Effects of hand position on maximum grip strength and discomfort

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Abstract

Background: Maximum grip strength can be used in designing work methods or workstations ergonomically. Though there is a standard protocol for measuring maximum grip strength, workers usually assume different upper-limb postures from the standard posture. It is known that grip strength can be affected by different postures. In many work conditions, the hand position can be determined as the ratio of the full reach distance of the worker. The grip strength data at various hand positions could be used practically in designing work methods or workstations.

Aims: The objective of this study was to measure grip strength and perceived discomfort at different hand positions and to investigate the effects of shoulder angle and reach distance on grip strength. Method: Maximum grip strength and discomfort were measured in 58 male volunteers at 15 different hand positions in standing posture. The hand position was defined by five hand directions (i.e. 0º, 45º, 90º, 130º, and 180º) of the shoulder flexion angle, and three hand-shoulder distances (i.e. 100%, 75%, and 50%) of arm reach. After gripping maximum strength, the subjects rated their perceived discomfort using a visual analog scale (VAS).

Results: Analysis of variance on grip strength and discomfort rating showed significant effects of hand-shoulder distance, hand direction and their interaction (p<0.05). No significant interaction effect of grip strength between hand-shoulder distance and hand direction was shown (p>0.05), while there was a significant interaction effect of discomfort and hand direction and hand-shoulder distance (p<0.05).

Conclusions: This study showed different effects on grip strength when individuals use different hand positions in order to grip. It is recommended that hand position should be over 75% of arm reach and in the reach direction of between 45º and 135º of the shoulder angle for optimum grip strength and comfort.

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Background

Grip strength has been widely used in evaluating the integrated performances of muscles in orthopaedics, rehabilitation and ergonomics. In particular, occupational ergonomists have tried to use strength data in redesigning work tasks requiring physical exertion, in order to reduce or eliminate the exposure of workers. There is a standard protocol for measuring grip strength recommended by the American Society of Hand Therapists (ASHT) in which the subject is seated with the shoulder adducted and neutrally rotated, the elbow flexed at 90º, and the forearm and wrist in neutral position. Using a standard protocol to measure grip strength is necessary, in order to be able to compare the measured grip strength of an individual to the existing reference data on grip strength, mainly in the area of orthopaedics and rehabilitation. In the workplace, workers are required to perform physically exerting tasks in various different body positions, which are usually far from what might be considered to be a standard posture. For this reason, several studies have attempted to measure maximum grip strength in a variety of non-neutral body postures.

Several studies have shown that grip strength is affected by the body postures of the upper extremity. In these studies, grip strength was measured in various upper-extremity postures, which were defined by the joint angles of the wrist, elbow and shoulder. In practical working conditions, workers generally hold a hand tool, control a machine or handle work materials at a given point and carry out a task by performing physical exertions. The anatomical point (i.e. a point with a distance from the worker in the direction of the line between the shoulder and the gripping hand) can be defined as the ‘relative position’ to the worker. It is thought that the grip strength data measured at postures defined by the joint angles are not ultimately applicable to practical work conditions. If there grip strength data were available, measured at various hand positions, defined in relation to the relative point of the worker, more practical guidelines would be able to be provided to industries to assist with the design of work tasks. This study aimed to: (i) measure the maximum grip strength at various hand positions that are defined as relative to the subject by distance and direction, and to (ii) investigate the variation of grip strength according to varying hand positions. It was presumed that the grip strength data at various hand positions could be used in more practical ways, particularly in occupational ergonomics.
Method

Subjects

Fifty-eight male university students participated in the experiment voluntarily, after being informed of the experimental protocol and possible risks. They had no history of musculoskeletal diseases in their right upper limb, were all healthy, and were able to perform the maximum gripping tasks. The students were all right-handed. Their mean (±SD) age, height, arm reach, body weight and body mass index (BMI) were 24.9 (±3.0) years, 176.2 (±4.7) centimetres (cm), 63.4 (±3.1) cm, 72.4 (±9.5) kilograms, and 23.3 (±3.0), respectively.

Hand positions and postures

Maximum grip strengths were measured at various hand positions, which were determined by ‘hand-shoulder distance’ and ‘hand direction.’ Hand-shoulder distance, which is the length between the hand and the shoulder joint, was expressed as the percentage of the subject’s maximum arm reach (i.e. %AR). The three hand-shoulder distances included in the experiment were 100%, 75%, and 50% of arm reach (i.e. ‘100%AR,’ ‘75%AR’ and ‘50%AR’). The mean values of 100%, 75%, and 50% of arm reach were 63.4 cm, 47.6 cm, and 31.7 cm, respectively.

Figure 1. Hand positions at 45° of hand direction with different hand-shoulder distances (a: 100%AR, b: 75%AR and c: 50%AR).

In the 100%AR condition, the subject held the grip of the hand dynamometer with the elbow fully extended and the wrist in the neutral position (Figure 1a). In 75%AR and 50%AR conditions, the hand dynamometer was moved to the positions where its distance from the shoulder was 75% and 50% of the maximum arm reach, respectively, without its direction being changed from the 100%AR condition (Figures 1b and 1c). The subject was asked to hold the grip of the hand dynamometer in a comfortable position.

The hand direction is the direction of the line from the shoulder to the hand, being expressed as the shoulder flexion angle in the 100%AR hand-shoulder distance. The five levels of the direction in the experiment were 0°, 45°, 90°, 135°, and 180°. Therefore, maximum grip strengths were measured at 15 different hand positions, i.e. 3 hand distances × 5 hand-shoulder directions.

Dependent variables

For each hand position, the maximum grip strength and the rate of discomfort were measured. The subject was asked to rate his feelings of discomfort for performing maximum grip strength. Rating of discomfort was carried out using the visual analog scale (VAS), where a 10 cm line with verbal descriptions ‘not uncomfortable’ and ‘extremely uncomfortable’ at each end was used. The subject marked the level of discomfort on the scale, after he had completed the maximum strength grip at each of the given hand positions.

Experimental apparatus

The hydraulic hand dynamometer (Jamar) was used in measuring maximal grip strengths in kilogram force (kgf). The dynamometer was attached to the holding bar, which is designed to be adjustable in height and direction (Figure 1). The attaching position of the hand dynamometer to the bar was able to be easily adjusted.

Experimental procedure

After being informed of the purpose and the method of the experiment, the subject signed a consent form for participation and completed a questionnaire about their current health condition, including information regarding the history of musculoskeletal disorders in their upper limb and their general health. The subject’s anthropometric data measured included height, weight and arm reach. The subject was then informed how to use the grip dynamometer and how to rate his feelings of discomfort. Each subject was asked to try to perform their maximum grip with the hand dynamometer several times in a training session, before the experiment began.

In the main experiment, the subject was instructed to assume the given hand position and hold the grip of the dynamometer. The subject held the grip tightly on the verbal signal of the experimenter and kept performing maximum strength for five seconds until the stop signal. The experimenter gave verbal encouragements while the subjects were performing the grip task. After finishing each task, the subject rated his feeling of discomfort and was given at least three minutes for a rest between each task. The subject was allowed to have a longer rest period, if it was required. The experimental order was fully randomized to avoid any order effect bias. It took about three hours for a subject to complete the experiment. The subject was required to take a balanced position and the relative positions of the feet to the holding frame were controlled in order to be consistent throughout the whole experiment.

Data treatment and analysis

For the discomfort rating, the length between the subject’s rating of their discomfort and the end point of the scale at ‘not uncomfortable’ was measured and recorded as the rate of discomfort. For both the grip force and discomfort rating, 2-way analyses of variance (ANOVA) were conducted with hand-shoulder distance and hand direction as the main factors. In the ANOVA model, statistical tests for the main factors and their interaction effect were performed according to the method of within-subject design of experiment. Duncan’s multiple range tests were conducted for the significant main effects at the significance level of 0.05. SAS (version 9.1) was used in the statistical analyses.
Results

Table 1 shows the results of the ANOVA on maximum grip strength and discomfort rating. The main effects of hand direction and hand-shoulder distance on grip strength and discomfort were statistically significant (p<0.05), and their interaction effect on discomfort was statistically significant (p<0.05). Maximum grip strength showed no significant interaction between the two main factors (p=0.39).

Table 1. Results of ANOVA for maximum grip strength and discomfort rating

<table>
<thead>
<tr>
<th>Sources of variation</th>
<th>Degree of freedom</th>
<th>Maximum grip strength (kgf)</th>
<th>Discomfort rating</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F</td>
<td>p</td>
<td>F</td>
</tr>
<tr>
<td>Hand direction (HD)</td>
<td>4</td>
<td>3.11</td>
<td>0.016**</td>
</tr>
<tr>
<td>Hand-Shoulder distance (HSD)</td>
<td>2</td>
<td>52.69</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>HD×HSD</td>
<td>8</td>
<td>1.06</td>
<td>0.391</td>
</tr>
</tbody>
</table>

*statistically significant at α=0.01, **statistically significant at α=0.05

Table 2 shows the mean values of maximum grip strength and discomfort ratings for different hand directions and hand-shoulder distances, and the results of the post-hoc tests. The mean maximum grip strength increased as the angle of hand direction increased from 0º to 135º while the mean maximum grip strength of the shoulder angle of 180º was slightly lower than that of the shoulder angle of 135º. Duncan’s multiple range test showed that the mean maximum grip strengths at over 90º of hand direction were significantly higher than those at under 90º of hand direction (p<0.05). The mean maximum grip strength increased as hand-shoulder distance increased. The post-hoc test showed that the mean maximum grip strengths at each distance were significantly different (p<0.05).

The discomfort ratings showed the lowest mean value when the hand-direction angle was 90º and the rating increased as the angle increased or decreased from 90º. The discomfort rating differences were all significant (p<0.05), except the hand-direction angles of 0º and 45º. The discomfort ratings also showed significant increase as the hand-shoulder distance decreased from 100% to 50% of AR (p<0.05).

Table 3 shows the mean maximum grip strength and discomfort ratings at different hand positions. When the elbow was fully extended (i.e. in the condition of 100%AR of hand-shoulder distance), maximum grip strength at different hand directions did not vary much. It ranged from 42.5kgf at 0º of hand direction to 43.1kgf at 135º of hand direction. When the hand-shoulder distance was 75% of arm reach, maximum grip strength increased as the angle of reach direction increased from 0º to 135º. In 50%AR of hand-shoulder distance, maximum grip strength showed the lowest value of 37.5kgf at 45º of hand direction, and it increased as the angle increased from 45º, with the highest value of 39.7kgf at 180º of hand direction.

When the hand-shoulder distances were 50% and 75% of AR, discomfort ratings showed similar pattern of variation. The discomfort ratings decreased as the hand-direction angle increased from 0º to 90º and then increased as the hand-direction angle increased from 90º to 180º. The difference between 75%AR and 50%AR of hand-shoulder distances was that the highest values were found at different hand directions. The highest values of the discomfort ratings were found in the 75%AR condition. In the condition of 100%AR, discomfort ratings showed relatively low values in 0–90º of hand direction as compared to those of over 135º of hand direction.

Table 2. Mean values of maximum grip strengths and discomfort ratings for different hand directions, and the result of Duncan’s multiple range tests

<table>
<thead>
<tr>
<th>Factors</th>
<th>Levels</th>
<th>Maximum grip strength (kgf)</th>
<th>Discomfort rating</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (SD)</td>
<td>Duncan’s test*</td>
<td>Mean (SD)</td>
</tr>
<tr>
<td>Hand directions</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0º</td>
<td>40.3 (8.5)</td>
<td>B</td>
<td>47.4 (26.8)</td>
</tr>
<tr>
<td>45º</td>
<td>40.4 (8.6)</td>
<td>B</td>
<td>44.8 (24.1)</td>
</tr>
<tr>
<td>90º</td>
<td>40.9 (7.8)</td>
<td>A B</td>
<td>39.1 (22.1)</td>
</tr>
<tr>
<td>135º</td>
<td>41.6 (8.4)</td>
<td>A</td>
<td>43.3 (22.2)</td>
</tr>
<tr>
<td>180º</td>
<td>41.3 (9.1)</td>
<td>A</td>
<td>48.6 (24.5)</td>
</tr>
<tr>
<td>Hand-shoulder distance</td>
<td>50%AR</td>
<td>38.6 (8.3)</td>
<td>C</td>
</tr>
<tr>
<td>75%AR</td>
<td>41.3 (8.3)</td>
<td>B</td>
<td>42.1 (20.6)</td>
</tr>
<tr>
<td>100%AR</td>
<td>42.7 (8.3)</td>
<td>A</td>
<td>35.1 (22.1)</td>
</tr>
</tbody>
</table>

*Result of Duncan’s multiple range test. No significant differences among same characters at α=0.05. A>B>C.

Discussion and conclusion

The maximum grip strength and discomfort ratings were measured at various hand positions, which were defined by the distance of the hand from the shoulder joint and the direction of the line from the shoulder to the hand. The maximum grip strength significantly increased as the hand-direction angle increased. The grip strengths with the hand-direction angles over 90º, (i.e. the hand is over the shoulder height), were higher than those with the hand-direction angle under 90º, though the difference was less than 1.3 kgf.

According to other studies that have tried to investigate the effect of shoulder flexion angle on grip strength, there seems to be a moderately positive relationship between the
grip strength and the shoulder angle, though the increase of the grip strength was not remarkable. In these two studies, the subjects maintained the elbow fully extended and the wrist in the neutral position at various shoulder flexion angles, which is the same condition of 100%AR hand-shoulder distance in the current study. In the 100%AR condition, the grip strength showed no significant difference among different shoulder flexion angles, though slightly higher values of grip strength were shown in 135° and 180° of shoulder angle as compared to the lower angles of the shoulder angle. Considering that grip strength did not vary much as the shoulder angle varied in the previous studies, the results of this study suggest similarity with previous work in this area, even though no statistical significance among different shoulder flexion angles and grip strength was found in the current study.

In the 75%AR and 100%AR hand distances, grip strength increased as the shoulder angle increased. It is noteworthy that there are some different results in the highest and lowest grip strengths between two hand-shoulder distances. In the 75%AR distance, the direction of 180° of shoulder angle appeared to make the subject feel uncomfortable to grip with maximum force, due to the upper extremity posture. In the 50%AR distance, the subject seemed to feel uncomfortable, due to the abducted upper arm and deviated wrist posture.

Ratings of discomfort at various hand positions also showed significant differences. Though it is not perfectly shown, the discomfort almost increased as the grip strength decreased. These results showed that subjective ratings can be a reliable measure for the evaluation of physical exertions.

Maximum grip strength significantly decreased as the hand-shoulder distance decreased in all hand directions. The decreasing quantity of maximum grip strength from 75%AR to 50%AR of hand-shoulder distance was larger than that from 100%AR to 75%AR. It seems that the decrease of maximum grip strength is closely related to the upper-limb postures, particularly to the wrist posture. As the distance decreases, the subject had to abduct his upper arm, flex his elbow and bend his wrist to the ulnar direction. Although the angles of elbow flexion and ulnar deviation of the wrist varied according to the subjects, the non-neutral postures seem to affect exerting maximum strength. From these results, we can presume that when a work task requires a worker to make a grip force in the area of less than 75% of AR, the maximum force he or she can perform is less than 90% of their maximum grip strength. Therefore, in designing a work or workplace, a distance more than 75% of AR should be provided for a gripping task or the requiring force should be reduced more than 10% from the normal condition.

Because the hand position for maximum gripping was only controlled by two factors (i.e. the relative distance and direction of the hand to the shoulder), the upper limb's joint angles were slightly different among the subjects' for the same hand position, except for the 100%AR hand-shoulder distances. The upper-limb joint angle included the joint angles in the shoulder, the elbow and the wrist. In the 100%AR distances, the subjects’ maintained the wrist in a neutral position, the elbow fully extended, and the upper arm flexed, as much as given angles. In this study, the angles of each subject were not measured, which make it difficult to analyse the relationship between the joint angles and the reduction of grip strength. In the future, it would be necessary to measure the joint angles and to try to evaluate the muscular activities together.

The subjects participated in the experiment were all males and most of them were university students. The grip strength data from these subjects may not be able to be generalized to the working population and would need to be used with caution in the application to work design. However, the results of this study showed the different effects of hand position on grip strength and it is expected that the results of this study will be able to inform both the design of work and workspace.

Acknowledgement

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References


