The effects of shoulder load and pinch force on electromyographic activity and blood flow in the forearm during a pinch task — **Source link** ↗

Bart Visser, Pernille Nielsen, Heleen de Kraker, Heleen de Kraker ...+5 more authors

Institutions: National Institute of Occupational Health, Vanderbilt University Medical Center, VU University Amsterdam, University of Copenhagen ...+1 more institutions

Related papers:

- Reliability of bloodflux measurements from the upper trapezius muscle during muscle contractions

- Effects of external load and abduction angle on EMG level of shoulder muscles during isometric action.

- Intramuscular pressure and electromyography in four shoulder muscles.

- On shoulder muscle load : an experimental study of muscle pressures, EMG and blood flow

- The effect of arm support on supraspinatus muscle load during simulated assembly work and welding.

The effects of shoulder load and pinch force on electromyographic activity and blood flow in the forearm during a pinch task

Visser, B.; Nielsen, P.K.; de Kraker, H; Smits, M.G.; Jensen, B.R.; Veeger, H.E.J.; van Dieen, J.H.

Link to publication in VU Research Portal

The effects of shoulder load and pinch force on electromyographic activity and blood flow in the forearm during a pinch task

BART VISSER*†‡, PERNILLE KOFOED NIELSEN§,
HELEEN DE KRAKER†‡, MIRIAM SMITS†,
BENTE RONA JENSEN‖,
DIRKJAN VEEGER†¶ and JAAP H. VAN DIEËN†

†Institute for Fundamental and Clinical Human Movement Sciences,
Faculty of Human Movement Sciences, Vrije Universiteit Amsterdam, The Netherlands
‡Body@Work, Research Center Physical Activity, Work and Health, TNO VUmc,
Amsterdam, The Netherlands
§Department of Physiology, National Institute of Occupational Health, Copenhagen,
Denmark
¶Laboratory for Measurement and Control, Delft University of Technology,
Delft, The Netherlands
‖Department of Human Physiology, Institute of Exercise and Sport Sciences,
University of Copenhagen, Denmark

The object of the current study was to determine whether static contraction of proximal musculature has an effect on the blood flow more distally in the upper extremity. Static contractions of muscles in the neck shoulder region at three levels (relaxed, shoulders elevated and shoulders elevated loaded with 4.95 kg each) were combined with intermittent pinch forces at 0, 10 and 25% of the maximum voluntary contraction (MVC). Blood flow to the forearm was measured with Doppler ultrasound. Myoelectric activity of the forearm and neck-shoulder muscles was recorded to check for the workload levels. Across all levels of shoulder load, blood flow increased significantly with increasing pinch force (21% at 10% MVC and by 44% at 25% MVC). Blood flow was significantly affected by shoulder load, with the lowest blood flow at the highest shoulder load. Interactions of pinch force and shoulder load were not significant. The myoelectric activity of forearm muscles increased with increasing pinch force. The activation of the trapezius muscle decreased with increasing pinch force and increased with increasing shoulder load. The precise mechanisms accounting for the influence of shoulder load remains unclear. The results of this study indicate that shoulder load might influence blood flow to the forearm.

Keywords: Upper extremity musculoskeletal disorders; Electromyography; Blood flow; Computer work

*Corresponding author. Email: b.visser@fbw.vu.nl

1. Introduction

Work-related upper extremity musculoskeletal disorders (UEMSDs) have been given a variety of names, such as repetitive strain injury, cumulative trauma disorder and occupational cervico-brachial disorder. Both specific and non-specific disorders of muscles, tendons and nerves of the neck, shoulder and upper extremity are classified under these terms (Kroemer 1989, Muggleton *et al.* 1999, Sluiter *et al.* 2001). Epidemiological studies and reviews clearly show that these disorders have become a major problem over the past decades, with high and apparently increasing incidence and prevalence rates (Bernard 1997, Buckle and Devereux 1999, Sluiter *et al.* 2001).

Restriction of blood flow and the resulting reduction in muscle tissue oxygenation during sustained repetitive work has been suggested to contribute to the development of UEMSDs (Carayon *et al.* 1999, Galen *et al.* 2002, Larsson 2003). The suggestion that local circulatory problems and, thus, disturbances of homeostasis play a role in the development of UEMSDs can also be found in several models proposed to describe the patho-physiology of UEMSDs (Edwards 1988, Jonsson 1988, Sjøgaard and Sogaard 1998, Kadefors *et al.* 1999, Sjøgaard *et al.* 2000).

A possible and often-mentioned explanation for the lack of blood supply is an increased intramuscular pressure, which impedes microcirculation (Järvholm *et al.* 1988, Jensen *et al.* 1995). This hypothesis is supported by studies that have investigated tissue oxygenation (Murthy *et al.* 1997) and hyper-compensation in blood flow post exercise (Byström and Kilbom 1990, Jensen *et al.* 1993, Jensen 1997, Byström *et al.* 1998, Røe and Knardahl 2002). In this context, Jensen *et al.* (1993) found post-exercise hyperaemia values of twice the resting blood flow even after isometric handgrip exercise at an intensity as low as 2.5% maximum voluntary contraction (MVC) and Røe and Knardahl (2002) found such hyperaemia after computer work.

An alternative mechanism was proposed by Keller *et al.* (1998), who suggested that blood flow can be compromised due to compression of the brachial plexus. The thoracic inlet would be reduced in size by forward displacement of the head and shoulder girdle in combination with scapular protraction. This may result in compression of the brachial plexus, which can have effects distally, including oedema, fibrosis and temperature changes.

Repetitive hand or finger motions involving static contractions of more proximal musculature have been shown to characterize tasks that pose a high risk with regard to UEMSDs (Bernard 1997, Sluiter *et al.* 2001). These risks are most pronounced in high intensity work in industry but can also be found in low intensity jobs (Bernard 1997). An example of this type of work is computer work, where static contractions of the shoulder and neck muscles occur to maintain the position of the arm in the gravitational field, while forearm muscles contract intermittently to move the fingers. Although the static activity of the neck and shoulder muscles can be reduced by providing a horizontal support to the forearm, it cannot be totally prevented (Visser *et al.* 2000). In addition, static loading of the neck and shoulder muscles will be influenced by the position of the head and shoulder girdle. Postural deviations, such as forward displacement of the head and shoulder girdle, often occur during computer work (Keller *et al.* 1998).

The objective of the present study, therefore, was to determine whether static contraction of proximal musculature has an effect on the blood flow more distally in the upper extremity.

2. Methods

A repeated-measures experimental design was used to determine blood flow to the forearm and activity of neck shoulder and forearm musculature in subjects performing pinching tasks at different intensities combined with three levels of neck shoulder loading. The dependent variables for this study were the following:

1. The volume of blood flow (ml/min) through the brachial artery, which is the main artery in the arm, from which the forearm muscles receive their blood supply.
2. The 50th percentile of the Amplitude probability distribution function (APDF) of the electromyographic signal expressed as a percentage of maximal excitation (%EMGmax) from the descending part of the trapezius muscle, the extensor carpi radialis brevis muscle and the extensor digitorum muscle. The forearm muscles were selected because they play a major role in pinching and can be reliably monitored with surface electromyography. The trapezius muscle was chosen because of its contribution to the neck shoulder load. The use of the APDF is a widely accepted method of quantifying EMG signals.

2.1. *Subjects*

A total of 13 healthy, right-handed male subjects, without a history of musculoskeletal complaints in neck, shoulders or hands/wrists, participated in the study. The measurements were performed on the dominant side. Prior to the experiment, subjects filled in an informed consent form and the Nordic questionnaire (Kuorinka *et al.* 1987). The average age of the subjects was 33 (SD 8) years, their average body height was 180 (SD 3) cm and their average body mass was 75 (SD 10) kg.

2.2. *Protocol*

After standard preparation, surface EMG electrodes were placed on the location of the descending part of the trapezius muscle, the extensor carpi radialis brevis muscle and the extensor digitorum muscle. For the trapezius, the electrode pair was placed along the direction of the muscle, 2 cm lateral to the midpoint of the line between the seventh cervical vertebra and the acromion. For the extensor carpi radialis brevis muscle, electrodes were positioned on the palpable muscle belly at approximately 45% of the total length of the radius as measured from the styloid process. For the extensor digitorum muscle, electrodes were positioned on the palpable muscle belly at approximately 25% of the length of a line from the lateral epicondyle of the humerus to the midpoint of the styloid processes of radius and ulna, as measured from the lateral epicondyle of the humerus.

Initially, subjects performed three static MVCs for each muscle, to determine the maximum voluntary excitation (EMGmax). There were at least 60 s of rest in between the trials. For the extensor muscles in the forearm, three maximal handgrips and three maximal wrist and finger extensions against a flat, vertical resistance were performed. For the trapezius muscle, resistance to the combination of maximal elevation and maximal abduction of the upper arm against manual resistance was used.

The subjects then performed isometric pinching with the thumb opposing the index and middle finger of the dominant hand. The subjects sat in a standardized posture with the upper arm elevated 40° in a plane of elevation approximately 10° outward relative to

the sagittal plane. The forearm was held horizontally in the sagittal plane and neutral with regard to pronation and supination. The wrist was held in a neutral position. A small force transducer (model Q07309; Futek, Irvine, CA, USA) hung on a cord exactly between the thumb and the index and middle finger (figure 1). Two maximal voluntary pinch forces were measured to determine the appropriate pinch force for the trials performed by each individual subject.

A balanced design of three pinch forces with three static load levels at the shoulders was used. The combination of these pinch forces and shoulder loads was chosen to simulate work with low intensity. The contraction–relaxation ratio for the pinch force in all the exercise periods was 10:2 s (10 s contraction followed by 2 s relaxation) and each trial lasted for 3 min.

Pinch forces were set at 0, 10 and 25% of maximal pinch force. The first static shoulder load level was with the shoulders relaxed ('arms hanging'). The second load level was with the shoulders raised bilaterally to an indicated level ('shoulders lifted') with no external load. The third load level was with raised shoulders and a load (4.95 kg) added to each shoulder ('loaded'). Each load was attached to a belt passing over the acromion.

The exerted pinch force and the target force level were both presented on a computer screen. In addition to the visual feedback, verbal feedback was given about the contraction and relaxation periods. There was at least 5 min rest in between trials.

2.3. *Data acquisition and analysis*

The blood velocity waveforms were measured beat by beat using a Doppler ultrasound scanner (Diasonics VST Masters Series System; GE-Medical, Waukesha, WI, USA). A 5 MHz probe (Curved Linear Array; GE-Medical) was placed over the brachial artery,

Figure 1. Pinch force measurements.

just proximal to the elbow. Gain settings were the same for all the subjects and were kept constant in all measurements. All recordings were stored on videotape for later analysis.

Blood flow data were analysed from the videotapes using the software on the ultra-sound scanner. Mean peak blood velocity (MPBV) was determined from the maximum outline trace of the blood velocity wave form during one cardiac cycle. MPBV values were obtained three times per minute during the second and third minutes of the exercise period. Assuming a parabolic velocity profile in the vessel, the mean blood velocity (MBV) is half as high as the MPBV. For each subject, the radius of the vessel was obtained from the average of the three brachial artery diameter measurements. Ten out of 13 Doppler datasets were complete and thus judged suitable for analysis.

Because the data of the exercise periods contained data points from the 10 s con-tractions ('on' points) as well as from the two second relaxations ('off' points, see figure 2), the 'off' points were identified, where appropriate. To prevent the influence of the 'off' data points to be over- or underestimated, a weighted average, based on the duration of the contraction and relaxation periods (10 and 2 s), was calculated.

For each subject, the weighted average of the MBV per trial was calculated. Finally the absolute values of forearm volume blood flow were calculated according to the formula:

$$F = MBV * \pi r^2 \tag{1}$$

where F is the absolute volume blood flow in ml/min and r is the radius of the brachial artery (cm) (Hughson *et al.* 1996).
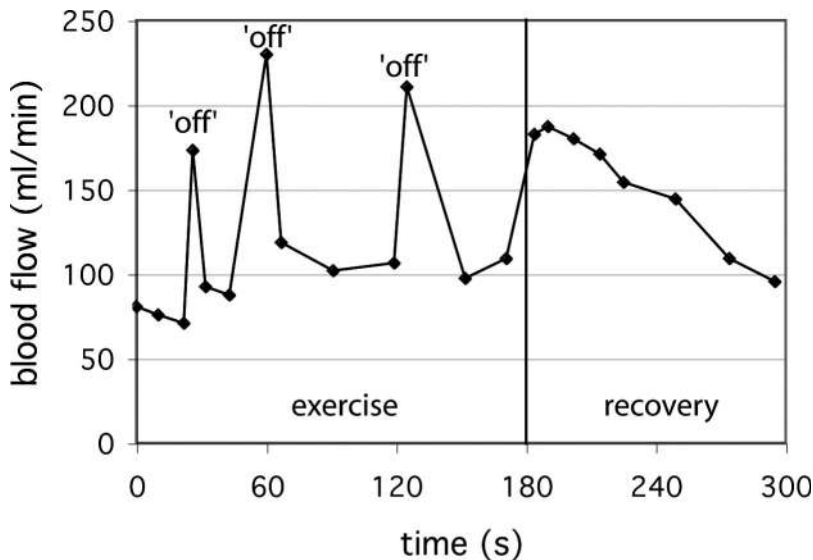

Figure 2. Example of the time course of blood flow during 3 min exercise and 2 min recovery. During exercise, the 'off' points represent mean blood flow of a cardiac cycle within a 2 s relaxation period and the other data points represent mean blood flow of a cardiac cycle during a 10 s pinching period. Note the rapid response of the blood flow during relaxation.

Electromyography was measured from the muscle bellies of the descending part of the trapezius muscle, the extensor carpi radialis brevis muscle and the extensor digitorum muscle using an EMG-system (Porti-17[TM]; TMS, Enschede, The Netherlands; input impedance $> 10^{12} \Omega$, CMRR > 90 dB, software Poly5) and bipolar surface electrodes (Ag-AgCl, type N-10-A; Medicotest, Denmark). Signals were analogue band-pass filtered (10–400 Hz), amplified 20 times and A-D converted (22 bits) at 1000 Hz. EMGmax values for each muscle were derived from the MVC and the maximal pinch force trials by selecting the highest 1 s average of the rectified signal across all these contractions. The EMG data were rectified, filtered (4th order Butterworth lowpass 5 Hz) and normalized to the EMGmax. The 50th percentile, median, activity over the exercise period was subsequently calculated.

2.4. *Statistical analysis*

SPSS software (version 7.5; SPSS Inc., Chicago, IL, USA) was used for the statistical analysis of the data. In case of missing data, a missing values analysis was done with an EM-estimation (estimated means, maximum number of iterations: 100). ANOVA-repeated measures was used for analysing the main and interaction effects of pinch level and shoulder load. Post-hoc tests were also performed with ANOVA-repeated measures. The level of significance was set at $p < 0.05$.

3. Results

To show the time course of blood flow and the influence of the 2-s interruption (relaxation period) of the pinching task on the blood flow, a typical example of the records is shown in figure 2. The peaks at times 26, 60 and 125 s are measurements during the interruptions in the trial.

Average blood flow values of ten subjects at the three pinch and three shoulder levels are shown in figure 3. In the exercise period, blood flow increased with increasing pinch
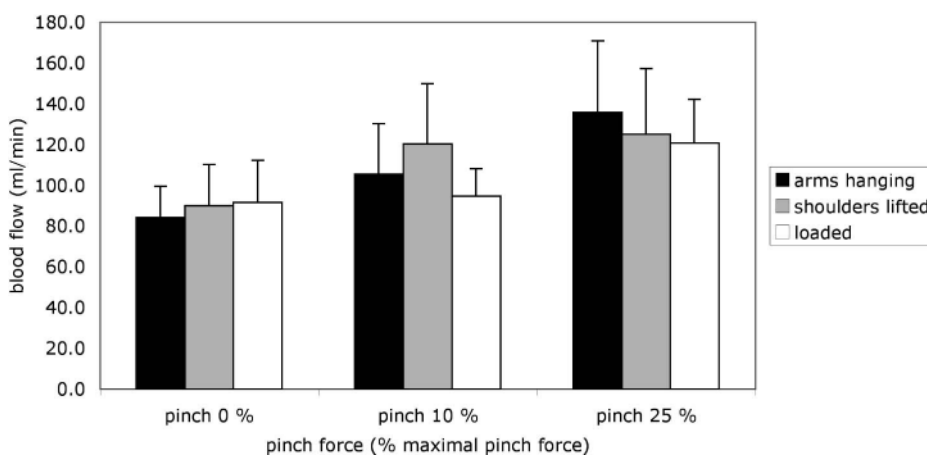

Figure 3. Mean and standard deviation of blood flow at the three shoulder static load levels (arms hanging; shoulders lifted; loaded) combined with the three levels of pinch force (0%, 10% and 25% of maximal pinch force).

force ($p < 0.001$) and was affected by shoulder load ($p = 0.024$). No interaction between pinch force and shoulder load was found. Post-hoc, the effect of shoulder load was only explained by a significantly lower blood flow during the 'loaded' condition compared to the 'shoulders lifted' condition ($p = 0.005$). For the pinch force, all post-hoc tests showed significantly increased blood flow with increasing pinch force. No interaction effects were found. A summary of the main and post-hoc effects is given in table 1.

No influence of time on EMG measurements during the exercise periods was found. Therefore, the average values over the exercise periods were used for analysis. For the forearm muscles, the EMG-activity increased significantly with increasing pinch force. Figure 4 shows the effect of pinch force at three shoulder loads. All post-hoc tests showed increasing EMG signals with increasing pinch force. Shoulder load had a minor but significant effect on the EMG amplitude of one of the forearm muscles, the carpi radialis brevis muscle ($p = 0.048$). Post-hoc testing showed a higher activation in the 'shoulders lifted' condition than in the 'arms hanging' condition ($p = 0.048$).

Table 1. Summary table of the statistical results of the blood flow data.

	p-value
Shoulder static load	0.024*
Arms hanging (no load) < shoulders lifted (no load)	0.274
Arms hanging (no load) > loaded	0.073
Shoulders lifted (no load) > loaded	0.005*
Pinch force	<0.001*
0% < 10% maximal	<0.001*
0% < 25% maximal	<0.001*
10% < 25% maximal	<0.001*
Shoulder static load × Pinch force	0.311

*Values are significant at $p < 0.05$. Post-hoc tests are shown only when a significant effect was found.
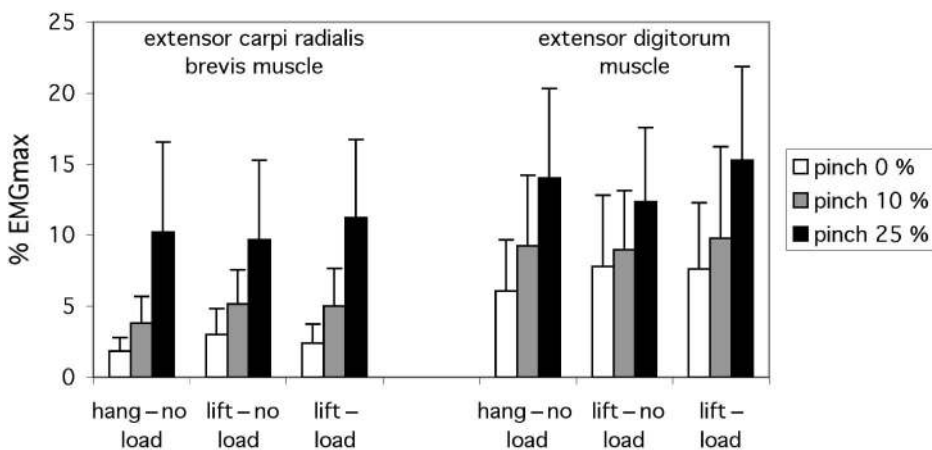

Figure 4. Mean and standard deviation of electromyographic activity (% EMGmax) of the extensor carpi radialis brevis muscle and the extensor digitorum muscle at the three shoulder static load levels (arms hanging; shoulders lifted; loaded) combined with the three levels of pinch force (0%, 10% and 25% of maximal pinch force).

The EMG amplitude of the trapezius muscle significantly decreased with increasing pinch force and significantly increased with increasing shoulder load (figure 5). All post-hoc tests showed significantly higher EMG signals with higher shoulder load. The effect of pinch force appeared to be caused by a significant drop between the 0 and 10% conditions ($p = 0.003$) and 0 and 25% conditions ($p = 0.011$). No interaction effects were found. A summary of significant main and post-hoc effects on the muscle activity is given in table 2.
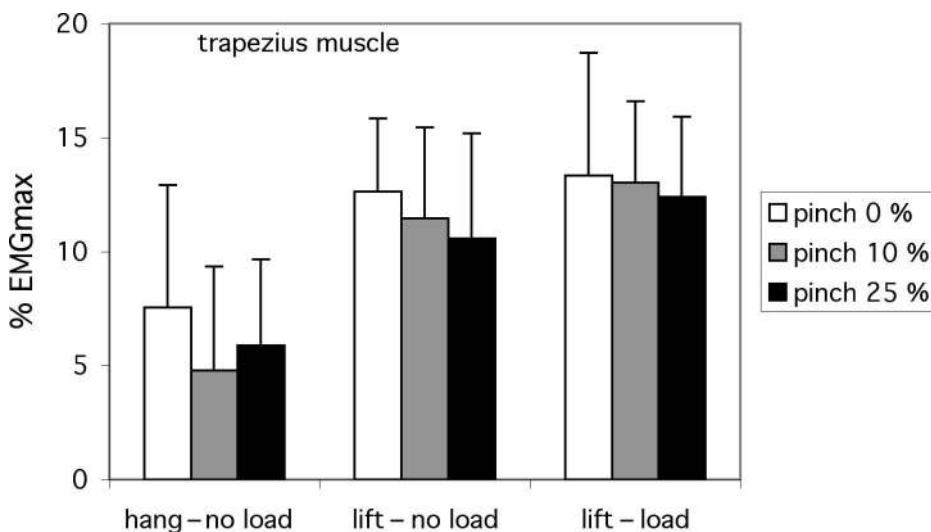

Figure 5. Mean and standard deviation of electromyographic activity (% EMGmax) of the trapezius muscle at the three shoulder static load levels (arms hanging; shoulders lifted; loaded) combined with the three levels of pinch force (0%, 10% and 25% of maximal pinch force).

Table 2. Summary table of the statistical results of the electromyographic data.

	Extensor carpi radialis brevis (P50) *p*-value	Extensor digitorum (P50) *p*-value	Trapezius (P50) *p*-value
Shoulder static load	0.048*	0.223	<0.001*
Arms hanging (no load) < shoulders lifted (no load)	0.042*	–	<0.001*
Arms hanging (no load) > loaded	0.067	–	<0.001*
Shoulders lifted (no load) > loaded	0.441	–	0.036*
Pinch force	<0.001*	<0.001*	0.005*
0% < 10% maximal	<0.001*	0.028*	0.003*†
0% < 25% maximal	0.001*	0.001*	0.011*†
10% < 25% maximal	0.003*	0.002*	0.788
Shoulder static load × Pinch force	0.074	0.333	0.632

P50 = 50th percentile.
*Values are significant at $p < 0.05$. Post-hoc tests are only shown when a significant effect was found.
†The direction of the post-hoc effect of pinch on the trapezius muscle is opposite to that on the forearm muscles, i.e. 0 > 10%.

4. Discussion

A positive association was demonstrated between intermittent pinch grip exercise and blood flow to the forearm muscles. In addition, a significant effect of static shoulder load on blood flow to the forearm was found.

An increase in blood flow to the forearm caused by an increase in force exerted by forearm muscles has been found in several studies (Byström and Kilbom 1990, Jensen *et al.* 1993, Jensen 1997, Byström *et al.* 1998). Despite differences in protocol, such as performing pinch grip instead of handgrip exercise and performing the task intermittently instead of continuously, similar results were obtained in the present study. Active hyperaemia, a phenomenon of local regulation, might be responsible for this increase in flow. As a result of increased metabolic activity of the exercising muscle, various factors (for example, decreased oxygen concentration and increased concentrations of carbon dioxide and hydrogen ions) act upon the arteriolar smooth muscle and cause it to dilate (Radegran and Saltin 1998). In addition, central vascular control mechanisms and increased cardiac output occur in response to exercise, leading to increased blood flow. An increase in blood flow might also be induced by a rapid rise in blood pressure (Hisdal *et al.* 2004). This rise in blood pressure can be seen as a cardiovascular reflex to muscle contractions independent of the muscle mass involved (Williams 1991). Simultaneously, muscle contraction resulting in compression of the vessels may counteract these mechanisms (Jensen *et al.* 1993). Since the results of the present study show an increase in flow during the trials, the former mechanisms apparently outweigh the latter mechanism. This is possibly due to the fact that exercise during this study was performed intermittently (with each 10 s contraction followed by a 2 s relaxation (as illustrated in figure 2), through which the intramuscular pressure will have dropped frequently so that hyperaemia was elicited, even though only briefly.

In addition to the influence of pinch force on blood flow, a significant main effect of shoulder load on blood flow in the arm was found. No previous reports of such a relationship have been found. There are two possible mechanisms that might explain this effect: 1) compression of the vessels in the shoulder region by contraction of the shoulder muscles; 2) competition for the available volume of blood. Shoulder elevation and the associated muscle tension and movement of anatomical structures relative to each other might compress the vessels and restrict flow, as suggested by Keller *et al.* (1998). Similarly, in patients with thoracic outlet syndrome, vascular compression causes upper extremity pain, numbness, weakness and fatigability (Rayan 1998, Coletta *et al.* 2001). However, the blood pressure in the great arteries in the shoulder is probably higher than the pressure that is generated in the shoulder muscles during the shoulder load conditions. It is estimated that the latter is approximately 42 mmHg based on data from Järvholm *et al.* (1988) and that the pressure in the arteries is approximately 110 mmHg. Consequently, this mechanism is not expected to result in a major obstruction of blood flow.

Alternatively, competition between shoulder and forearm muscles for the available volume of blood might explain the results. No literature about blood flow distribution within the upper extremity during exercise has been found. Kilbom and Brundin (1976) investigated the distribution of blood flow when isometric handgrip exercise (at 20% MVC) was added to light dynamic leg exercise. Leg blood flow was unaffected when the handgrip exercise was added. However, other experiments showed that circulatory responses during combined exercise are lower than the sum of those developed during the corresponding single exercises (Grucza *et al.* 1989, Kagaya and Ogita 1992, Saito *et al.*

1992, Kagaya *et al.* 1994). In one experiment, when subjects were cycling (at 50–60% VO$_{2\text{max}}$) and arm exercise was added, a decrease in leg blood flow was found (Harms 2000). Ogita and Kagaya (1996) compared the cardio-respiratory responses to various combinations of upper and lower limb exercise with the sum of the responses to the component exercises. They found a decrease in the exercise duration and forearm blood flow when comparing rhythmic handgrip exercise (at 50% MVC until exhaustion) added to rhythmic plantar flexion (at 10% MVC) with handgrip exercise alone at the same intensity. This decrease in blood flow was found only when handgrip exercise was added to plantar flexion, not when plantar flexion (at 50% MVC) was added to handgrip exercise (at 10% MVC). At present it remains unclear which of the two mechanisms accounts for the reduced blood flow in the high shoulder load condition.

The fact that no clear unambiguous effect of shoulder load on arm blood flow was found may be due to effects of an opposing mechanism. First, the increase in forearm muscle activity with shoulder loading might promote blood flow and, hence, partially offset the mechanisms discussed above. Second, with increasing shoulder load the total active muscle mass increases, which may also promote blood flow, through effects on cardiac output. However, changes in cardiac output appeared to be responsible for only a minor part of the blood flow increase in comparable exertions (Jensen *et al.* 1993). In addition, the actual shoulder load imposed by the experimental manipulations may have varied between subjects, reducing the power of the experimental design.

The EMG results indicate that the tasks can be qualified as low intensity. The average 50th percentile was lower than 15% MVE for all the muscles. Although the loading of the shoulder seems to be rather artificial in the 'loaded' condition, the levels of activation are not rare for low intensity tasks. Westgaard *et al.* (1996) showed similar activation levels for the trapezius muscle in office work.

From the EMG results, it can be concluded that the different intensities of pinch force and shoulder load lead, as intended, to increasing levels of distal and proximal muscle activity, respectively. Trapezius activity, however, also decreased significantly with increasing pinch force. Post-hoc tests revealed that the difference between 0% pinch force and 10% pinch force (i.e. between no pinch and pinch) was responsible for this decrease. A reduction in activity is expected when the subjects use the transducer as a support. However, since the force transducer was hung in such a way that only a little weight could be supported, it is not likely that this explains the reduction in trapezius activity. Just holding the arm in position apparently is a greater challenge for the trapezius than pinching at low intensities. A similar result was found in a previous study, at a higher pinch force a decrease in trapezius activity was found (Visser *et al.* 2003). It seems plausible that this reduction in trapezius activation is related to a change in the demands for keeping the arm stable. Jeka and Lackner (1994) found in their study on postural control that just touching a stable point (with the fingertip) led to an improvement in whole body stability, which was similar to holding a stable endpoint with the whole hand. The fact that the subjects were holding the force transducer while pinching might similarly facilitate stabilization of the arm. During the 'no pinch' trials this extra stability was lacking, which apparently increased trapezius activity.

5. Conclusions

In conclusion, increased pinch force increased blood flow to the forearm. Static shoulder load had an effect on blood flow to the forearm with a decreased blood flow at the high

load condition. The precise mechanisms accounting for the influence of shoulder load remain unclear. Trapezius activity decreased from that while keeping the arm still in the desired position (0% maximal pinch force) to that during pinching tasks (10% and 25% maximal pinch force). This decrease is probably due to facilitation of stabilizing the arm as a consequence of the information provided by holding the force transducer.

The results of this study indicate that shoulder load might influence blood flow to the forearm. It would seem to be beneficial to find out whether this influence might lead to a cumulative deficiency of blood flow over time and thus be a risk factor for UEMSDs in the long term. Postural effects on blood flow, such as those demonstrated here, might aggravate symptoms of UEMSDs related to reduced vasodilation during exercise such as demonstrated by Pritchard *et al.* (1999).

References

BERNARD, B.P., 1997, *Musculoskeletal Disorders (MSDs) and Workplace Factors – A Critical Review of Epidemiologic Evidence for Work-related Musculoskeletal Disorders of the Neck, Upper Extremity, and Low Back* (Cincinnati, OH: National Institute for Occupational Safety and Health).

BUCKLE, P. and DEVEREUX, J., 1999, *Work-related Neck and Upper Limb Musculoskeletal Disorders* (Luxembourg: Office for Official Publications of the European Communities).

BYSTRÖM, S., JENSEN, B., JENSEN-URSTAD, M., LINDBLAD, L.E. and KILBOM, A., 1998, Ultrasound-Doppler technique for monitoring blood flow in the brachial artery compared with occlusion plethysmography of the forearm. *Scandinavian Journal of Clinical and Laboratory Investigation*, **58**, 569–576.

BYSTRÖM, S.E. and KILBOM, A., 1990, Physiological response in the forearm during and after isometric intermittent handgrip. *European Journal of Applied Physiology and Occupational Physiology*, **60**, 457–466.

CARAYON, P., SMITH, M.J. and HAIMS, M.C., 1999, Work organization, job stress, and work-related musculoskeletal disorders. *Human Factors*, **41**, 644–663.

COLETTA, J.M., MURRAY, J.D., REEVES, T.R., VELLING, T.E., BRENNAN, F.J., HEMP, J.R. and HALL, L.D., 2001, Vascular thoracic outlet syndrome: successful outcomes with multimodal therapy. *Cardiovascular Surgery*, **9**, 11–15.

EDWARDS, R.H.T., 1988, Hypotheses of peripheral and central mechanisms underlying occupational muscle pain and injury. *European Journal of Applied Physiology*, **57**, 275–281.

GALEN, G.P.V., MÜLLER, M.L.T.M., MEULENBROEK, R.G.J. and GEMMERT, A.W.A.V., 2002, Forearm EMG response activity during motor performance in individuals prone to increased stress reactivity. *American Journal of Industrial Medicine*, **41**, 406–419.

GRUCZA, R., KAHN, J.F., CYBULSKI, G., NIEWIADOMSKI, W., STUPNICKA, E. and NAZAR, K., 1989, Cardiovascular and sympatho-adrenal responses to static handgrip performed with one and two hands. *European Journal of Applied Physiology and Occupational Physiology*, **59**, 184–188.

HARMS, C.A., 2000, Effect of skeletal muscle demand on cardiovascular function. *Medicine and Science in Sports Exercise*, **32**, 94–99.

HISDAL, J., TOSKA, K., FLATEBO, T., WAALER, B. and WALLOE, L., 2004, Regulation of arterial blood pressure in humans during isometric muscle contraction and lower body negative pressure. *European Journal of Applied Physiology*, **91**, 336–341.

HUGHSON, R.L., SHOEMAKER, J.K., TSCHAKOVSKY, M.E. and KOWALCHUK, J.M., 1996, Dependence of muscle VO2 on blood flow dynamics at onset of forearm exercise. *J Appl Physiol*, **81**, 1619–1626.

JÄRVHOLM, U., STYF, J., SUURKULA, M. and HERBERTS, P., 1988, Intramuscular pressure and muscle blood flow in supraspinatus. *European Journal of Applied Physiology*, **58**, 219–224.

JEKA, J.J. and LACKNER, J.R., 1994, Fingertip contact influences human postural control. *Experimental Brain Research*, **100**, 495–504.

JENSEN, B.R., 1997, Doppler blood flow and peripheral resistance in the forearm during and following low-level isometric hand-grip contractions. *Advances in Occupational Medicine and Rehabilitation*, **3**, 21–35.

JENSEN, B.R., FALLENTIN, N., BYSTRÖM, S. and SJØGAARD, G., 1993, Plasma potassium concentration and Doppler blood flow during and following submaximal handgrip contractions. *Acta Physiologica Scandinavica*, **147**, 203–211.

JENSEN, B.R., JØRGENSEN, K., HUIJING, P.A. and SJØGAARD, G., 1995, Soft tissue architecture and intramuscular pressure in the shoulder region. *European Journal of Morphology*, **33**, 205–220.

JONSSON, B., 1988, The static load component in muscle work. *European Journal of Applied Physiology*, **57**, 305–310.

KADEFORS, R., FORSMAN, M., ZOËGA, B. and HERBERTS, P., 1999, Recruitment of low threshold motor-units in the trapezius muscle in different static arm positions. *Ergonomics*, **42**, 359–375.

KAGAYA, A. and OGITA, F., 1992, Peripheral circulatory readjustment to superimposition of rhythmic handgrip exercise to plantar flexion of different duration. *Journal of Exercise Science*, **2**, 5–12.

KAGAYA, A., SAITO, M., OGITA, F. and SHINOHARA, M., 1994, Exhausting handgrip exercise reduces the blood flow in the active calf muscle exercising at low intensity. *European Journal of Applied Physiology*, **68**, 252–257.

KELLER, K., CORBETT, J. and NICHOLS, D., 1998, Repetitive strain injury in computer keyboard users: pathomechanics and treatment principles in individual and group intervention. *Journal of Hand Therapy*, **11**, 9–26.

KILBOM, A. and BRUNDIN, T., 1976, Circulatory effects of isometric muscle contractions, performed separately and in combination with dynamic exercise. *European Journal of Applied Physiology and Occupational Physiology*, **36**, 7–17.

KROEMER, K.H.E., 1989, Cumulative trauma disorders: their recognition and ergonomics measures to avoid them. *Ergonomics*, **20**, 274–280.

KUORINKA, I., JONSSON, B., KILBOM, Å., VINTERBERG, H., BIERING-SORENSEN, F., ANDERSSON, G. and JORGENSEN, K., 1987, Standardized Nordic questionnaires for the analysis of musculoskeletal symptoms. *Ergonomics*, **18**, 233–237.

LARSSON, S.E., 2003, Neck-shoulder pain in relation to blood microcirculation and EMG, psychophysiological stress. In *Chronic Work-Related Myalgia – Neuromuscular Mechanisms behind Work-related Chronic Muscle Pain Syndromes*, H. Johansson, U. Windhorst, M. Djupsjöbacka and M. Passatore (Eds.), pp. 111–115 (Umeå: Gävle University Press).

MUGGLETON, J.M., ALLEN, R. and CHAPPELL, P.T., 1999, Hand and arm injuries associated with repetitive manual work in industry: a review of disorders, risk factors and preventive measures. *Ergonomics*, **42**, 714–739.

MURTHY, G., KAHAN, N.J., HARGENS, A.R. and REMPEL, D.M., 1997, Forearm muscle oxygenation decreases with low levels of voluntary contraction. *Journal of Orthopaedic Research*, **15**, 507–511.

OGITA, F. and KAGAYA, A., 1996, Differential cardiorespiratory response to combined exercise with different combinations of forearm and calf exercise. *European Journal of Applied Physiology and Occupational Physiology*, **73**, 511–515.

PRITCHARD, M.H., PUGH, N., WRIGHT, I. and BROWNLEE, M., 1999, A vascular basis for repetitive strain injury. *Rheumatology (Oxford)*, **38**, 636–639.

RADEGRAN, G. and SALTIN, B., 1998, Muscle blood flow at onset of dynamic exercise in humans. *American Journal of Physiology*, **274**, H314–H322.

RAYAN, G.M., 1998, Thoracic outlet syndrome. *Journal of Shoulder and Elbow Surgery*, **7**, 440–451.

RØE, C. and KNARDAHL, S., 2002, Muscle activity and blood flux during standardised data-terminal work. *International Journal of Industrial Ergonomics*, **30**, 251–264.

SAITO, M., KAGAYA, A., OGITA, F. and SHINOHARA, M., 1992, Changes in muscle sympathetic nerve activity and calf blood flow during combined leg and forearm exercise. *Acta Physiologica Scandinavica*, **146**, 449–456.

SJØGAARD, G., LUNDBERG, U. and KADEFORS, R., 2000, The role of muscle activity and mental load in the development of pain and degenerative processes at the muscle cell level during computer work. *European Journal of Applied Physiology*, **83**, 99–105.

SJØGAARD, G. and SOGAARD, K., 1998, Muscle injury in repetitive motion disorders. *Clinical Orthopaedics and Related Research*, **351**, 21–31.

SLUITER, J.K., REST, K.M. and FRINGS-DRESEN, M.H.W., 2001, Criteria document for evaluation of the work-relatedness of upper extremity musculoskeletal disorders. *Scandinavian Journal of Work, Environment and Health*, **27**, 1–102.

VISSER, B., DE KORTE, E., VAN DER KRAAN, I. and KUIJER, P., 2000, The effect of arm and wrist supports on the load of the upper extremity during VDU work. *Clinical Biomechanics*, **15**, S34–S38.

VISSER, B., DE LOOZE, M.P., VEEGER, D.E., DOUWES, M., GROENESTEIJN, L., DE KORTE, E. and VAN DIEEN, J.H., 2003, The effects of precision demands during a low intensity pinching task on muscle activation and load sharing of the fingers. *Journal of Electromyography and Kinesiology*, **13**, 149–157.

WESTGAARD, R.H., JANSEN, T. and JENSEN, C., 1996, EMG of neck and shoulder muscles: the relationship between muscle activity and muscle pain in occupational settings. In *Electromyography in Ergonomics*, S. Kumar and A. Mital (Eds.), pp. 227–258 (London: Taylor and Francis).

WILLIAMS, C.A., 1991, Effect of muscle mass on the pressor response in man during isometric contractions. *Journal of Physiology*, **435**, 573–584.