force pinch grip exertions have been related to fatigue, discomfort, and injury to the hand/wrist complex in industrial populations. In a study of sewing machine operators, T. J. Armstrong and Chaffin (1979) showed that operators with a history of carpal tunnel syndrome used pinch grips more frequently and that the force used during these pinch grip exertions was greater than that employed by the control group (women performing the same jobs at the time that the case group members reported their symptoms). The effects of pinch grip exertions on the intrinsic muscles of the hand were considered by Punnett and Keyserling (1987) in a study of employees in a garment shop. They found a positive correlation between pinch grip duration and hand pain in this population.

In vitro work by Smith, Sonstegard, and Anderson (1977) gave further support to the deleterious effects of pinch grips, particularly those performed with the wrist in flexed postures. Using biomechanical modeling techniques, Cooney and Chao (1977) illustrated that the magnitude of the externally applied forces in the pinch grip is significantly smaller than the magnitude of the resulting internal forces in the tendons and joint contact forces. These studies collectively indicate that gathering basic information about the biomechanical properties and characteristics of pinch grip exertions may lead to design principles and intervention strategies to reduce fatigue, discomfort, and injury of the distal upper extremity.

A number of studies have considered various factors affecting pinch grip strength, such as age, sex, stature, body weight, wrist posture, and elbow posture (e.g., Apfel, 1986; Dempsey & Ayoub, 1996; Hook & Stanley, 1986; Lamoreaux & Hoffer, 1995; Mathiowetz, Rennells, & Donohoe, 1985). Pinch grip span is one factor that may be under the control of the ergonomist, and therefore understanding the relationship between pinch grip span and pinch grip force could lead to interventions to reduce the risk of fatigue, discomfort, and injury.

Two previous studies that attempted to quantify the relationship between pinch grip span

Address correspondence to Gary Mirka, Department of Industrial Engineering, Box 7906, North Carolina State University, Raleigh, NC 27695-7906; mirka@eos.ncsu.edu. **HUMAN FACTORS,** Vol. 44, No. 4, Winter 2002, pp. 569–577.

and pinch grip strength had remarkably different results. Dempsey and Ayoub (1996) assessed the pinch grip strength capability of 16 participants (8 men and 8 women) using a custom-made pinch grip dynamometer. A Wheatstone bridge configuration (Fathallah, Kroemer, & Waldron, 1991) employing two aluminum bars was used to measure participants' pinch grip strength. The bars were spaced at 1, 3, 5, and 7 cm and were mounted such that it was necessary to squeeze both bars equally to achieve a valid pinch grip force measurement. Results of the lateral pinch grip strength assessment showed that pinch width had a significant effect on pinch force, with the average (across participants) force increasing from 1 to 5 cm, peaking at 5 cm, and declining at the 7-cm grip span.

Another study, conducted by Imrhan and Rahman (1995), evaluated the pinch grip strength of 17 male participants. This research team also developed its own pinch grip strength dynamometer, wherein a steel handle was attached to a Chatillon digital push/pull force gauge. This handle could be slid up and down, enabling the pinch grip width to be adjusted to seven fixed widths: 2.0, 3.2, 4.4, 5.6, 6.8, 8.0, and 9.2 cm. The participant's thumb rested on the handle, and his fingers pulled up on the force gauge to produce a force. This testing apparatus was mounted to a height-adjustable tripod stand, and the force measurements were read directly from the Chatillon force gauge. The results demonstrated that pinch width had a significant effect on force production, showing that the strongest grip span was the smallest span (2.0 cm) and the weakest grip span was the largest span (9.2 cm), with a decline between these points.

The results of the aforementioned two studies are clearly contradictory in their description of the relationship between lateral pinch grip force and lateral pinch grip span. The specific aims of the current research were (a) to test the hypothesis that lateral pinch grip span distance has an effect on lateral pinch grip strength, (b) to describe this relationship in terms of relative grip span (percentage of a participant's own grip span distance, instead of absolute grip span distance), and (c) resolve the conflicting results presented in the previous work.

METHODS

Participants

The participants in this study were 40 unpaid volunteers (19 men and 21 women) with varied backgrounds in manual work. Participants were not recruited based on their history of work in any particular industry or history of performing specific work tasks. All were in good health at the time of the study, and no participants had acute or chronic musculoskeletal injuries to their upper extremities. Each provided written informed consent before participation. Thirty-one of the participants were right handed. Pertinent anthropometric data appear in Table 1.

Apparatus

The lateral pinch grip force measuring apparatus consisted of a stable wooden frame supporting a commercially available pinch grip dynamometer (B & L Engineering, model 7485, Sante Fe Springs, CA; Figure 1). A pulley system mounted within a wooden housing was fabricated that allowed for the measurement of lateral pinch grip force for pinch grip spans ranging from 4 mm (the minimum when the thickness of the material of the hand loop was considered) to the participant's maximum lateral pinch grip span. In this system of pulleys, the dynamometer was mounted on an aluminum rod, allowing it to rotate freely and eliminating the possibility of non-pinch-grip forces influencing the reading of the dynamometer. Visible movement of the dynamometer during an experimental trial indicated an imbalance in the pinch grip forces, and that trial would then be repeated. Grip span of the dynamometer was changed using the turnbuckle in the pulley system.

Pilot work indicated that a good approximation of a functional, maximum lateral pinch grip span was 70% of the distance from the interphalangeal joint of the thumb to the distal interphalangeal joint of the index finger (Figure 2) with the thumb maximally abducted. This measurement was taken for each participant, and 70% of this value was used as the maximum lateral pinch grip span in the subsequent experimentation for that participant. The minimum grip span for the experimentation was determined as the minimum spacing between the loops that did not allow the loops to touch

TABLE 1: Participant Anthropometry

Participant	Mean	*SD*	Minimum	Maximum
Age (years)	33.4	10.8	21	54
Height (cm)	174.4	11.3	156.9	199.5
Mass (kg)	77.8	19.7	50	127.3
Right (cm)				
Forearm circumference	27.3	3.4	21.5	33.5
Hand length	18.7	1.5	15.9	22.6
Hand breadth	8.4	0.8	7.0	9.9
Hand breadth including thumb	10.2	0.9	8.5	12.0
Hand circumference	20.4	2.0	16.8	24.3
Hand circumference including thumb	23.7	2.3	19.4	29.0
Left (cm)				
Forearm circumference	27.0	3.5	19.9	34.5
Hand length	18.8	1.6	15.8	22.8
Hand breadth	8.4	0.9	7.0	10.0
Hand breadth including thumb	10.2	1.0	8.4	12.3
Hand circumference	20.2	2.1	16.0	24.4
Hand circumference including thumb	23.4	2.3	19.0	27.6

during a maximum voluntary contraction, as this would create an unmeasured force caused by the physical interaction between the loops. The minimum and maximum lateral pinch grip span for one person is shown in Figure 3. Finally, the intermediate lateral pinch grip spans were calculated as percentages of this range.

Experimental Task

Participants sat in front of the experimental apparatus and assumed a whole-body posture consistent with that suggested in the American Society of Hand Therapists (ASHT) standards (seated, elbow 90°, forearm parallel to the floor,

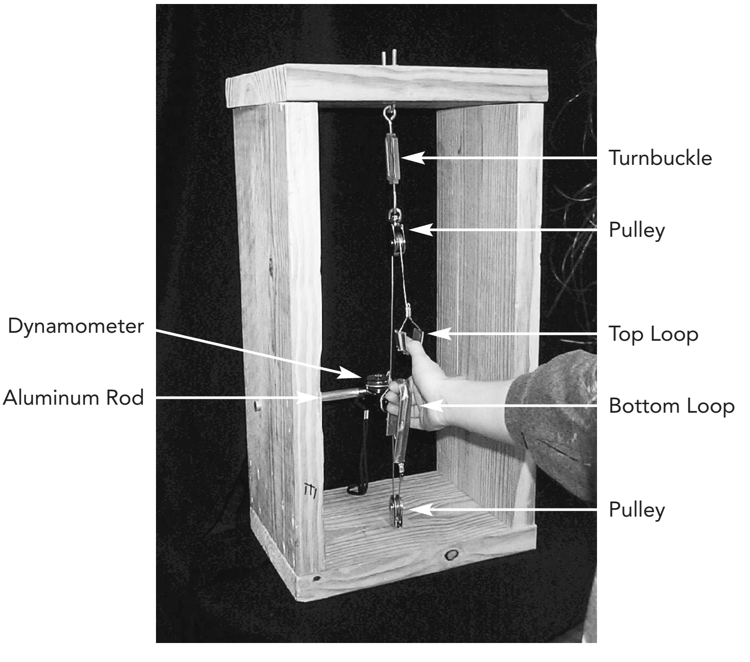

Figure 1. Pinch grip dynamometer apparatus in wooden housing.

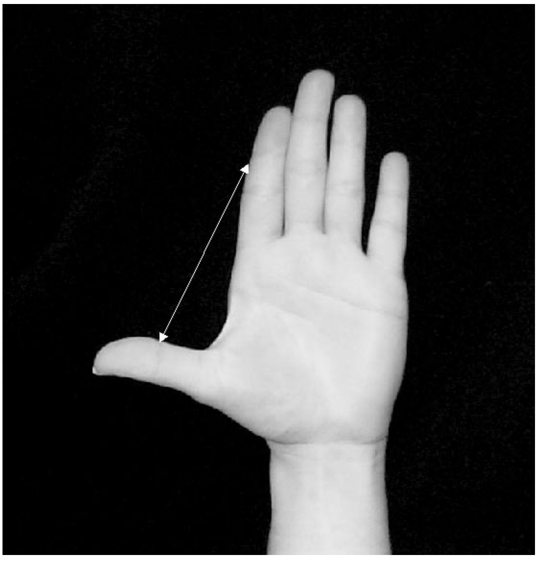

Figure 2. Distance between distal interphalangeal joint of index finger and interphalangeal joint of the thumb.

shoulder adducted with 0° rotation, and wrists neutrally positioned; Fess & Moran, 1981) to ensure good repeatability in maximum pinch grip exertions (Mathiowetz, Weber, Volland, & Kashman, 1984). To maintain consistency in this posture/orientation, participants remained stationary during the experiment, and the wooden housing was moved back and forth between the right and left hand during successive trials. Participants placed their fingers into the loops of the apparatus and performed the sequence of maximum voluntary pinch grip exertions.

The order of presentation of the grip spans was randomized, and the grip spans were tested on each hand. Each maximum voluntary exertion (MVE) was held for 2 s; the peak force exerted during the trial was read from the dynamometer dial at completion. This method most closely follows that of the "sudden maximal contraction" exertion of Williamson and Rice (1992). This method differs from that proposed by Caldwell et al. (1974) because previous pinch grip research has shown that longer-duration exertions were not as maintainable for pinch grip exertions (Berg, Clay, Fathallah, & Higginbotham, 1988). There was one trial per hand for each grip span, and each trial consisted of two MVE pinch grips separated by a 30-s rest break (Rice, Leonard, & Carter, 1998).

Mathiowetz (1990) found that the greatest test-retest reliability of maximum pinch grip force capabilities was generated when participants performed three MVEs and the average of these was used to quantify pinch grip strength. However, pilot work for the current

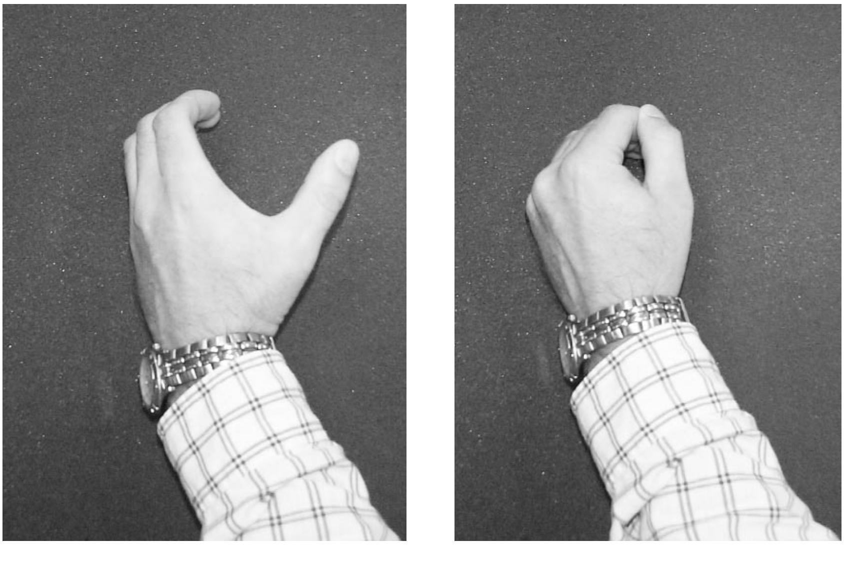

Figure 3. Example minimum and maximum lateral pinch grip spans used in this study.

study generated concerns about the time-dependent fatigue effects with the number of exertions that were planned, so only two repetitions per trial were conducted, and the average of these two peak values was determined for each hand at each grip span. After a participant completed the two MVEs with one hand, the dynamometer apparatus was moved to the other hand and the participant performed the two exertions as outlined. He or she then rested for 2 min, during which time the experimenter adjusted the grip span of the dynamometer for the next trial. This process was continued until all 11 grip spans were evaluated.

Experimental Design

Independent variables. The two independent variables in this experiment were lateral pinch grip span and hand. The levels of lateral pinch grip span were 0%, 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%, and 100% of the participant's maximum lateral pinch grip span. The hand independent variable had two levels: dominant and nondominant.

Dependent variable. The dependent variable in this study was the peak lateral pinch grip force, defined as the average of two values: the peak force measured in the first MVE and the peak force measured in the second MVE.

Statistical analysis. Before we conducted the analysis of variance (ANOVA), we validated the assumptions of this analysis procedure by (a) conducting a chi-square test to test for equality of the variances of the dependent variables across the levels of the independent variables and (b) by plotting the residuals as a function of grip span and order of run in the experiment. Once these and the other ANOVA assumptions (linearity, random process) were validated, the ANOVA procedure was used to evaluate the effects of the independent variables on peak lateral pinch grip force.

In this study the statistical model consisted of both fixed effects (hand and grip span) and random effects (participant). An expected mean squares procedure was used to determine the appropriate F ratios for evaluating the model main effects and interaction. Tukey's honestly significantly different (HSD) post hoc test was conducted on all significant effects. Finally, a regression analysis was conducted to establish the relationship between lateral pinch grip span (in absolute terms – i.e., not normalized to the participant's maximum lateral pinch grip span) and the lateral pinch grip force. This analysis was conducted on the data from the male participants, the data from the female participants, and the complete data set.

RESULTS

The assumptions of the ANOVA procedure were confirmed with the chi-square test, illustrating the homoscedasticity of the response variances (calculated χ^2 value = 12.47, χ^2 statistic at an α of .05 = 18.31). The plots of the model residuals revealed no systematic trends in the residuals as a function of pinch grip span or position within the sequence of trials.

The plot of the peak lateral pinch grip force reveals a consistent trend of increasing lateral pinch grip force with greater span (Figure 4). This trend was seen in 36 of the 40 participants, and the 4 who did not show this trend generally had a slight reduction in force as they went from 80% to 100% of maximum grip span distance.

The ANOVA showed no significant effect of the interaction between pinch grip span and hand (p = .5175). The main effect of pinch grip span was a significant factor in predicting peak lateral pinch grip force ($p < .0001$; Tukey's HSD results are shown in Table 2), whereas the independent variable of hand was not a significant factor (p = .4281). This latter result agrees with the findings of C. A. Armstrong and Oldham (1999) in their study of power grip strength and pulp-to-pulp pinch grip strength.

The regression analysis of the nonnormalized dominant hand data resulted in three regression equations that can be used to predict lateral pinch grip strength in newtons (N) as a function of lateral pinch grip span (Equations 1–3):

For males (R^2 = .11): Lateral pinch grip strength = 100 N + 3.93 × lateral pinch grip span (cm). (1)

For females (R^2 = .05): Lateral pinch grip strength = 75 N + 2.41 × lateral pinch grip span (cm). (2)

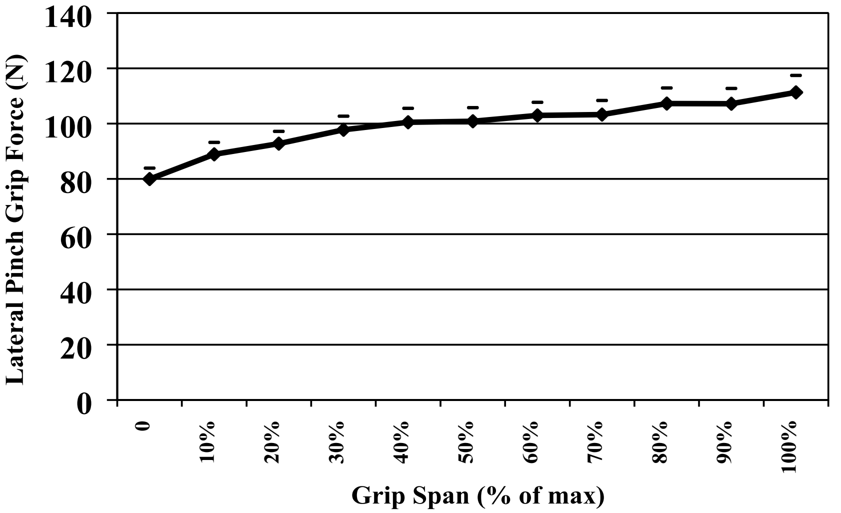

Figure 4. Lateral pinch grip force as a function of the percentage of the participant-specific maximum functional lateral pinch grip span. (Horizontal bars show the standard error of the estimates.)

For all (R^2 = .07): Lateral pinch grip strength = 86 N + 3.56 × lateral pinch grip span (cm). (3)

DISCUSSION

Changes in lateral pinch grip span affect the length-tension relationship of the participating muscles as well as the moment arm of the muscles about the multiple joints involved in generating the pinch grip force. Because of these variable (as a function of grip span) biomechanical characteristics of the lateral pinch grip, it was difficult to predict a priori how changes in lateral pinch grip span would affect lateral pinch grip strength. This experiment was conducted to empirically derive the relationship between lateral pinch grip span and lateral pinch grip force, and the results indicate that pinch grip strength increases with greater grip spans. The principal result of this work is that the optimal grip spans for generating maximum pinch grip force occur from 80% to 100% of a person's maximum lateral pinch grip span, as it has been defined here (70% of the distance from the interphalangeal joint of thumb to the distal interphalangeal joint

TABLE 2: Tukey's HSD Test on Mean Grip Force (N) at Different Grip Spans

Grip Span	Mean	Tukey Grouping A	B	C	D	E	F
I00%	111.3	X					
90%	107.2	X	X				
80%	107.2	X	X				
70%	103.3		X	X			
60%	102.9		X	X			
50%	100.8		X	X			
40%	100.5		X	X			
30%	97.8			X	X		
20%	92.7				X	X	
10%	88.9					X	
0%	80.0						X

of the index finger with the thumb maximally abducted).

There have been two other notable studies testing the effects of pinch grip span on force production. Dempsey and Ayoub (1996) found that the optimal grip span was 5 cm, whereas Imrhan and Rahman (1995) found that the optimal grip span was 1 cm. The data from the current study are more consistent with that of Dempsey and Ayoub (Figure 5) and may be attributed to the similarities in the apparatus and testing procedures. First, both the current study and Dempsey and Ayoub used a testing apparatus that effectively isolated the pinch grip. Imrhan and Rahman noted that their apparatus did not register force when the participant pushed down on the top handle of their dynamometer, but forces exerted only on the bottom handle (lifting of the experimental apparatus) would register and could have influenced their results. Second, both the current study and Dempsey and Ayoub positioned participants according to the ASHT recommendations, whereas Imrhan and Rahman did not.

Although the trends in the results of this study were consistent with those of Dempsey and Ayoub (1996), there were some subtle differences. First, Dempsey and Ayoub did not find a consistently increasing trend in lateral pinch grip force as a function of increasing lateral pinch grip span, as was found in the current study. They found that the lateral pinch grip strength increased from 1 to 5 cm (peaking at 5 cm) and then dropped off at the 7-cm span, whereas our study showed a consistent increase in strength as grip span increased. We believe this difference is attributable to the differences between the absolute and relative lateral pinch grip span approaches. In the sample of 40 participants in the current study, 3 participants' (7.5%) maximum lateral pinch grip span (as defined here) was less than the 7-cm value used by Dempsey and Ayoub. Had these 3 participants attempted to exert force at the 7-cm grip span, their forces would have been dramatically lower, and this may explain the reduction found at the 7-cm level in the previous work.

Arguments could certainly be made for both methods of assessing maximum lateral pinch grip strength; we feel that the participant-specific (relative to participant anthropometry)

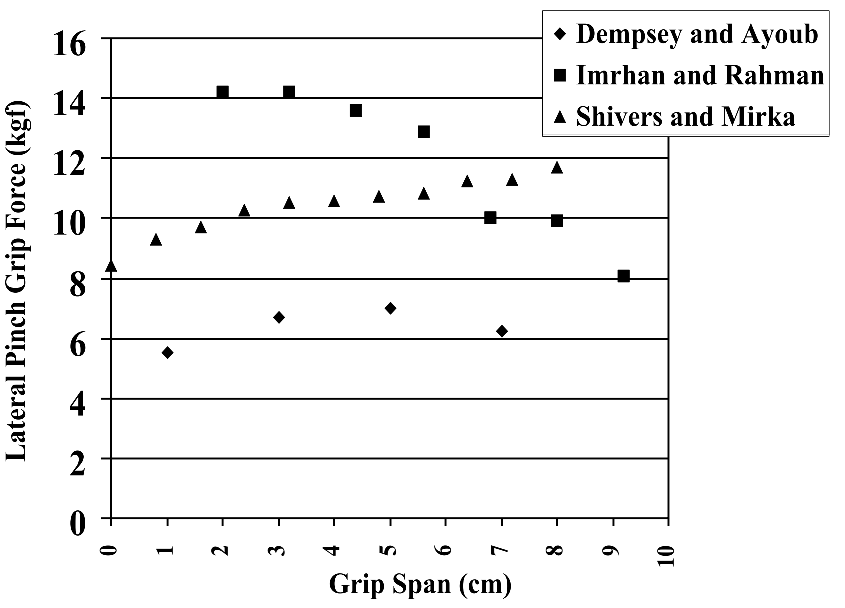

Figure 5. Lateral pinch grip force as a function of the lateral pinch grip distance for Dempsey and Ayoub (1996), Imrhan and Rahman (1995), and the current study. Note: Data for the current study are plotted relative to the average maximum lateral pinch grip span for the participant population and are placed on the same axes as data for previous studies for trend comparison purposes only; kgf = kilograms force.

grip spans create a less ambiguous relationship between grip span and grip force, whereas the absolute grip spans have more direct application in population-based design applications.

The second difference between the two studies is the difference in the absolute magnitude of the lateral pinch grip force. We think this can be attributed to the fact that our data reflect the average of two instantaneous peak forces, whereas the values of Dempsey and Ayoub (1996) were calculated using the average value across 2-s exertions. This again reflects two valid approaches to quantifying pinch grip strength, but it also highlights an important difference that should be considered when interpreting results from studies of human strength.

The motivation for the current study was founded on observations of sewing and upholstery operations in the furniture manufacturing industry during our ongoing ergonomics intervention project. Both jobs involve highly repetitive, hand-intensive activities. Workers performing sewing tasks pinch (pulp pinch and lateral pinch grips), grasp, and tug on fabric to align it correctly as they feed it into a sewing machine. Upholsterers secure fabric to furniture frames by gripping and pulling the fabric using a lateral pinch grip with their nondominant hand and then staple the fabric to the frame with their dominant hand. Our assessment that these repetitive, hand-intensive tasks were problematic was supported by both a review of incidence rates and a worker survey. (Methods of Occupational Safety and Health Administration Form 200 log analysis and surveys are summarized in Mirka, Smith, Shivers, & Taylor, 2002.)

A number of jobs require maximal or near-maximal lateral pinch grip forces, and the applicability of the current study's results to these types of tasks is clear. In addition, however, our results can have implications for tasks with repetitive pinch grips that do not approach an individual's maximum capacity. The relative amount of force (percentage of maximum) produced by muscular tissue has been shown to affect blood flow in the tissue, which in turn affects the rate of muscular fatigue during isometric exertions (Sjøgaard, Savard, & Juel, 1988). Therefore, reducing the intensity of the muscle contraction by placing the hand in a posture with a greater capacity illustrates another way that the results of the current study can be applied.

Relating the results of the current study to these furniture industry jobs highlights potential areas of improvement. These occupational pinch grips are at a 1- to 4-mm grip span, with only the thickness of the fabric/leather separating the two participating digits (most closely related to the 0% maximum grip span measurement considered in this study). The results of this study indicate that this grip span is not the most effective one for generating large forces, and it could be easily extrapolated that larger pinch grip spans could have the potential to reduce fatigue through the reduction in the percentage of maximum force that would be required for a given pinch grip force requirement. Therefore, it is logical that larger grip spans may be a positive design alternative when maximum or near-maximum pinch grip forces are required. Applying this principle poses a challenge related to dexterity and learning of these pinch grips, but it may have a positive effect if these challenges can be met.

A couple of limitations of the current study should be noted. First, and most important, pinch grip strength is only one of several issues that should be considered when designing a task with significant pinch grip requirements. The internal biomechanical loading patterns that exist in each of these pinch grip spans should be considered to gain an overall perspective on the benefits and drawbacks of a larger lateral pinch grip span. Second, although the age range of the participant population was 21 to 54 years, the majority of the participants were of college age, which limits our ability to extrapolate this response to older populations. The response of an older population is of particular interest when considering how often a pinch grip is necessary, not only in occupational activities but also in the activities of daily living.

CONCLUSIONS

Repetitive, high-force pinch grip exertions are common in many occupational activities. The goal of the current study was to quantify the relationship between lateral pinch grip span (distance between the thumb and index finger) and lateral pinch grip force. The lateral pinch grip strength at the participant's maximum functional lateral pinch grip span was 40% higher than that found at the smallest lateral pinch grip span considered. This result may have significant implications for pinch grip design criteria, but the implications of these postures from an internal loading perspective need to be investigated further.

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Carrie L. Shivers is a motorcycle plant ergonomist for Honda of America Mfg., Inc., in Marysville, OH. She received her M.S. in industrial engineering at North Carolina State University in 2001.

Gary A. Mirka is an associate professor of industrial engineering at North Carolina State University. He received his Ph.D. in industrial and systems engineering at Ohio State University in 1992.

David B. Kaber is an associate professor of industrial engineering at North Carolina State University. He received his Ph.D. in industrial engineering in 1996 at Texas Tech University.

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