

Hand grip increases shoulder muscle activity

An EMG analysis with static handcontractions in 9 subjects

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We examined 4 shoulder muscles—the supraspinatus, infraspinatus, the middle portion of the deltoid and the descending part of the trapezius—with electromyography (EMG) in abducted and flexed arm positions, in 9 healthy subjects. The subjects were asked to produce a static handgrip force of 30% and 50% of maximal voluntary contraction (MVC) in 8 different arm positions. In all positions, the subjects held a dynamometer in the hand. The myoelectric activity in the shoulder muscles with only the dynamometer in the hand was compared to the EMG activity when static contractions were added. There was an association between static handgrip and shoulder muscle activity, as revealed by EMG. The EMG activity increased in the supraspinatus muscle in humeral flexion from and above 60° and in 120°

abduction. In the infraspinatus muscle, the changes were less; a significant increase, however, was noticed in flexion. In the deltoid muscle there was a tendency towards increased activity in positions lower than 90°, in the higher arm positions, the activity decreased. There was no significant alteration regarding the EMG activity of the trapezius.

Our findings imply that high static handgrip force, particularly in elevated arm positions, increases the load on some shoulder muscles. The stabilizing muscles (the rotator cuff) were more influenced than the motor muscles by hand activity. Handgrip activity is important to evaluate while assessing shoulder load in manual work and in clinical evaluations of patients with shoulder pain.

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Earlier studies have revealed some risk factors for high loads and pain in the shoulder region. Among these are heavy industrial work (Herberts and Kadefors 1976, Herberts et al. 1984), elevated arm (Järvholm 1990), increased hand load (Sigholm et al. 1984), and repetitive muscle strain (Campbell Semple 1991).

We found no studies regarding an association between hand muscle activity and shoulder muscle activity. We have earlier presented a study showing that intermittent isometric hand activity influenced the activity of different shoulder muscles (Sporrøng et al. 1995). We have now assessed whether static hand activity affects the shoulder muscles, and, if so, whether the relation varies among the tested shoulder muscles, if there is an individual variability and if the association depends on the degree of arm elevation.

Subjects and methods

9 healthy subjects (mean age 27) participated in the study (Table 1). The dominant side was studied. The supraspinatus, the infraspinatus, the middle part of the

deltoid and the upper part of the trapezius muscle were studied. The hand activity was monitored by EMG-signal analysis from the extensor carpi ulnaris muscle. The grip force was measured by using a handgrip dynamometer with a weight of 600 g. 2 static hand activities were tested: 30% and 50% of maximal grip strength during 10 seconds.

The effect of hand activities was investigated in 8 different positions of the upper arm, composed of flexion and abduction at 4 elevation angles. Flexion

Table 1. Subjects

Subject	Dominant side	Sex	Age	Height (cm)	Weight (kg)
1	r	f	29	170	73
2	r	f	34	175	78
3	r	f	21	170	65
4	r	f	31	169	68
5	r	m	27	180	66
6	l	f	28	163	65
7	r	m	24	175	55
8	r	m	25	177	62
9	r	f	25	168	66

was performed in the sagittal plane and abduction in the scapular plane. The elevation was 30°, 60°, 90°, and 120° in each plane. In all arm positions, the elbow was flexed to 90° and the rotation of the upper arm was kept in a neutral position (Heck et al. 1965).

The EMG activity in the shoulder muscles was estimated using monopolar intramuscular recordings, picked up by means of single intramuscular wire electrodes made of a nickel chromium alloy. These were placed in the proper position (Basmajian 1985) in the muscles by means of a hypodermic needle. The indifferent electrode was a silver/silver chloride surface electrode, taped at the 7th cervical spinal processus. The myoelectric activity from the extensor carpi ulnaris muscle was recorded with a bipolar surface electrode.

The electrodes were connected to a 6-channel EMG-amplifier. The amplified EMG signals were recorded on a multichannel FM tape-recorder. The quality of the muscle signals recorded was supervised visually on an oscilloscope and the rectified signals were registered on a recorder.

The final processing of the EMG signals was performed on a computer. The root mean square values (RMS) were used as activity parameters and mean power frequency (MPF) of the myoelectric signal was used to identify signs of muscle fatigue, since MPF diminishes with increasing fatigue. The RMS was considered a quantity measure of the myoelectric activity, the MPF a quality measure. Each segment was submitted to an automatic quality control procedure to eliminate possible signal disturbances (Arvidsson 1982).

All experiments were performed with the subject sitting in a chair in an upright position. The subjects were asked to perform a maximal hand contraction for a few seconds, with the arm hanging straight down and a straight elbow. The MVC (maximal voluntary contraction) was recorded and used to calculate the 30% and 50% levels of specific hand activities for each individual in the following tests. The subject was asked to elevate the arm and keep it still for 10 seconds, with the load of the handgrip dynamometer in the hand, to permit a registration of the EMG activity related to posture. Then one of the two hand activities was performed while the subject maintained the same arm position. In both test situations, the subject thus held the dynamometer in the hand. The EMG activity in the shoulder muscles, related to the posture of the arm and load in the hand, was compared to the EMG activity when one of the two hand activities was added. This sequence was repeated in all arm positions and hand activities, but was separated by 2 minutes of rest. The order of the different combinations was ran-

domized for each subject.

The change in muscle activity was expressed in percent of the mean value for the EMG-activity in the corresponding arm position. The relative change in myoelectric activity was calculated for each combination of arm position, handgrip force, shoulder muscle and subject.

Statistics

A nonparametric test, Fisher's test for pair comparisons (Bradley 1968), was used to assess changes. A special technique was used to test the importance of angle. For each individual and type of situation, the Pearson correlation coefficient between angle and change was determined and Fisher's test for pair comparisons was applied to the correlation coefficients to test whether the mean of the coefficients differed significantly from zero. Two-tailed tests were used (Tables 2 and 3).

Results

The relative changes in myoelectric activity, due to the hand activity, varied between the different shoulder muscles. The individual differences were large in some positions and muscles but small in others (Table 4). No signs of muscular fatigue were detected.

Table 2. Comparison between myoelectric activity in 5 muscles at 4 levels of arm positions with or without added static hand activity. Figures are p-values (Fisher's test for pair comparisons, Bradley)

	Level	A	B	C	D
SSP	30°	0.7	0.2	1.0	0.1
	60°	0.6	0.02	0.4	0.09
	90°	0.2	0.004	0.1	0.03
	120°	0.01	0.008	0.05	0.01
ISP	30°	0.6	0.2	0.5	0.1
	60°	0.9	0.09	0.8	0.1
	90°	0.6	0.05	0.4	0.2
	120°	0.2	0.05	0.3	0.02
TRP	30°	0.5	0.2	0.9	0.09
	60°	0.7	0.5	0.7	0.5
	90°	0.3	0.9	1.0	0.6
	120°	0.8	0.06	0.5	0.08
DLT	30°	0.1	0.2	0.2	0.6
	60°	0.8	0.5	0.5	0.9
	90°	0.02	0.1	0.05	0.1
	120°	0.02	0.3	0.02	0.6
ECU	30°	0.004	0.004	0.004	0.004
	60°	0.004	0.004	0.004	0.004
	90°	0.004	0.004	0.008	0.004
	120°	0.008	0.008	0.008	0.008

SSP supraspinatus, ISP infraspinatus, TRP trapezius, DLT deltoid, ECU extensor carpi ulnaris, A abduction, B flexion, C 30% of MVC, D 50% of MVC.

Table 3. Comparison between myoelectric activity in 5 muscles with or without added hand activity and testing the importance of angle. Figures are p-values (Pearson correlation coefficient and Fisher's test)

	A	B	C	D
SSP	0.02	0.2	0.04	0.04
ISP	0.4	0.01	0.06	0.2
TRP	0.8	0.3	0.9	0.5
DLT	0.004	0.004	0.008	0.1
ECU	0.1	0.01	0.09	0.03

For abbreviations, see Table 2.

Muscle activity related to the degree of elevation (Tables 2, 3 and 5)

The supraspinatus muscle had an increase in EMG activity in abduction as well as in flexion. The increase was greatest for 90° and 120° of arm elevation. The increased activity was significant from and above 60° of flexion and in 120° of abduction.

In abduction the muscle activity of the infraspinatus muscle increased to a small extent, but the change was not significant. In flexion, the muscle activity increased to a greater extent, but no statistical significance was reached.

Table 4. Relative changes in percent of EMG-activity in 4 shoulder muscles and 1 lower arm muscle with added hand activity in 9 subjects

	S	A				B				C				D			
		30°	60°	90°	120°	30°	60°	90°	120°	30°	60°	90°	120°	30°	60°	90°	120°
SSP	1	-8	0	2	mv	-10	6	30	mv	-14	-2	25	mv	-5	8	8	mv
	2	-9	-10	27	28	-15	14	13	4	-12	-1	18	26	-11	6	22	5
	3	-1	-1	-38	3	7	5	7	9	6	-2	-12	1	0	6	-18	11
	4	5	17	11	7	14	29	26	7	-1	4	-1	5	19	41	38	10
	5	-8	7	33	8	-2	-5	21	34	-6	1	2	7	-4	4	52	35
	6	-7	-31	-14	12	25	5	13	14	-6	-21	-6	-8	23	-15	4	32
	7	20	25	45	54	29	43	32	58	14	21	14	43	27	47	63	68
	8	9	21	48	27	7	10	20	37	11	24	54	27	5	7	15	37
	9	16	6	16	16	11	11	6	6	6	11	6	6	22	6	16	16
ISP	1	4	1	-1	mv	1	2	5	mv	-2	2	3	mv	7	2	2	mv
	2	-1	0	-2	14	-9	1	-5	15	-11	-6	-4	11	1	7	-3	18
	3	-1	-17	-32	3	6	-2	7	5	4	-21	-21	-4	1	2	-10	11
	4	18	21	12	8	14	37	37	33	5	5	8	19	26	53	41	22
	5	10	21	32	31	11	16	46	59	0	5	9	19	20	32	68	62
	6	-41	-26	-25	-17	-8	-12	-8	-6	-34	-12	-23	-23	-15	-23	-9	1
	7	-18	23	5	52	41	50	33	60	14	25	-3	37	32	48	41	75
	8	12	-1	-14	4	8	24	18	26	8	1	3	-1	12	22	2	31
	9	-17	-17	-6	-6	0	0	6	-6	-17	-12	-6	-6	0	-6	6	-6
TRP	1	-3	-1	-9	mv	-6	-12	-15	mv	-7	-6	-12	mv	-3	-6	-13	mv
	2	-14	-11	-7	0	-11	-4	-21	13	-14	-7	-9	3	-11	-8	-19	16
	3	8	10	15	7	14	7	12	12	13	4	8	12	9	12	20	7
	4	11	12	20	-4	13	13	11	8	6	2	9	-7	18	23	22	12
	5	-3	-3	2	-10	-10	-6	-6	-9	-5	3	8	-4	-8	-12	-12	-15
	6	-11	-17	-12	7	20	-14	-1	5	-26	-15	-7	-6	19	-16	-6	18
	7	11	17	14	28	35	37	25	42	6	20	7	26	26	33	32	44
	8	7	-3	6	-10	28	1	4	24	20	1	8	2	13	-3	2	12
	9	19	9	9	0	0	19	-19	0	0	9	-9	0	19	19	0	0
DLT	1	16	12	5	mv	17	16	-3	mv	5	11	-9	mv	28	18	11	mv
	2	-2	-4	-7	-47	-2	1	-33	-9	-2	-6	-57	-67	-3	2	-43	11
	3	5	1	-17	2	1	2	6	-4	13	17	15	0	-7	-14	-26	-2
	4	-10	-27	-15	-28	-3	7	-16	-7	-1	-8	-24	-28	-12	-11	-7	-7
	5	-3	-19	-2	-27	-13	-12	-35	-77	-6	-3	-12	-49	-38	-28	-25	-55
	6	28	15	-6	-2	21	4	-14	7	17	13	-6	-8	31	7	-14	14
	7	16	24	-4	-4	55	38	20	14	10	17	-8	-4	38	44	23	14
	8	3	-11	-11	-20	4	-14	0	-3	1	-19	-3	-3	5	-6	-8	-19
	9	6	-6	-22	-6	0	-6	-50	-11	0	11	-33	-22	6	-22	-39	-6
ECU	1	108	101	78	mv	136	130	75	mv	47	72	23	mv	197	160	130	mv
	2	29	25	37	29	77	54	46	8	29	18	21	1	125	96	62	38
	3	52	76	36	38	81	67	57	41	45	46	25	28	88	94	68	51
	4	45	40	35	22	62	83	48	33	13	11	-1	17	95	111	84	37
	5	118	115	101	85	132	102	125	97	68	52	38	51	182	165	188	132
	6	48	57	49	73	58	40	65	74	20	34	31	42	86	63	83	105
	7	64	62	49	56	99	85	47	70	51	50	17	47	88	97	78	79
	8	61	42	26	10	85	88	49	64	55	34	19	14	90	96	55	59
	9	66	178	85	132	113	103	113	75	75	160	141	56	103	122	56	150

For abbreviations, see Table 2, and S subjects, mv missing value.

Table 5. Relative changes in EMG-activity in percent (median values) in 5 muscles as a consequence of static handgrip in different degrees of abduction and flexion

	A				B			
	30°	60°	90°	120°	30°	60°	90°	120°
SSP	-1	6	16	14	7	10	20	12
ISP	-1	0	-2	6	6	2	7	21
TRP	7	-1	6	0	13	1	-1	10
DLT	5	-4	-7	-13	1	2	-14	-6
ECU	61	62	49	47	85	85	57	67

For abbreviations, see Table 2.

Table 6. Relative changes in EMG-activity in percent (median values) in 5 muscles as a consequence of static handgrip with 30% and 50% of maximal voluntary contraction in different degrees of elevation

	C				D			
	30°	60°	90°	120°	30°	60°	90°	120°
SSP	-1	1	6	7	5	6	16	24
ISP	0	1	-3	5	7	7	2	20
TRP	0	2	7	1	13	-3	0	12
DLT	1	11	-9	-15	5	-6	-14	-4
ECU	47	46	23	35	95	97	78	69

For abbreviations, see Table 2.

The changes in the trapezius muscle were small and insignificant.

The influence of hand activity on the deltoid muscle was dependent on the elevation angle. In the lower arm positions, the deltoid muscle activity increased in abduction as well as in flexion, but in the higher arm positions there was a reduction of muscle activity. The differences were significant in 90° and 120° abduction.

Muscle activity related to the force of the hand grip (Tables 2, 3 and 6)

The supraspinatus muscle had increased muscle activity in both levels of handgrip force in all positions. The change in muscle activity was related to the arm elevation angle. The increase in activity was significant for 90° and 120° of arm elevation with 50% hand activity of MVC, and in 120° with 30% of MVC.

The infraspinatus muscle responded with small and insignificant changes with the lower level of handgrip, but with the higher level there was a significantly increased activity in the 120° position.

The trapezius muscle showed small and insignificant alterations.

The activity in the deltoid muscle depended on the angle of arm elevation for both levels of handgrip force. In the lower arm positions there were no significant differences in muscle activity. In the 120° position the activity decreased significantly.

Discussion

Arm abduction above 120° requires external rotation of the upper arm (An et al. 1991). We purposely limited the elevation to this degree, so that upper arm rotation would not be required. Neither the degree of rotation of the upper arm nor the degree of flexion in the elbow has any important influence on the shoulder muscle load (Sigholm et al. 1984). To what extent the degree of rotation of the forearm can influence the shoulder load is unknown. We used standard positions in this experiment to minimize this problem.

We know from earlier studies that an increased weight in the hand increases the muscle activity in the shoulder when raising the arm (Hagberg 1981, Sigholm et al. 1984). But we do not know whether hand activity affects the individual shoulder muscles in a different way, depending on the load in the hand. We chose the load in this study to simulate the weight of an industrial handtool as much as possible, in order to simulate a working situation.

Our findings indicate that static hand activity influences the muscle activity in the 4 investigated shoulder muscles. The supraspinatus, the infraspinatus (in flexion) and, to a lesser extent, the deltoid muscles were most influenced by static hand activity. In the supra- and infraspinatus muscles there was a positive correlation between the degree of the shoulder muscle activity and the intensity of the handgrip exertion in most of the tested arm-positions. Several studies have pointed out that some muscles—for instance, the deltoid muscle (Michiels and Bodem 1992), the trapezius muscle (Inman et al. 1944, Jensen 1995), and the subscapularis muscle (Kadaba et al. 1992)—should be regarded not as single muscles but rather as functional units which work on their own to a large extent. Recent studies have shown a complex interaction between the shoulder muscles in shoulder joint movements (Pearl et al. 1992, Keating et al. 1993). Not only the supraspinatus muscle but also the rest of the rotator cuff muscles contribute significantly to abduction (Sharkey et al. 1994).

Our observations emphasize the complexity of the interaction between handgrip activity and shoulder muscle activity. The supraspinatus muscle is highly active in the levels of motion where the myoelectric activity increased the most, from and above 60° of

elevation. Therefore an added activity is of clinical interest, since shoulder peritendinitis or impingement to a large extent probably are connected with an overload of this muscle (Herberts et al. 1984), and we know that there is a heavy static loading in this muscle in overhead work (Kadefors et al. 1976). Of several tested shoulder muscles, the supraspinatus was the first in which myoelectric signs of muscular fatigue developed (Hagberg 1981).

We know from earlier studies (Sigholm et al. 1984) that handload dependence is greater for stabilizing muscles (rotator cuff muscles) than for pure motor muscles (deltoideus, trapezius). Therefore the need for stabilizing the shoulder joint increases with hand activity.

The compressive force in the shoulder joint reaches its maximum at about 90° of elevation (Poppen and Walker 1978). At this level, the supraspinatus muscle, with its horizontal alignment, is very active. A further increase in supraspinatus activity, secondary to hand activity, could explain why the deltoid muscle activity seems to decline on these higher levels, whereas there seems to be a tendency towards increased deltoid activity on the lower levels of motion. The supraspinatus activity thus enables the deltoid muscle to diminish its activity, the main function of the middle part of the deltoid muscle being abduction (Kronberg et al. 1990).

The large individual variability in the muscle activities accords with our previous findings (Sporrong et al. 1995). We know that the scapulohumeral rhythm at the onset of elevation, is highly variable (Perry 1988). This variation in the onset of scapular movement persists through the first 60° of flexion and the first 30° of abduction, but from there on there is a ratio of, in general, 1.5:1 between humeral and scapular movement. Another possible explanation of the individual variation can be the so-called redistribution of shoulder muscle activity (Palmerud et al. 1995).

Our findings emphasize that it is the stabilizing muscles of the shoulder, the supraspinatus in particular, that increase their activity while increasing hand-grip activity. This is relevant to mechanical calculations in order to evaluate the shoulder muscle load (Inman et al. 1944, De Luca and Forrest 1973, Arborelius 1986, Högfors et al. 1987, 1991).

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