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A Biomechanical Assessment of Isometric Handgrip Force and Fatigue at Different Anatomical Positions

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The present work examined the handgrip force at different anatomical positions for both hands. Anthropometrics, handgrip force, and fatigue were obtained from a representative sample of 20 males randomly selected from the German Jordanian University students. The hand dynamometer first was calibrated with respect to the volunteer's maximal grip strength, and he was then asked to squeeze maximally until the grip force decreased to 50% of its maximal due to fatigue; this test was performed for both hands at different anatomical positions with 2 min of rest for recovery of muscle function. The results showed differences in the handgrip force between subjects of the same anatomical positions and for the different anatomical positions, differences in the time for 50% of the force maximal for both right hand and left hand, higher time required to achieve 50% of maximal handgrip force for the nondominant hand, and maximal handgrip force was obtained when arm adduction with 90 degrees forward at the elbow joint. Recommendations for future work are to measure fatigue time at different percentages, 25%, 50%, 60%, and 75% of maximal force and to investigate the factors affecting handgrip force over a larger sample.

Keywords: actin and myosin, anthropometric parameters, nutrition

Biomechanics is a multidisciplinary activity that requires knowledge from physical and engineering sciences, along with knowledge of biological science (Chaffin et al., 2006). Skeletal muscle forms almost 50% of the body weight and consists of muscle fibers, connective tissue, and nerve elements. An average human muscle fiber is 5 cm long at rest and .5 mm in diameter, and muscles can contract isometrically (muscle generates force without changing its length, e.g., the muscles of the hand as they generate sufficient force to prevent an object from being dropped) or isotonically (constant internal force is produced and the muscle shortens).

Therapists, physicians, engineers, and coaches are interested in hand strength measurement as it establishes the baseline from which they assess their treatment, designing the hand and in evaluation of athletics performance. Muscle strength is important for success in many sports and games, an element of motor performance and health and fitness status (Armstrong et al., 1982; Trombly, 1983; Mayer et al., 1985; Kirkendall et al., 1987), and a mechanism by which to identify safety and jobs demands (Deborah, 2005; Chaffin et al., 2006).

The measurement of handgrip strength for any person gives an assessment of his or her musculature. The average person's handgrip strength correlates moderately highly with total strength of 22 muscles of the body when training programs are designed (DeVries, 1980).This is an indication of the importance of handgrip strength measurements.

Several researchers have used different techniques, including electromyography, dynamometers, Jackson evaluation system, isokinetic dynamometers, and force plates to measure muscle strength (Quaine & Vigouroux, 2004; Liu et al., 2003; Kawakami et al., 2000; Blackwell et al., 1999). The isokinetic dynamometers were used to examine the hamstring and quadriceps muscles for karate practitioners (Al-Kilani et al., 1993). The dynamometers and Jackson evaluation system were used to measure handgrip force and the strength of different body segments (Al-Kurdi, 1994, 1995; Qassem et al., 1996.

The strength measurement of handgrip has been studied by several researchers (Baumgartner & Jackson, 1987; Shephard et al., 1991; Loughery & Jackson, 1991; Bohannon, 2001; Matos et al., 2007; Schlüssel et al., 2008). The coal miner's handgrip is 40% greater than physical fit students (Baumgartner and Jackson, 1987). Handgrip strength increased with age and significantly decreased after 40 and 50 years old for women and men (Schlüssel et al., 2008). Elderly subjects presenting less hand muscle fatigue resistance and weaker grip strength were reported by Bautmans et al. (2007). Maximal voluntary handgrip strength is considered a reliable tool in nutritional assessment (Schlüssel et al., 2008). Other researchers reported that handgrip strength may be a good predictor of body cell mass depletion, surgery complications, and mortality (Guo et al., 1996; Humphreys et al., 2002; Wang et al., 2005; Alvares-da-Silva & Reverbel da Silveira, 2005).

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A simple hydraulic hand dynamometer was also used to assess the handgrip force before and after general anesthesia.

Muscle fatigue is defined as an exercise-induced reduction in the maximal force capacity of muscle (Gandevia, 2001). The intense use of muscles that leads to a decline in performance is known as *fatigue* (Allen et al., 1995). Muscle fatigue depends on the type and intensity of exercise, the specific muscle groups involved, and the physical environment in which the activity occurs. Characteristic of muscle fatigue include reduction in muscle force production capability and shortening velocity, as well as prolonged relaxation of motor units between recruitment (Allen et al., 1995).

The handgrip force and fatigue relationship has been studied by several researchers (Quaine & Vigouroux, 2004; Khweileh & Al-Kurdi, 2008). Differences between handgrip muscular force and fatigue were examined and showed that a time period of 60 s was not adequate to achieve high levels of fatigue (Khweileh & Al-Kurdi, 2008). Although the above researchers studied the relationship between the handgrip force and fatigue, none of them studied the handgrip force at different anatomical positions.

The assessment of upper limb fatigue based on the force change index was examined and the results showed the index can be applied for fatigue assessment (Roman-Liu et al., 2005). No gender difference was found in the fatigability of the forearm muscles during intermittent submaximal handgrip contractions, independent of muscle strength (Gonzales & Scheuermann, 2007).

Therefore, this study aims to

1. Measure the maximum handgrip strength at different anatomical positions and 50% fatigue using grip force transducer and power laboratory attached to the computer.
2. Examine the relationship between the handgrip strength and fatigue at different anatomical positions.
3. Examine some properties of muscle fatigue.
4. Determine the main effect of the different anatomical positions on handgrip force.

Methods

Data were obtained from a representative sample of 20 males randomly selected from the German Jordanian University students. The students were instructed to self-adjust the dynamometer so that it fit comfortably to their hand in order to obtain their best performance. Before data collection, each student conducted a trial to get familiar with instrument and procedures.

Handgrip force was measured using a grip force transducer. The hand dynamometer first was calibrated with respect to the volunteer's maximal grip strength (Figure 1). The drag over the largest response was performed to select a range of data that includes both the relaxed and maximum force signal, the volunteer was then asked to squeeze maximally until the grip force decreased to 50% of its maximum due to fatigue, as this is the most valid test in isometric submaximal contractions (Staszkiewicz et al., 2002). This test was performed for both hands at different anatomical position with 2 min of rest for recovery of muscle function. The decline in maximal force during a sustained contraction was observed. Figure 2 shows selection of trace for calibrating to relative strength and units conversion dialog with relaxed signal selected and fatiguing contraction.

Results

In this study, seven anatomical positions were studied (Table 1), and anthropometric data of the 20 subjects were collected (Table 2). Handgrip forces in both sides (dominant and nondominant) were recorded (Tables 3 and 4) using grip force transducers attached to a power laboratory and a computer screen, for different anatomical positions.

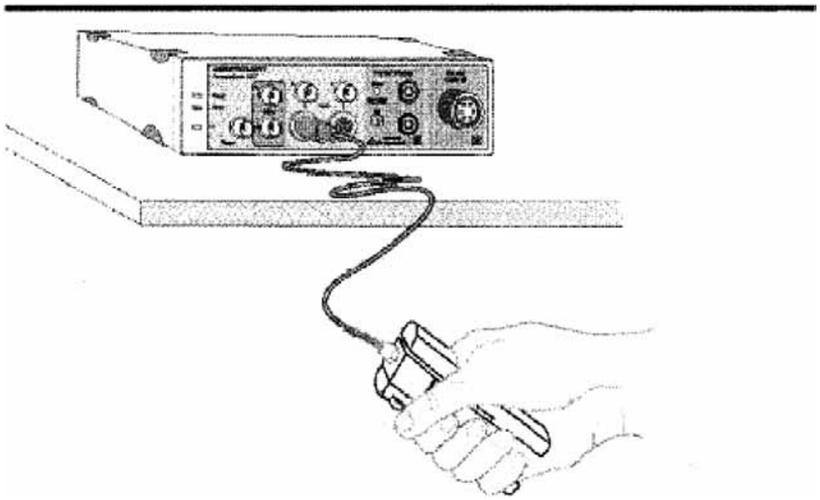

Figure 1 — Connections for measuring grip strength and muscle fatigue (AD Instruments).

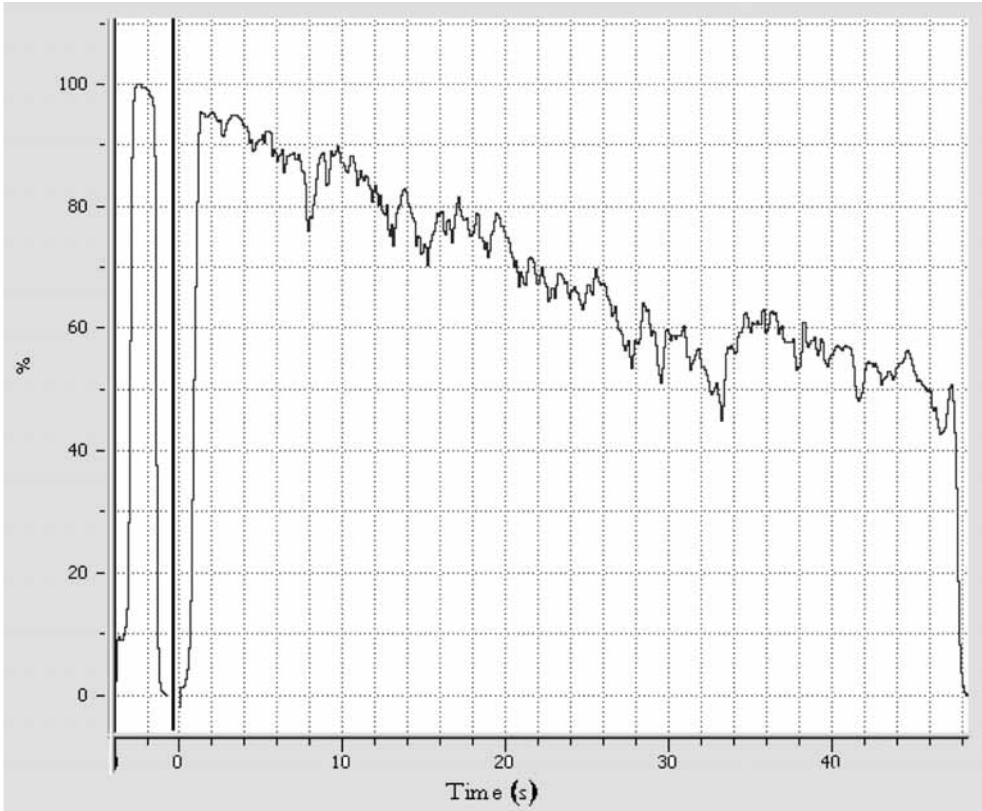

Figure 2 — Maximum and grip force, and fatigue at 50% (AD Instruments).

Table 1 The different anatomical positions considered in the present work

Position	Description
Position 1	Arm adduction with 180º at elbow joint.
Position 2	Arm adduction with 90º forward at elbow joint.
Position 3	Arm perpendicular to the frontal plane.
Position 4	Arm abduction with 90º at shoulder joint and 180º at elbow joint.
Position 5	Arm abduction with 90º at shoulder joint and 90º at elbow joint with the forearm perpendicular to the frontal plane.
Position 6	Arm abduction with 180º at shoulder joint and 180º at elbow joint.
Position 7	Arm abduction with 180º at shoulder joint and 90º at elbow joint.

The decline in maximum handgrip force during sustained contraction was observed and properties of muscle fatigue were examined (Figure 3). In addition to this, an ANOVA was used to determine the main effect of the different positions on handgrip force (Tables 5 and 6).

Discussion

The handgrips of both hands were measured. Table 3 shows variations in both the right handgrip force and time required for the force to decrease to 50% of its maximum between the subjects and also between the grip forces at different anatomical positions. The maximal handgrip force was between 247 and 308 N.

Table 3 also shows that the maximal force was produced at Anatomical Position 2 and the minimum force was produced at the Anatomical Position 7. From mechanical point of view, one would expect such results when the arm is adducted with 90 degrees forward at elbow joint Position 2, as in this position more actin cross-bridges occur than in Position 7.

Table 4 shows ranges of the values of both the left handgrip force and time required for 50% of its maximal value between the subjects and for the different anatomical positions. The maximal force was between 236 and 290 N. Table 4 also shows that the maximal force was produced at Position 1 when the arm was adducted with 180 degrees at elbow joint, and the minimal force is obtained

Table 2 Anthropometric data of the study participants

No.	Age	Total Body Mass (kg)	Total Body Height (m)	Forearm Length (m)	Forearm Mass (kg)
1	20	71	1.73	0.4	2.059
2	20	82	1.83	0.43	2.378
3	20	97	1.8	0.44	2.813
4	20	85	1.81	0.46	2.465
5	20	103	1.86	0.49	2.987
6	21	92	1.85	0.47	2.668
7	21	87	1.78	0.47	2.523
8	20	76	1.79	0.48	2.204
9	21	89	1.8	0.49	2.581
10	21	96	1.84	0.46	2.784
11	21	79	1.85	0.47	2.291
12	21	80	1.8	0.46	2.32
13	21	83	1.78	0.47	2.407
14	21	85	1.72	0.48	2.465
15	20	85	1.7	0.47	2.465
16	21	99	1.78	0.45	2.871
17	21	79	1.74	0.46	2.291
18	21	73	1.73	0.48	2.117
19	21	81	1.77	0.47	2.349
20	20	87	1.72	0.48	2.523
Average	20.6	85.5	1.8	0.47	2.5

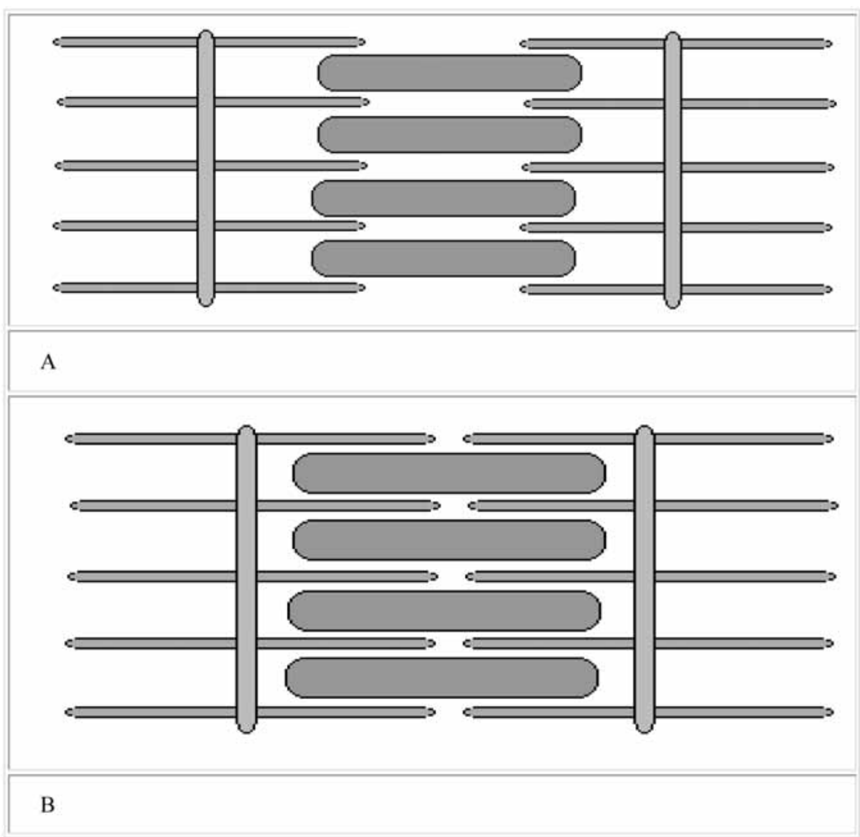

Figure 3 — (A) The muscle is stretched but little overlap between actin and myosin. The isometric tension will be low. (B) Active cross-bridges, so the isometric tension is high.

Table 3 Maximum right handgrip force (newtons) and time (seconds) for 50% of the maximal force

Position 1		Position 2		Position 3		Position 4		Position 5		Position 6		Position 7	
Max.	50% Fatigue	Max.	50% Fatigue	Max.	50% Fatigue	Max.	50% Fatigue	Max.	50% Fatigue	Max.	50% Fatigue	Max.	50% Fatigue
361.6	16.7	465	11.6	265.3	17.5	309.3	21.4	327.8	20.6	308.1	19.8	305	29.6
279.8	36.4	300.8	25.9	301.8	26.3	288.2	33.8	244	34.5	265.9	25.6	265.9	30
335.6	50.6	334.3	25.7	344	23.6	331.2	36.7	291.8	20.3	340	23.4	291.5	3.8
252.5	26.3	338	26.1	332.8	28.2	347.6	17.9	314.7	16.8	315.3	21.4	308.3	17.7
436,2	14.7	376.4	17.4	242.6	26.7	290.4	54.7	244.3	21.9	317.5	24.1	266.9	30.1
260.4	17.7	344.2	20.7	254	25.2	240.3	30.8	275.5	23.5	273	24.4	245.5	28
279.8	35.9	382.5	33.4	411	31.7	383.7	31.3	315.5	32.1	356.8	30.4	295.1	30.8
257.9	26.6	311.5	31.2	379.7	32.6	257.6	36.8	204.4	35.2	194.8	31.6	223.5	24.9
284.4	38.3	304	13.5	279.2	26	264.9	24.1	272	21.4	311.4	33	275.3	24.9
386.1	42.9	298	47.3	304	39.4	262.1	36.8	225.1	38.7	234	40.8	186.9	40.7
449.5	55.1	350.5	34.5	338.6	79.8	324.8	60.7	314.6	42	252	71.2	192.7	61.1
293.4	24.4	268.3	28.1	320	23.2	262.3	26.5	327.2	18.1	361.3	11.9	185.1	12.9
320.1	18.1	306.4	9.6	246.9	21.8	257.3	21.5	272.7	22.1	332.5	17.7	297.9	16.6
217.2	48.6	178.7	31.4	190	34.2	204.4	21.8	165.4	21.6	177.1	22.7	183.6	21.8
134	57.2	137.6	59.9	176.4	22.6	161.1	33.3	105.3	50.1	82.5	48.2	135.2	28.3
297.3	29.7	331	48.5	311.5	40.4	341.1	31.2	327.6	36.5	393.6	32.4	300.6	37.1
343.7	20.8	243.5	11.1	376.7	21.9	333.1	19.3	310.1	17.5	166.7	8.1	258.3	21.4
381.4	21.6	312.5	20.2	301.6	27.1	304.3	18.1	310.9	15.5	290.4	22.8	244.6	29.2
350.4	11.1	351	13.6	336.3	14.5	290.8	14.9	334.8	18.1	358	12.8	331.3	14.5
103.2	108.1	242.6	56.6	269.8	53.4	192.3	51.3	215.9	44.2	189.2	27.6	156.8	17.1
294.1	35.04	308.8	28.3	299.1	30.8	282.3	31.1	269.9	27.5	276.0	27.4	247.5	26.0

Table 4 Maximum left handgrip force (newtons) and time (seconds) for 50% of the maximal force

Position 1		Position 2		Position 3		Position 4		Position 5		Position 6		Position 7	
Max.	50% Fatigue	Max.	50% Fatigue	Max.	50% Fatigue	Max.	50% Fatigue	Max.	50% Fatigue	Max.	50% Fatigue	Max.	50% Fatigue
336.1	17.2	303.1	13.2	308.3	24.7	315.7	12.1	258	20.9	379.7	15.1	305.7	14.7
281.5	36	276.5	30.7	291.2	30.7	228.5	34.9	211.2	31.7	243.8	38.1	249	25.9
331.8	62.4	314.1	32.8	304.6	19.8	295	19	251.9	23.7	258.2	20.2	264.5	20.3
266.9	31.5	315.7	18.9	250.6	37.4	266,5	29.4	274.4	25.3	390	21.8	356.5	21.4
377	15.9	308.4	21.2	254.6	24.4	275.5	50.6	217.8	28.1	300.9	25.1	252.7	25.9
245.5	28.6	291.6	31.8	232	21.1	229.7	45.1	249.5	38.7	262.5	32.8	245	20.7
285	30	324.9	38.6	289.1	27.6	274	19.8	317.6	36.2	393.5	28	235.3	35.5
302.8	22.4	234.8	34.2	242.2	22.3	255.4	36.7	199.4	32.4	218.5	31.1	198.8	23.6
285.2	28.7	194	26.2	273.5	20.7	312.5	21.1	239.4	25.9	252	27.4	284.5	25.3
284	63.5	266.6	34.5	257.8	34.2	231	42.9	266.5	32.3	186.4	51.8	155.2	44.6
297.8	58.4	257.1	48.7	264.1	50.8	290.3	58.1	188.6	46.1	188.8	47.8	208.2	21.1
373.9	52.6	379.2	39.7	351	28.2	357.7	25.3	299	22.9	304.4	17.5	292.4	12.3
327.3	16.9	266.1	10.9	268.3	12.6	259.8	15.9	272.2	17.6	263.1	11.5	289.4	17.2
149.2	39.8	142.7	46.1	138.5	66.5	136.4	42.1	173.7	23.8	131.7	42.9	192.1	19.6
118.7	98.6	121	53.1	136.9	65.6	115.6	26.9	102	11	104	50.1	124.7	27.8
391.7	48.8	325.4	46.9	337.2	40.4	288.9	27.5	288.4	32.7	316.9	38.8	325.3	26.1
240.8	20.3	265.2	21.1	330.3	14.3	280	23.9	218	12.5	295.7	9.9	205.9	14.1
261.1	46.6	327,3	31.7	303.4	22.3	300.4	24.3	271.8	8.4	297.2	12.2	264.2	19.4
386.8	13.3	323.6	17.1	312.5	17.2	293.3	11.1	310.6	11.3	342	11.6	395.8	7.8
262.9	86.7	202.4	20.7	189.4	26.8	172.8	48.9	126.7	36.9	148.4	21.5	117.4	42.2
290.3	40.9	269.0	30.9	266.7	30.3	258.5	30.7	236.8	25.9	263.8	27.7	248.1	23.2

at Position 5 when the arm was abducted with 90 degrees at shoulder joint and 180 degrees at elbow joint.

Examining the relationship between the handgrip strength and fatigue at different anatomical positions, Tables 3 and 4 show the fatigue time for both left-hand and right-hand force to reach to 50% of the maximum, which varies between 26.0 and 35.4 s for the right hand and from 23.2 to 40.9 s for the left hand.

The above variations in the values of handgrip force shows higher values in the force for the right hand .Time required for fatigue production could be due to abnormalities of actin, which are responsible for reducing contraction rate and decreasing force development (Karsanov et al., 2001).When a muscle is stretched and no overlap between the actin and myosin, little tension is produced, and when a muscle is shortened, overlap would occur and tension will increase (Ismail, 2008). Figure 4, Panels a and b, demonstrate such overlap mechanism.

The properties of the muscle fatigue were examined; the maximal force values and fatigue time are plotted for all subjects. Figures 5 through 8 demonstrate the pattern of the handgrip force for both the left hand, when arm adduction with 90 degrees forward at elbow, and the right hand, when arm adduction with 90 degrees forward at elbow); handgrip force for the left hand when arm abduction with 180 degrees at shoulder joint and 90 degrees at elbow joint; and handgrip force for the right hand when arm abduction with 180 degrees at shoulder joint and 90 degrees at elbow joint.

The grip force in patients with chronic tennis elbow was markedly reduced at the pathological side, but there was also a striking reduction of the grip force at the pathological side when the grip force was measured with a straight elbow, compared with the standard position of 90 degrees flexion (De Smet & Fabry, 1997). This reduction was highly significant at the pathological side but not at the normal, control side.

This result indicates that handgrip force with 90 degrees forward at elbow is higher than with a straight elbow; such a result is consistent with the results obtained in this study.

A predictive equation was developed to expresses the maximum force of the handgrip in relation to upper-limb posture and gender, and such an equation is valuable especially in establishing norm values (Roman-Liu, 2003). Muscle force is generated by myosin cross-bridges interacting with actin. As estimated from stiffness and equatorial X-ray diffraction of muscle and muscle fibers, most myosin cross-bridges are attached to actin during isometric contraction (Bershitsky et al., 1997).

The main effect of the different anatomical positions on handgrip force was examined using ANOVA. Table 5 shows the descriptive means of the different anatomical positions, and Table 6 shows no significant difference between the different anatomical positions (p = .332).

In summary, a measurement protocol involving grip force transducers attached to a power laboratory and computer screen was used to assess the biomechanical effect of different anatomical position on handgrip force and also the effect of time for producing 50% of the force maximum. The obtained data and its analysis showed differences in the handgrip force between subjects of the same anatomical positions and for the different anatomical positions, and also differences in the time for 50% of the force maximum for both right hand and left hand. In addition to this, higher time required to achieve 50% of maximal handgrip force for the nondominant hand was observed and maximal handgrip force was obtained when arm adduction with 90 degrees forward at elbow joint.

Table 5 Descriptive means of the different anatomical positions

Number	*N*	Mean	Std. Deviation	Std. Error
1.00	20	497.5150	913.2289	204.2042
2.00	20	308.8400	71.7896	16.0526
3.00	20	299.1100	60.2930	13.4819
4.00	20	282.3400	55.7886	12.4747
5.00	20	269.9800	61.8293	13.8255
6.00	20	276.0050	80.5093	18.0024
7.00	20	247.5000	56.7867	12.6979
Total	140	311.6129	351.5923	29.7150

Table 6 ANOVA for the differences in the grip forces

	Sum of Squares	*df*	Mean Square	*F*	Sig.
Between Groups	853843.796	6	142307.299	1.159	.332
Within Groups	16328938.121	133	122773.971		
Total	17182781.917	139			

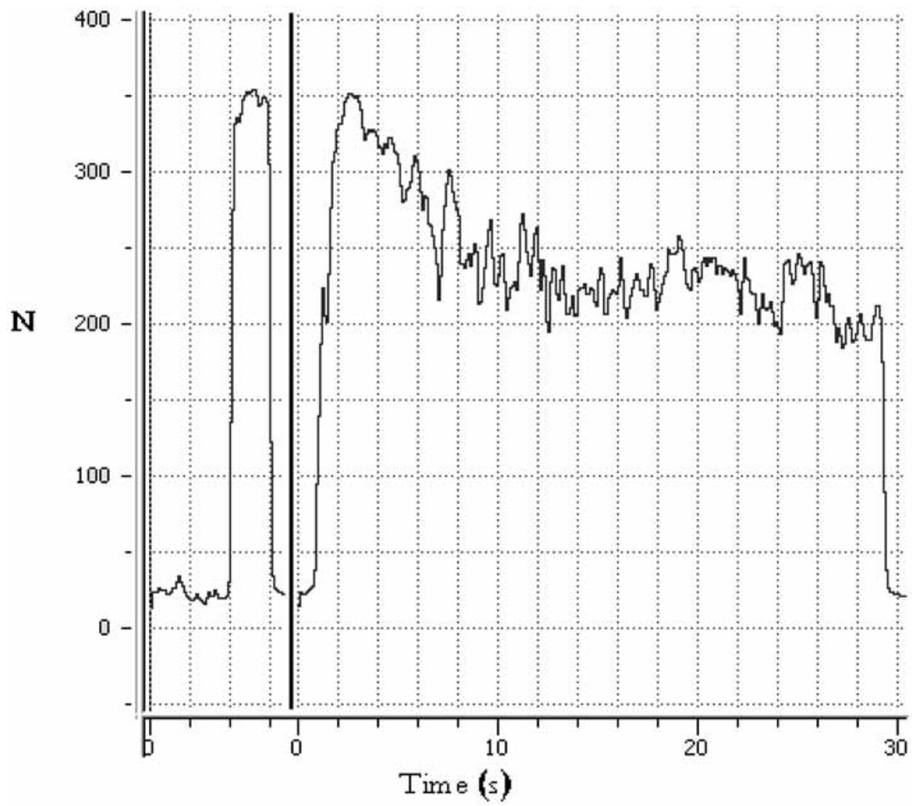

Figure 4 — The maximum handgrip force versus time.

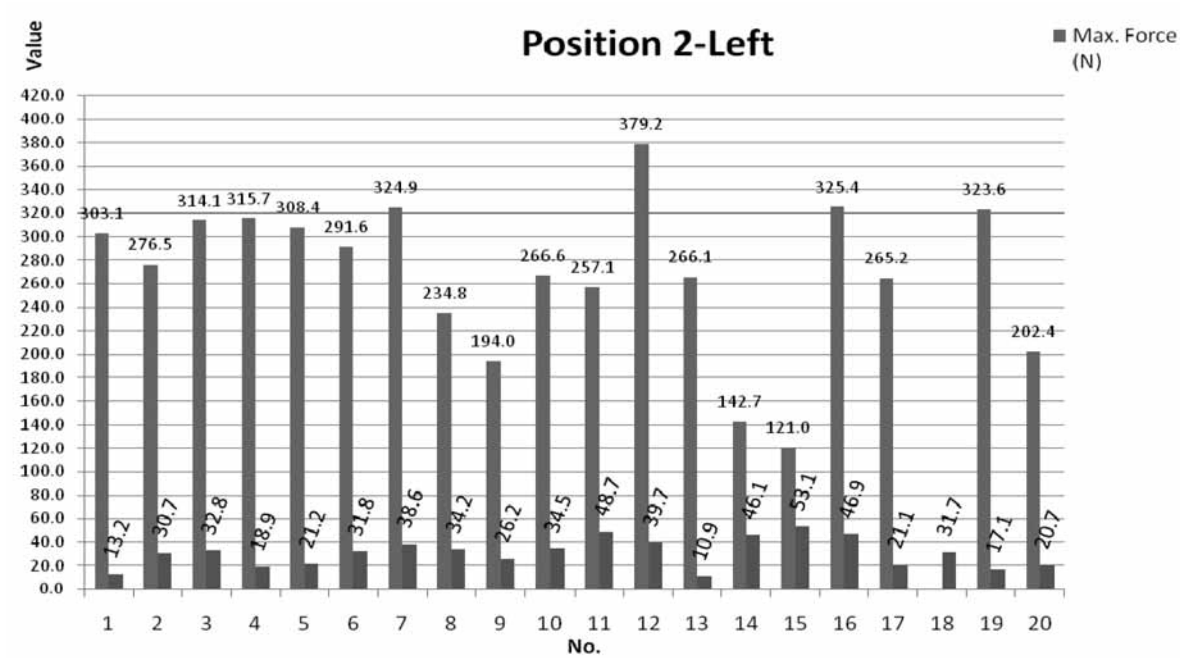

Figure 5 — Handgrip force for left hand (arm adduction with 90 degrees forward at elbow joint).

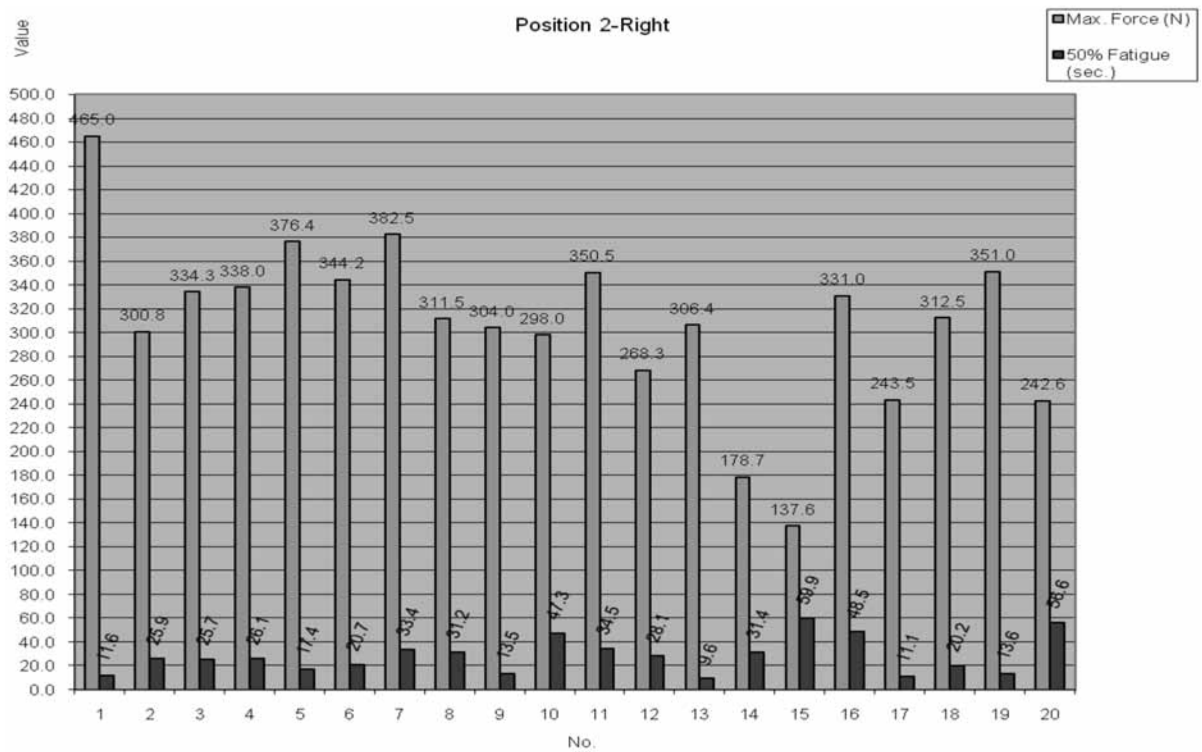

Figure 6 — Handgrip force for right hand (arm adduction with 90 degrees forward at elbow joint).

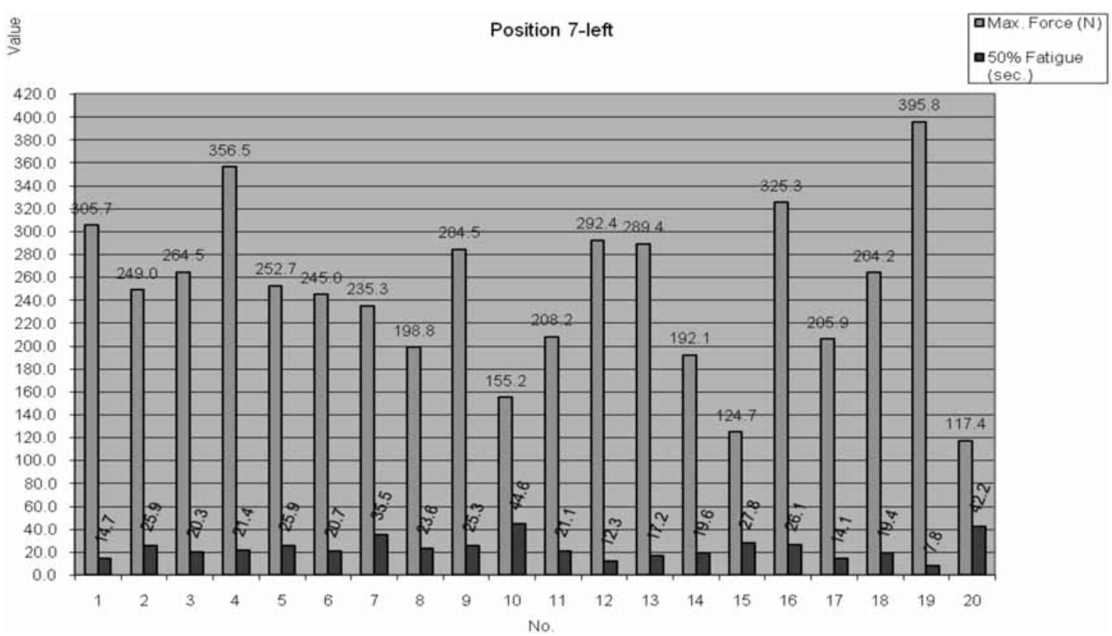

Figure 7 — Handgrip force for left hand (arm abduction with 180 degrees at shoulder joint and 90 degrees at elbow joint).

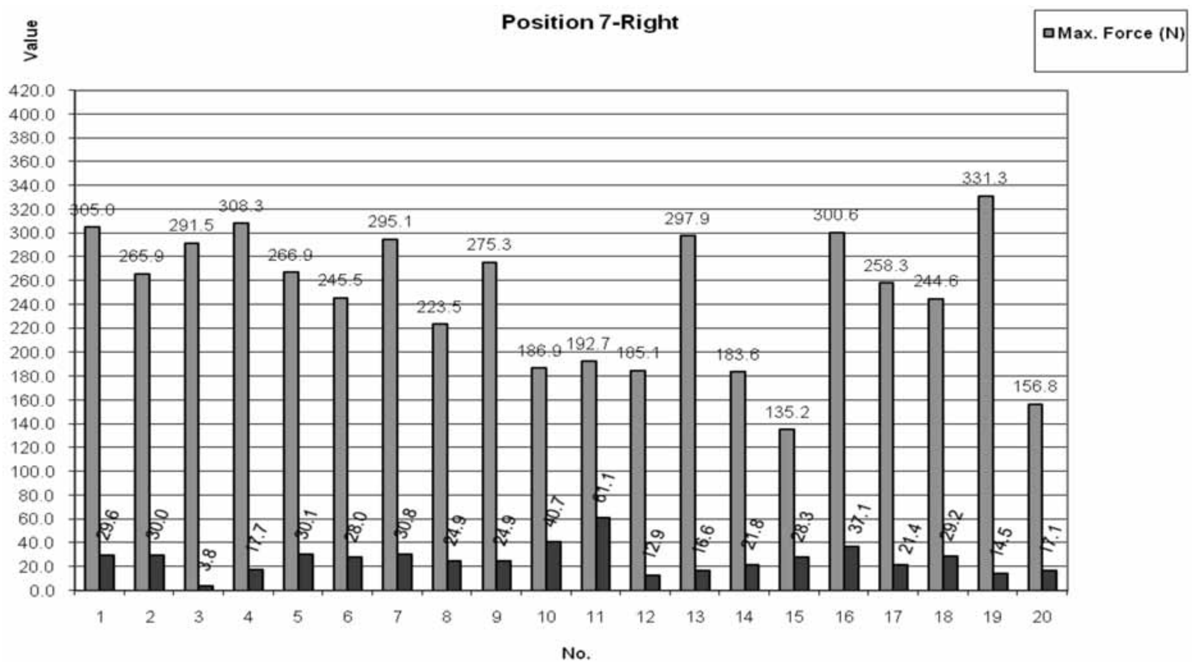

Figure 8 — Handgrip force for right hand (arm abduction with 180 degrees at shoulder joint and 90 degrees at elbow joint).

The researchers recommend the following to be done in future research.

Evaluate the handgrip force in a larger sample for different anatomical positions for both male and females of different age groups.

Measure fatigue time at different percentages, 25%, 50%, 60%, 75%, of maximal force.

Investigate factors affecting handgrip force (actin and myosin, anthropometric parameters, nutrition).

Use statistical analysis with regression to determine the variables affecting grip force.

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