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Dependence of grip strength on shoulder position and its implications for ergonomics practice

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Abstract

Grip strength (GS) variability due to positional changes in the upper extremity joints is of importance while designing workstations and work methods. This study was conducted to analyze the GS variations due to positional changes at shoulder joint when some important variables were under control. The GSs of dominant and nondominant hands were measured in eight shoulder (0°, 45°, 90°, and 135° of flexion and abduction) and standard test positions (STP). One hundred and thirteen subjects 20–30 years old completed the study. At the dominant side, no significant difference was observed in the pairwise comparisons between STP and the others. Maximum and minimum GSs were obtained in 0° abduction and 45° flexion and abduction, respectively. At the nondominant side, GSs were significantly lower ($p < 0.001$) in the corresponding test positions and demonstrated more variability. The findings of this study can contribute to the available knowledge to guide occupational ergonomists in their practices.

KEYWORDS

grip strength, human performance, measurement, work design, workers' health

1 | INTRODUCTION

Grip strength (GS) is utilized for specific purposes in ergonomics, as well as medicine and rehabilitation (Bao & Silverstein, 2005; MacDermid, 2005; Uğurlu, Özkan, & Özdoğan, 2008). In ergonomics, it is used for quantifying force exertion levels required for a specific task (Bao, Spielholz, Howard, & Silverstein, 2009), deciding on the suitability of a worker for a particular job (Harbin & Olson, 2005), evaluating the effectiveness of worksite health promotion interventions (Sertel, Üçsular, & Uğurlu, 2016), and designing hand tools (Cakit, Durgun, Cetik, & Yoldas, 2014; Kong & Lowe, 2005), work methods (Chaffin, 1997; Finneran & O'Sullivan, 2010) and workstations (Bhatt & Sidhu, 2012; Hallbeck et al., 2010).

While designing an industrial workstation or a work method, primary concerns are the improvement of the equipment performance and matching the abilities of the operator with the task requirements. An appropriate balance between the capabilities of workers and the requirements of a task can be achieved with the application of ergonomics principles, supported by precise and up-to-date scientific information. By this way, productivities of the workers and the total system can be optimized. In addition, workers' physical and mental well-being, job satisfaction, and safety can be improved (Das & Sengupta, 1996). All requirements of a particular job should be considered for a successful work task design (Konz & Johnson, 2008). This also includes effective and safe manipulation of the instruments or tools within the reaching area of the hands. However, a worker may not sustain initial adequate grip force throughout various arm positions. If the worker's GS falls below a critical level not adequate to effectively stabilize an instrument or tool in his hand, he can try to compensate it with abnormal and sometimes risky movement patterns. Muscle fatigue may further exacerbate this situation. For example, a car assembly worker lifting parts from shoulder level to the overhead or mounting them located at various heights with a wrench can encounter with these problems. This can result in acute injuries or cumulative trauma disorders over an extended period of time.

There are many factors having the potential of affecting GS performance. Some of these are individual (Hanten et al., 1999;

Morse, Jung, Bashford, & Hallbeck, 2006; Nicolay & Walker, 2005) while others are related to testing methodology (Kattel, Fredericks, Fernandez, & Lee, 1996; Richards, 1997; Richards, Olson, & Palmiter-Thomas, 1996). How the changes in body posture and upper extremity joint positions influence the maximum GS scores have been the subject of many studies. In these studies, effects of the positional changes in the forearm (Richards et al., 1996), elbow (Kumar, Parmar, Ahmed, Kar, & Harper, 2008; Ng & Fan, 2001), and shoulder joints (Dabholkar, Pal, & Yardi, 2015; Kattel et al., 1996) have been investigated. In addition, GS variations due to combined movements of more than two upper extremity joints (Kong, 2014; Parvatikar & Mukkannavar, 2009) and postural changes (Richards, 1997) have also been searched.

Most of them have demonstrated that the GS performance can change depending on the variations in the body posture and isolated or combined positions of upper extremity joints. Several possible mechanisms have been held responsible for these changes. The significantly different GS performances among various combinations of the elbow, forearm, and wrist positions were linked to the variations in the length-tension characteristics of the muscles directly involved with the production of grip force (Kattel et al., 1996; Richards et al., 1996). However, the changes in GS performance due to different body postures, particularly the upper extremity geometry being maintained were explained with neural mechanisms. It was suggested that variations in the level of arousal due to altered peripheral impulses might reflexively or directly affect the mechanisms involved in the production of grip force (Balogun, Akomolafe, & Amusa, 1991; Richards, 1997). But, methodological differences among these studies, apparently insufficient number of subjects (Kattel et al., 1996; Roman-Liu & Tokarski, 2002), testing only one side of body (Kong, 2014; Parvatikar & Mukkannavar, 2009), analyzing performances of both sexes together (Mathiowetz, Rennells, & Donahoe, 1985; Ng & Fan, 2001), and inclusion of subjects belonging to only a particular occupational category (Balogun et al., 1991; Kuzala & Vargo, 1992) cause difficulty in interpreting the effects of postural and positional changes on the GS performance.

Located in the proximal end of the arm, the shoulder joint is responsible for the positioning of the hand in space during the performance of open-chain activities. The effects of variations at shoulder position on GS performance have been investigated in several studies (Dabholkar et al., 2015; Kong, 2014; Parvatikar & Mukkannavar, 2009). The general result of these studies is that GS performance can change in response to variations in shoulder position even when a particular elbow, forearm and wrist geometry, and body posture are maintained. However, shoulder articulation differentiates from the other upper extremity joints in terms of its relation with muscles involved in the production of GS. The most proximal origin for these muscles is just above the elbow joint (Lippert, 2011). That means that length-tension characteristics of these muscles are independent of shoulder joint position. Therefore, it is difficult to explain these observed changes with only variations in the length-tension characteristics of the grip-related muscles.

Another issue is that statements of many studies in this field are based on findings from only the dominant or right hand. However, many work task and workstation designs also consider the use of nondominant side and hand tools are designed in a way that they should be able to be used by either hand (Konz & Johnson, 2008). Therefore, it is important to know how shoulder position affects the GS performance not only at the dominant but also at the nondominant side. A detailed literature search was conducted on PubMed, Google Scholars, CINAHL, and national scientific databases with keywords related to the scope of the study and its purpose. Further searches were conducted on the reference lists of the literature found in the keyword search. There was a strong evidence that dominant hand was stronger than the nondominant one in the related literature. However, this was based on the comparisons between the scores obtained in only one arm posture. In general, that was the standard test position (STP; Fess, 1992). Therefore, this statement cannot be generalizable to all other arm positions. Although dominant and nondominant hands may differ in terms of some components of muscular performance (Morse et al., 2006; Nicolay & Walker, 2005), GS imbalance in favor of dominant hand cannot be explained only with the variations between the contraction characteristics of the grip-related muscles at each body side. There are also strong suggestions that distinct neural control mechanisms are used for the dominant and nondominant hands (Coelho, Przybyla, Yadav, & Sainburg, 2013; Sainburg & Kalakanis, 2000). In addition, little information is available on how these neural mechanisms work in different arm geometries.

In summary, although the GS is a classical issue in ergonomics, it still deserves investigation while considering the abundance of factors having the potential of affecting its performance and complicated interactions among them. This study was conducted to test the hypothesis that the maximum static GS performance in response to positional variations at the shoulder joint does not change at both sides of the body while some variables known to affect GS performance are under control.

2 | METHODS

2.1 | Study design and subjects

The study design was cross-sectional. This study was conducted at İstanbul Bilim University as part of an MSc thesis project. The approval for the study was obtained from the Ethics Committee of Istanbul Bilim University Faculty of Medicine. Recruitment period was between January and May 2012. To minimize the effects of gender and age variables on the GS performance, only females between the ages of 20 and 30 years were recruited. A priori power analysis was conducted to calculate the minimum number of subjects (MNS). As the normative data was not available for the studied population, the average GS score obtained at the STP from the first 30 subjects was referenced for the priori power analysis. The MNS to analyze the GS changes due to various arm positions (within-subjects effects) at the power (1-β err prob) level of 0.85 was found to be 18 for each side of the body (dominant hand: partial $\eta^2 = 0.286$, effect size = 0.632, nondominant hand: partial $\eta^2 = 0.365$, effect size = 0.758, α err prob = 0.05, the correlation among repeated measures = 0.8). The MNS to compare GS means between dominant and nondominant hands at the same power level for the two-tailed test was calculated as 94 (effect size = 0.312, α err prob = 0.05, correlation between groups = 0.8). The larger MNS value (i.e., 94) was referenced for the recruitment of an adequate number of subjects.

The recruitment locations were selected to include subjects with different occupational characteristics and consisted of university buildings, a student dormitory, a state hospital, and industrial and managerial workplaces. Poster announcements and verbal invitations were used to recruit eligible subjects. All volunteers were requested to read and sign the consent form. The exclusion criteria were as follows: any previous diseases, injuries, or conditions resulting in permanent limitations in upper extremity functions; any congenital malformation and restricted range of motion in any upper extremity joints; inability to accomplish usual daily tasks; any chronic diseases and conditions known to affect musculoskeletal performance, such as arthritis, diabetes, and asthma; entrapment neuropathies, such as carpal tunnel syndrome. In addition, subjects experiencing acute pain and excessive fatigue during measurements or having difficulty in implementing the test instructions accurately were excluded from the study. The data of the excluded subjects were not included in the statistical analysis.

2.2 | Evaluation and measurements

Demographic information was obtained. The body height and weight were measured. Body mass index (BMI) (kg/m^2) was calculated for each patient. Arm, forearm, and hand lengths were measured with a tape measure. Hand and wrist widths were measured with a caliper. Handedness was questioned. For subjects unsure about their dominant hands, hand dominance was determined by the hand they used to write with. Occupations and leisure-time activities of the participants were questioned.

The maximum static GS was measured with a calibrated standard Jamar dynamometer (Asimov Engineering, Los Angeles, CA). The same dynamometer was used throughout the study. Before starting the measurements, each subject was trained on the test protocol. All tests and training were supervised and conducted by one author of the study between the hours of 10.00 and 16.00.

The GS measurements were taken at nine different arm positions: one in the STP (Fess, 1992) and the others in 0°, 45°, 90°, and 135° shoulder flexion and abduction. The test protocol proposed by the American Society of Hand Therapists (ASHT) was used for all test positions (Fess, 1992). Measurements at all test positions were taken while subjects were sitting upright on a chair without arm rests. Elbow was in full extension in all except the STP. The forearm was in the neutral rotation and wrist joint was in 20–30° extension in all test positions. The selected forearm and wrist positions were in accordance with the test protocol proposed by the ASHT (Fess, 1992). O'Driscoll et al. (1992) demonstrated that a minimum of 25° of wrist extension is required for optimum grip strength. The whole arm of the subject was externally rotated at the tested body side so that palm faced anteriorly to enable shoulder abduction above 90°. The neutral rotation of the forearm with respect to the upper arm was attempted to be preserved. The measurements were started with the STP and continued with those in shoulder flexion or abduction for consecutive subjects. The dominant side was tested first in all test positions. After completing all measurements in a direction at the dominant side, those in the same direction at the nondominant side followed these. To control fatigue, the order of shoulder angles was randomly assigned to one of the four predetermined sequences. Each patient was requested to squeeze the handle as hard as possible. The handle of Jamar dynamometer was set to the second notch for all patients. Each trial continued for 3 s. The mean of three trials was recorded as the test result. This is the preferred method among practitioners (Mathiowetz, Weber, Volland, & Kashman, 1984). It was demonstrated that there was a consistent trend for the mean of three trials to produce the highest reliability (Hamilton, Balnave, & Adams, 1994). Two- and three-minute rests were allowed between each trial and each shoulder position, respectively. The dynamometer was reset to zero before each trial and read to the nearest increment. If a patient was not able to produce a stable grasping during squeezing, another chance was given to repeat the test after a resting period of about 2 min.

A poster with reference lines was used to provide the angular accuracy for shoulder positioning (Figure 1). The conformity with the upper extremity positions was visually controlled during the measurements.

2.3 | Statistical analysis

Test means were stratified by handedness and arm positions and reported as mean ± *SD* and 95% confidence intervals. Repeated measures of analysis of variance (ANOVA) was used to analyze the effect of different arm positions on the GS performance. Post hoc tests using the Bonferroni correction have been conducted. Paired-samples *t* test was used to compare GS scores between the dominant and nondominant hands. The level of significance was set at $p < 0.05$. Repeated measures ANOVA and paired-samples *t* test were performed using SPSS 20.0 Software (SPSS Inc., Chicago, IL). Priori and post hoc power analyses were conducted to compute total sample sizes and achieved power levels, respectively. G*Power Software (Düsseldorf, Germany) was used for power analyses.

3 | RESULTS

A total of 133 subjects were recruited. Twelve of them were excluded from the study due to at least one of the items stated in the exclusion criteria. Afterward, eight subjects left the study due to acute pain, fatigue, unwillingness, or difficulty in cooperation. One hundred and thirteen subjects eventually completed the study. Post

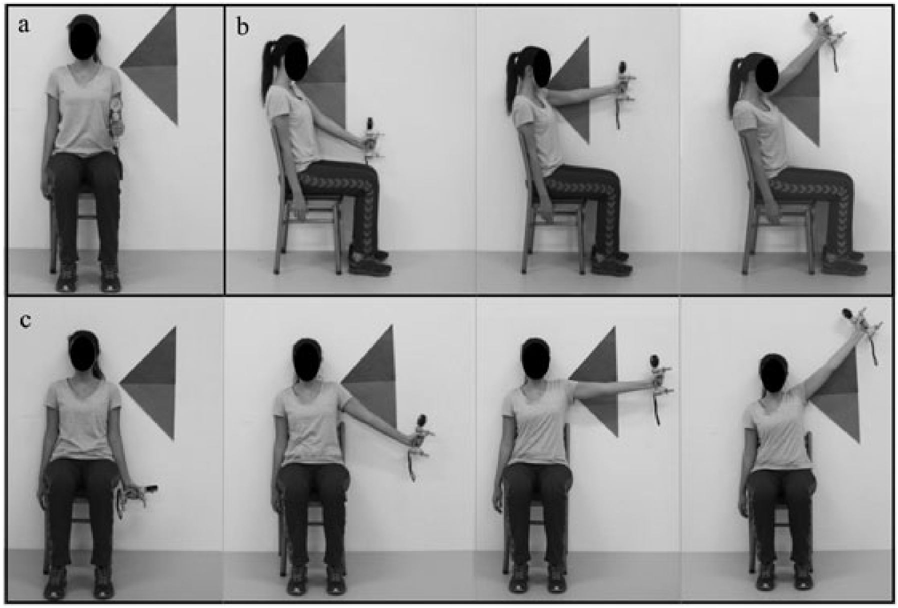

FIGURE 1 (a) Standard test position, (b) positioning of the arm during measurements in shoulder flexion, (c) positioning of the arm during measurements in shoulder abduction

hoc power analysis to compute the achieved power has yielded the following results. Repeated measures ANOVA: α err prob = 0.05, the correlation among repeated measures = 0.8, dominant side: partial $\eta^2 = 0.254$, effect size = 0.583, 1-β err prob = 1.0, nondominant side: partial $\eta^2 = 0.349$, effect size = 0.732, 1-β err prob = 1.0. Paired-samples *t* test: effect size = 0.517, α err prob = 0.05, the correlation between groups = 0.8, 1-β err prob = 0.99. These achieved power levels were higher than those aimed at the beginning of the study.

About 8% of the participants were left-handed. The mean BMI value (22.5) was in normal range. Occupations of the participants were representatives of different jobs having strength ratings from sedentary to heavy and included office workers, students, teachers, academic staff, cleaning and maintenance workers, and various health professionals. None of the participants reported regular engagement in sport activities. Characteristics of the subjects are shown in Table 1.

TABLE 1 Subject characteristics

Characteristics	Total subjects
Number of subjects	113
Gender of subjects	Female
Age (yr)[a]	24.6 ± 3.42
Age interval (yr)	20–30
Hand dominance (n)	
Right	104
Left	9
Physical properties of the subjects[a]	
Body height (cm)	163 ± 6.32
Body weight (kg)	60.2 ± 10.5
BMI (kg/m^2)	22.5 ± 3.59
Arm length (cm)	
D	71.52 ± 3.45
ND	71.25 ± 3.44
Forearm length (cm)	
D	43.09 ± 2.1
ND	43.04 ± 3.73
Hand length (cm)	
D	18.63 ± 0.88
ND	18.61 ± 0.88
Wrist width (cm)	
D	5.37 ± 0.32
ND	5.33 ± 0.33
Hand width (cm)	
D	7.68 ± 0.36
ND	7.59 ± 0.34

Note. BMI: body mass index; D: dominant side; ND: nondominant side; SD: standard deviation.
[a]Shown as the mean ± *SD*.

3.1 | Dominant side

Average GS scores are demonstrated in Table 2. Maximum GS score (25.1 kg) was obtained in 0° abduction position. The lowest score (24.2 kg) was at 45° flexion. The GS scores, in general, were very close to each other in all tested positions at this body side. The difference between the maximum and minimum scores for all test positions was only 0.92 kg. This was 0.63 kg for the flexion and 0.77 kg for the abduction positions. The mean GS scores obtained in abduction and flexion positions were almost identical (24.84 and 24.64 kg, respectively). Although, further analysis of the data revealed that some significant differences, $F(8, 896) = 4.911$, $p < 0.0001$; were available between some of these positions, this was only limited to the two positions (45° flexion vs. 90° flexion and 45° flexion vs. 0° abduction; Figure 2). The GS score obtained in the STP did not significantly differ from those at the other test positions.

TABLE 2 Average grip strength scores (kg)

	Dominant hand				Nondominant hand				
Test positions	Mean	*SD*	Range (min-max)	95% CI of the Mean	Mean	*SD*	Range (min-max)	95% CI of the Mean	% Difference
Standard position	24.38	4.76	12.67–36.67	23.50–25.27	22.50	5.25	10.67–36.67	21.52–23.48	8.4
0° flexion	24.75	4.52	14.33–38.00	23.91–25.60	23.36	4.83	10.67–38.00	22.47–24.27	5.9
45° flexion	24.20	5.10	13.00–38.67	23.25–25.16	22.81	5.12	10.67–36.67	21.86–23.76	6.1
90° flexion	24.83	5.01	12.00–37.00	23.90–25.77	23.09	5.09	11.67–37.67	22.14–24.04	7.4
135° flexion	24.76	5.02	13.00–36.67	23.82–25.70	23.32	5.23	11.67–38.33	22.35–24.30	6.4
0° abduction	25.12	4.97	13.67–38.67	24.19–26.04	23.39	4.86	12.00–37.00	22.49–24.30	7.2
45° abduction	24.35	5.28	10.67–42.00	23.36–25.34	22.38	5.21	11.33–37.00	21.42–23.36	8.9
90° abduction	24.89	5.01	11.67–40.00	23.96–25.83	23.13	5.08	11.33–38.00	22.19–24.08	7.8
135° abduction	25.01	5.07	13.33–40.67	24.06–25.96	23.15	5.09	12.00–39.00	22.20–24.10	7.7

Note. CI: confidence interval; *SD*: standard deviation.

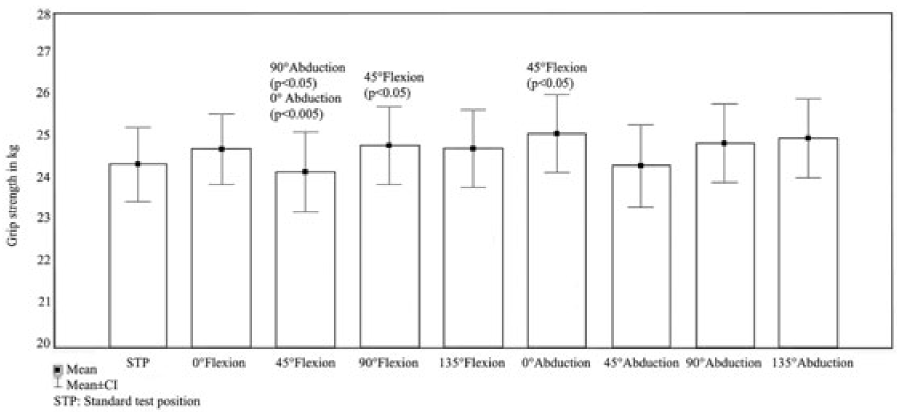

FIGURE 2 Graphical representation of grip strength scores in the test positions and comparison among them at the dominant side

3.2 | Nondominant side

In general, GS scores were lower than those at the dominant side (Table 2). The maximum and minimum scores were obtained in 0° (23.39 kg) and 45° (22.38 kg) abduction positions, respectively. Similar to that observed in the dominant side, GS scores were close to each other. The difference between the maximum and minimum scores was 1.01 kg. However, the variability of the scores was little higher in the abduction direction (1.01 kg vs. 0.55 kg). The mean GS scores obtained in the flexion and abduction positions were very close to each other (23.14 and 23.01 kg, respectively). Further analysis of the data revealed that significant differences were also available between some scores at that body side, $F(8, 896) = 3.482$, $p < 0.0001$; Figure 3). Unlike to that observed at the dominant side, significant differences were observed in seven pairwise comparisons. The GS score at 45° abduction position was significantly lower than those at other five positions. The GS score obtained at the STP was significantly lower than those of 0° abduction and 135° flexion.

3.3 | Comparison of the dominant and nondominant sides

The average GS scores on the dominant side were significantly higher in all test positions (Table 3). The maximum GS difference (1.96 kg) between the corresponding positions of both extremities was observed in 45° abduction. The STP followed this (1.88 kg). The maximum and minimum differences between the dominant and nondominant hands were observed in 45° abduction (8.4%) and 0° flexion (5.9%) positions, respectively. The GS differences between the dominant and nondominant hands were more variable in shoulder abduction, ranging 7.2–8.9% versus 5.9–7.4% in flexion.

4 | DISCUSSION

The hypothesis of the study was that the maximum static GS performance was independent of the positional changes at shoulder joint at both sides of the body while some variables known to affect GS performance were under control. In general, it was not rejected at the dominant side. The findings of the study were discussed in comply with the organization of the results section.

4.1 | Dominant hand

The GS scores at each position were very close to each other at this body side. Indeed, only two pairwise comparisons, including the lowest score obtained at 45° flexion position, were able to exceed the significance level. Only four research were found in the literature,

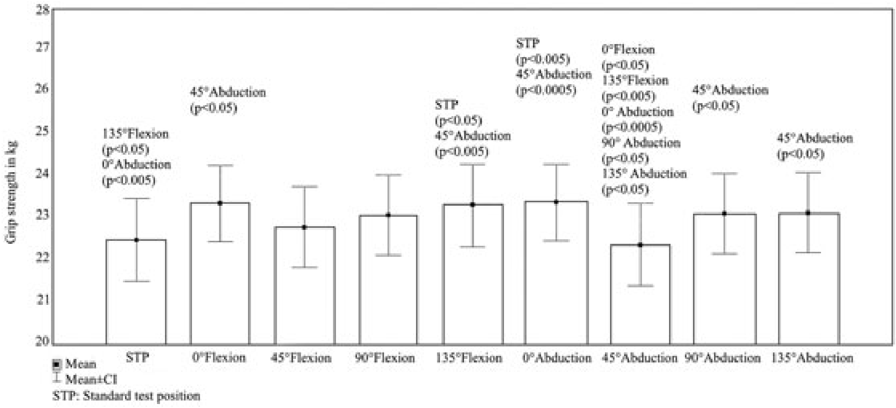

FIGURE 3 Graphical representation of grip strength scores in the test positions and comparison among them at the nondominant side

TABLE 3 The comparison of dominant and nondominant hand strengths (paired-samples *t* test)

	Paired differences (D-ND)				
Test positions	Mean	*SD*	*SEM*	95% CI of the difference	*p*
Standard position	1.88	2.27	0.21	1.46–2.31	0.001
0° flexion	1.38	2.47	0.23	0.92–1.84	0.001
45° flexion	1.39	2.45	0.23	0.94–1.84	0.001
90° flexion	1.74	2.31	0.22	1.31–2.17	0.001
135° flexion	1.44	2.30	0.22	1.00–1.87	0.001
0° abduction	1.73	2.25	0.21	1.31–2.15	0.001
45° abduction	1.96	2.55	0.24	1.49–2.44	0.001
90° abduction	1.76	2.53	0.24	1.29–2.23	0.001
135° abduction	1.85	2.31	0.32	1.43–2.29	0.001

Note. CI: confidence interval; D: dominant side; ND: nondominant side; SEM: standard error of mean.

whose methodologies similar to the present study for the tests in the flexion direction. In one of them, Su, Lin, Chien, Cheng, and Sung (1994) compared GS scores obtained in four upper extremity positions (0°, 90°, and 180° flexion and STP). Subjects were standing and holding their elbow in full extension during measurements. Age interval of them was wide (29–69 years) and their occupational characteristics were not mentioned. They found that GS score at 90° shoulder flexion was significantly higher than those in 0° and STP, and demonstrated a decline from 180° to 0°. Although these results were valid for female subjects, a similar pattern was also observed for the males in their studies. Similarly, Kong (2014) reported higher GS score in 90° shoulder flexion with full elbow extension compared with those in 45° and 0° (284, 266, and 265 N, respectively) in males. Another important finding of the study by Su et al. (1994) was that age and gender characteristics of their subjects were important variables that could affect the GS performance. Similar results were also reported by Roman-Liu and Tokarski (2002). Their study included only nine male participants aged 20–24 years. Although not significantly different ($p = 0.059$), GS score at 90° flexion was higher than that at the STP. In contrary to the findings of the studies by Su et al. (1994), Roman-Liu and Tokarski (2002) and Kong (2014), Rajendran, Thamburaj, Syed, Abudaheer, and Thiruvenkadam (2016) reported that neutral shoulder flexion led to higher GS scores when compared with 90° in females. The elbow was in full extension in both positions and the GS difference was more than twice (41.67 vs. 17.73 kg). Largely, the findings of the present study were not in agreement with those of these studies. As stated in the introduction section of this paper, there are many factors that can affect GS performance. Although the data of each gender were separately analyzed, problems related with the sufficiency of sample size and paying not enough attention to age and occupational characteristics of the subjects were available at these studies. If we consider the deterministic effects of these factors in the GS performance, it is very difficult to say their findings can be true reflections of the positional changes at the shoulder joint.

Another important finding at the dominant side was that the GS performance at the STP was not significantly different from those at the other positions. Although not fully generalizable to all possible positions of the arm, this is the first answer to the question that can GS performance measured in compliance with the standard test protocol be used for the other arm positions? Strength-tension characteristics of some grip-related muscles (e.g., m. flexor digitorum superficialis, m. extensor carpi radialis longus and brevis) can change at the STP. As these muscles have their origins in distal humerus the 90° flexion of elbow joint can alter their tension. Indeed, there are some signs of dependency of the GS performance on the elbow joint position (Kuzala & Vargo, 1992; Mathiowetz et al., 1985; Ng & Fan, 2001). However, the results of these studies are controversial.

Kattel et al. (1996) investigated the effect of shoulder abduction on the GS performance on 15 male subjects. They compared neutral shoulder position with 20° abduction position. Descriptions of the wrist and elbow angulations and forearm position were not clear or available in their paper. They found that the GS at neutral shoulder position was significantly higher than that at 20° abduction. The different test positions make it impossible to directly compare their findings with those of the present study.

4.2 | Nondominant hand

To our knowledge, this was the first study investigating the effects of positional changes at the nondominant shoulder joint on GS performance.

Similar to those observed at the dominant side, GS scores at 45° flexion and abduction positions were among the least. Variability of the scores among the test positions was little higher than those at the dominant side (1.01 vs. 0.92 kg). In general, it is hard to say that the study hypothesis is rejected at this body side. However, the majority of the pairwise comparisons (five of seven) demonstrating significant differences contained the least GS score obtained at 45° abduction. In other words, the distribution of them was not balanced among the test positions and specific to a particular position in general.

Nevertheless, some muscular and neurologic factors still might have been responsible for the differences between the dominant and nondominant hands (Coelho et al., 2013; Nicolay & Walker, 2005; Sainburg & Kalakanis, 2000). Some associations have been demonstrated between the hand grip and general upper extremity strengths (Rantanen, Pertti, Kauppinen, & Heikkinen, 1994). The lower GS scores can be associated with relatively weaker upper extremity muscles at the nondominant side. This may result in increased demand on shoulder muscles compared with the dominant side to stabilize the whole arm, thereby, reducing the concentration on grip force production, even though CNS tries to focus on the function instead of individual control of upper extremity joints. The amount of load on the shoulder joint may be an important factor. Shoulder joint tries to stabilize the whole arm against the total weights of the arm and the instrument being grasped. Although the weight of the Jamar dynamometer is not much while it is held in the STP, its rotating effect on the shoulder joint could be large due to the extended arm position. Relatively weaker shoulder muscles at the nondominant side may be at disadvantage to counterforce this additional weight.

Forty-five degree flexion and abduction were among the weakest positions at both sides. There may be a relationship between increased muscle activity to stabilize the shoulder joint and reduced GS at this angulation. Muscles playing a role in shoulder stabilization may be at a disadvantage in midrange and more force production may be demanded from them. "Over performing" shoulder stabilizers at this angle might reduce the concentration on the maximum GS production. Increased electromyographic (EMG) activities have been demonstrated in some components of the rotator cuff and deltoid muscles, especially during elevated arm positions (Kronberg, Nemeth, & Broström, 1990; Sporrong, Palmerud, & Herberts, 1996). However, it should be borne in mind that dynamic shoulder movements were used in most of these studies contrary to the static postures used in the present study. In the following studies, the weight of the dynamometer can also be eliminated to enlighten the relationship between probably "over performing" shoulder stabilizers and the GS performance.

4.3 | GS differences between dominant and nondominant hands

According to the findings of Hanten et al. (1999), Morse et al. (2006), and many other researchers, the dominant hand is stronger than the nondominant when tested at the STP. However, no information was available in the literature on the validity of this information for the other upper extremity positions. Findings of this study supported the common "belief" that the dominant hand is stronger than the other regardless of the arm position. However, the value of force inequality in favor of the dominant hand was not the same for all test positions. As seen in Table 2, the GS difference between the hands ranged from 5.9% to 8.9%. According to findings of the present study, the "10% rule" allegedly used in clinical practice seems to be invalid for different shoulder positions. Armstrong and Oldham (1999) warned clinicians about the applicability of this rule. The GS difference found in the present study was 8.4% at the STP, which was comparable to that (10.74%) reported by Petersen, Petrick, Connor, and Conklin (1989). The magnitude of the GS difference between the two body sides was higher in the abduction direction. Higher GS scores in abduction compared with flexion positions of the dominant side might be responsible for that and can be explained with the proximity of the frontal and scapular planes to each other. The scapular plane can be defined as the normal resting position of the scapula as it lies on the posterior rib cage at an angle of about 30° anterior to the frontal plane. Common functional activities occur on that plane (Lippert, 2011). While considering the role of dominant hand in daily activities and the proximity of these planes to each other, it is probable that GS scores in shoulder abduction will be higher than those in flexion. According to the results of an only one study (Dabholkar et al., 2015), GS performance does not differ in response to changes at shoulder positions among frontal, sagittal, and scapular planes. In the following studies, the characteristics of GS changes at various angles in the scapular plane deserve more investigation.

Recently, the number of evidence signaling that central nervous system (CNS) controls upper extremity as a whole has increased (Devanne, Cohen, Kouchtir-Devanne, & Capaday, 2002; Mason, Gomez, & Ebner, 2001; Scott, 2000). From the conventional point of view, it is in contrary to the individual control of each upper extremity segment during functional performances. This "simplification" is believed to reduce the complexity of motor control during the execution of a functional task (Mason, Gomez, & Ebner, 2002). By this way, CNS can focus on the quality of the task performance instead of the individual control of elbow, forearm, and hand segments interconnected with muscles and shoulder joint independent of the variations in the strength-tension characteristics of grip-related muscles. The findings from the dominant side may also support the idea of integrated control of upper extremity. However, this control mechanism may not be so effective at the nondominant side. Perhaps the optimum control mechanisms provided by CNS to produce the same response throughout the various shoulder elevation positions may gradually become less effective after a critical amount of loading on stabilizing muscles is reached.

4.4 | The effect of elbow position on the GS

The results of the present study also revealed findings on the effects of two elbow joint positions (i.e., 90° vs. 0° flexion) on the GS performance while the neutral rotation of the forearm was maintained. According to the results of previous studies, the role of the elbow position on the GS performance is controversial. Mathiowetz et al. (1985) demonstrated that subjects produced significantly higher GS scores with 90°

compared with 0° flexion (full extension) positions of the elbow. In contrary to the findings of them, Kuzala and Vargo (1992) reported that full elbow extension produced higher GS scores compared with 90° flexion. Ng and Fan (2001) and Kumar et al. (2008), however, stated that the GS scores were not significantly different between these two positions. Their results were also in comply with the findings of the present study.

4.5 | Implications of the results for the practice of ergonomics

The goal of occupational ergonomics is to maximize the performance of work systems found in diverse settings, such as production work and service industries. This can be accomplished by improving system performance and preventing injuries and illnesses associated with the tasks performed (Dempsey, 2003). The GS is an important input for the design of a work system requiring the use of a piece of equipment or tool. Although there are some study findings indicating that GS can change with the positional changes of the arm and body, normative data developed for specific populations at a particular arm position (Bohannon, Peolsson, Massy-Westropp, Desrosiers, & Bear-Lehman, 2006) have been used as if workers are going to work solely in a certain position. However, the results of these studies are controversial due to the reasons explained in the introduction section and limited to only the dominant hand. The findings of the present study dealing with some methodological issues not adequately addressed in the previous research in this field can contribute to the available knowledge and expected to enhance the ergonomics practice. Some examples can be given related to the practical implications of the findings: (a) If the information on maximum GS performance a worker can achieve in one of the test directions is necessary, his GS score obtained in the STP can be used at the dominant side; (b) for the tasks requiring stable grasping of an instrument with the nondominant hand, 45° abduction position should be avoided as much as possible; (c) at the dominant side, the positional changes in the elbow joint from full extension to 90° flexion is not expected to alter the grip stability. However, the same positional change at the nondominant side may affect grip performance.

4.6 | Study limitations

Although the importance of occupational characteristics has been considered, the findings of the study were not evaluated on the basis of occupations due to less number of subjects in each occupational category.

Fatigue might have affected subjects' performances. At the beginning of the study, some measures were taken to alleviate the effect of fatigue, including randomization of the test positions in each movement direction and allowing more than adequate rest periods between trials. Although Trossman and Li (1989) demonstrated that 60-s interval between trials was sufficient, at least 120-s rest period was allocated in the present study while considering the cumulative effect of fatigue. Muscle fatigue has central and peripheral components, which can be recovered in 5 min after brief high-intensity exercise (Carroll, Taylor, & Gandevia, 2016). Three trials at one side lasted about 5–6 min. While considering the findings reported by Carroll et al. (2016), this interval might be sufficient to provide enough rest for the other side. However, five subjects left the study due to general fatigue complaint in the last part of the measurements. Although this number corresponds to only about 4% of the total number of subjects involved in the measurements, it is difficult to say all the GS data are totally independent of the fatigue factor.

Measurement of GS first on the dominant side can also be criticized. Actually, it was a habit coming from the clinical practice. When measurements are taken only in the STP, the method of alternating dominant and nondominant or right and left hands after each trial can be used to reduce the effect of fatigue on the GS performance. This method could not be utilized in the present study. As it would require repositioning of the subjects and the poster at each trial for the measurements obtained in shoulder flexion and abduction positions. On the basis of the findings conveyed in the previous paragraph, it can also be concluded that the effect of first-tested hand preference must have been reduced. However, randomization of the first hand to be tested could be an additional method to further reduce concerns about this issue.

Neutral rotation of the forearm might be somewhat lost while trying to hold the whole arm in some external rotation. Although it was demonstrated that the positional changes between forearm supination and neutral rotation did not produce significant changes in the GS scores (De Smet, Tirez, & Stappaerts, 1998; Rantanen et al., 1994), methodological differences between the studies does not completely eliminate the possibility that the results have not been affected in some subjects.

5 | CONCLUSIONS

The GS is a commonly used physical parameter in ergonomics as well as medicine and rehabilitation. The GS performance of workers is an important input for the designs of workstations and work plans and predicting their physical capacities. There are many factors having the potential of affecting the GS performance of a worker. Postural and positional changes are among these factors. However, it is hard to make inference about their effects on the GS capacity of a worker by using the available literature. Considerable methodological differences among the studies and insufficiency in controlling the factors known to be effective on the GS performance complicate the interpretation and utilization of the findings of the previous studies in this field. To our knowledge, this study is unique in terms of consideration of these factors together and the inclusion of the nondominant hand.

The hypothesis that the maximum static GS performance was independent of the positional changes at the shoulder joint while some variables known to affect the GS performance were under control at the dominant side was not rejected. Although a somewhat different pattern was observed at the nondominant side, the number of pairwise comparisons demonstrating significant differences was limited. The idea that CNS controls the upper extremity as a whole instead of focusing on the individual control of each joint may be a factor. However, its effectiveness can decay at the nondominant side due to relatively weaker shoulder stabilizers. The EMG activities of the shoulder and forearm muscles at the test positions can be investigated to provide further evidence for this.

The findings of the present study can contribute to the available knowledge to guide further studies and be used by occupational ergonomists in their practices. However, some situations should be taken into account during the transferring of the results to the work practice. For example, the findings of the present study have been obtained in the laboratory environment and adequate resting intervals were provided most of the time. Real work conditions may differ from those of a laboratory environment and workers have to work until the signs of fatigue occur.

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