Journal of Ergonomics

Korol et al., J Ergonomics 2017, S6
DOI: 10.4172/2165-7556.S6-004

Research Article Open Access

Relation between Perceived Effort and the Electromyographic Signal in Localized Effort Activities of Forearm Muscles

Gadi Korol[1], Amir Karniel[1], Itzik Melzer[2], Adi Ronen[3], Yael Edan[3], Helman Stern[3] and Raziel Riemer[3]*

[1]Department of Biomedical Engineering, Ben-Gurion University of the Negev, P.O.B. 653, Beer-Sheva 8410501, Israel
[2]Department of Physical Therapy, Ben-Gurion University of the Negev, P.O.B. 653, Beer-Sheva 8410501, Israel
[3]Department of Industrial Engineering and Management, Ben-Gurion University of the Negev, P.O.B. 653, Beer-Sheva 8410501, Israel

Abstract

To understand the factors that determines human perception of effort. This study investigated the relationship between objective measures of exertion (handgrip force and electromyography – EMG) and perceived effort (Borg scale) during localized activities of the forearm muscles. This relation is important for understanding the factors that determine human perception of effort.

Method: Two hand-gesture experiments (low effort) and one handgrip force experiment (moderate to high effort) were carried out. During the experiments, Borg ratings, grip forces and EMG signals from six forearm muscles were obtained. The relationship between objective measurements and perceived effort were investigated using generalized linear mixed models.

Results: The linear models for predicting the Borg ratings based on gender and EMG provided R-squared values of up to 0.5 for generic models and up to 0.85 when fitting a model to individual subjects. In addition, the model based on the average EMG of all recorded muscles was found to as good as a model based on individual muscles. The results indicated that women rated low-effort activities as less being effortful than men, while there was no difference between genders for moderate- to high-effort activity.

Conclusion: The findings of this study demonstrated that muscle activation level (i.e. EMG) is related to perceived effort for localized hand effort tasks and can explain a large part of an individual's perceived effort. The results suggest that the perception of effort is related to the overall effort of the muscles and not to a specific muscle.

Keywords: Electromyography; Perceived effort; Localized effort

Abbreviations: ARMS: Average root mean square (of EMG); BMI: Body Mass Index; Borg scale (CR10): Borg scale category (C) ratio (R) 0 to 10; ECR: Extensor Carpi Radialis Brevis and Longus; ECU: Extensor Carpi Ulnaris; ED: Extensor Digitorum; EMG: Electromyography; FCR: Flexor Carpi Radialis; FCU: Flexor Carpi Ulnaris; GLMM: Generalized Linear Mixed Model; HF: Hand-Grip Force Experiment; HG1: Hand Gesture Experiment 1; HG2: Hand Gesture Experiment 2; MVIC: Maximum Voluntary Isometric Contraction; NRMS: Normalized Average Root Mean Square (Of EMG); PT: Pronator Teres; SS_{RES}: The Sum Of The Squared Residuals; SS_{TOT}: The Total Sum Of Squares.

Introduction

There are two common approaches for evaluating physical exertion. In the subjective approach, the user's subjective evaluation of the relative perceived effort (RPE) is evaluated, possibly on the Borg scale [1]. With the objective method, such phenomena as metabolic power, heart rate, electromyography (EMG) and applied load or force are measured. For measuring localized effort during physical activity computer mice, joysticks, touchscreens and hand gesture recognition interfaces EMG is the most common method even though. However, the relation between perceived effort and EMG has not been well studied.

The EMG signal obtained for a given muscle is related to the force generated by that muscle [2,3]. Additionally, an ensemble of EMG signals across all the relevant muscles can be used to represent the physical exertion associated with a task [4-6]. Mork and Westgaard [7], Skotte et al. [8], Agarabi et al. [9] used EMG signals of several muscles as a measurement for the level of physical exertion.

Several studies have focused on understanding the mechanism contributing to the sense of effort. McCloskey et al. [10] study the effect of fatigue on perceived effort. Other studies addressing the relation between force and RPE found a positive correlation (R_2>0.7) between RPE (as evaluated with the Borg scale) and objective measures of exerted torque or force during moderate to high effort e.g., Tiggemann et al. [11], during leg and bench press exercises. Other researchers investigating the relation between EMG signals of single muscle and perceived effort during isometric contractions found high correlations for the upper trapezius [12] and knee extensors [13]. Even though the above studies measured multiple muscles, only the relation between the activity of individual muscles and the level of physical exertion was reported. However, since most physical tasks are complex activities involving several muscles, it is reasonable to postulate that perceived effort would depend on combined muscle activity and not merely the activity of a single muscle.

To the best of our knowledge, the study of Dickerson et al. [14], which researched shoulder load during reaching tasks, is the only study of the combined effect of multiple muscles (as measured by EMG) and

***Corresponding author:** Raziel Riemer, Department of Industrial Engineering and Management, Ben-Gurion University of the Negev, P.O.B. 653, Beer-Sheva 8410501, Israel, Tel: +972 54 4908999; E-mail: rriemer@bgu.ac.il

Received September 13, 2017; **Accepted** September 26, 2017; **Published** October 04, 2017

Citation: Korol G, Karniel A, Melzer I, Ronen A, Edan Y, et al. (2017) Relation between Perceived Effort and the Electromyographic Signal in Localized Effort Activities of Forearm Muscles. J Ergonomics S6: 004. doi: 10.4172/2165-7556.1000.S6-004

load level on perceived effort. The study illustrates the importance of the relationship between EMG and perceived effort for understanding the factors that determine human perception of effort.

As far as we can determine, the relation between perceived effort and EMG recordings or the load on the forearm muscles is another area that researchers have not studied. While there have been studies that investigate the relation between subjective and objective approaches for evaluating physical exertion, this body of research has focused on moderate to high levels of effort and not on the low-effort activities that characterize many human-machine interactions.

In light of the paucity of research into low-effort activities, we addressed the issue of low-effort as well as moderate to high activity of the forearm muscles. This is important because of the increasing interaction between human and computer in the modern environment. These interactions are at relatively low effort (e.g. computer mice, touchscreen). At the same time, our study focuses on reviewing a question that is subject to controversy in the literature—whether there are differences in perceived effort between men and women during physical activity. Previous studies seeking to reveal gender differences during different activities present contradictory findings. While the following studies found no gender difference: Demura et al. [15] in researching subjective muscle fatigue sensation during sustained static gripping. 2) Demello et al. [16] examining the ratings of perceived exertion during moderate to submaximal running exercise. 3). Pincivero et al. [17] demonstrated no significant differences in the perceived exertion response between males and females during sub-maximal inertial knee extension exercise. On the other hand, O'Connor et al. [18] found that women compared with men rate eccentric exercises at the same relative intensity level as less effortful while Koltyn et al. [19], in comparing perceived effort among competitive swimmers during submaximal swimming (90% of maximal velocity), discovered that the RPE was lower in females despite their greater objective strain (mean HR).

In researching the relationship between objective measures of exertion during localized activities of the forearm muscles, we mainly used muscle activity (EMG) and perceived effort, as evaluated on the Borg scale (CR10). Further we also study the relation between applied load and the Borg scale (CR10). Since the question of how perceived effort relates to the combined effect of several active muscles has been rarely studied. This research seeks to provide insights into understanding the mechanisms determining perceived exertion and as to whether there is indeed a gender difference in perceived effort during physical activity involving the forearm muscles.

Methods

The study consisted of three localized effort experiments: (a) two hand gesture experiments (designated HG1 and HG2) that included low-exertion tasks where no external force was applied, and (b) a handgrip force experiment (HF) that comprised a moderate- to high-exertion task in which the subjects exerted pressure against an external force.

For each experiment, EMG signals were correlated with Borg ratings. In addition, a generalized linear mixed model (GLMM) analysis was used to fit linear models in order to predict the level of perceived effort based on gender, EMG and force. Furthermore, to test whether the relationship between the EMG and the Borg ratings that were obtained in the first hand gesture experiment (HG1) could be generalized to the other experiments, the Borg ratings in the HG2 and HF experiments (i.e., test datasets) were compared to Borg rating predictions based on the models that were developed using the HG1 dataset.

Participants

A total of 54 healthy students (27 females, 27 males), with an average age of 25.44 (SD 1.71) and an average BMI of 22.56 (SD 2.49), were recruited for the three different experiments: (a) first hand gesture experiment (HG1)-18 students (nine females, nine males), (b) second hand gesture experiment (HG2)-16 students (eight females, eight males), and (c) a handgrip force experiment (HF)-20 students (ten females, ten males). The subjects were all right-handed with no reported musculoskeletal or neurological disorders of the right forearm and hand. All participants signed informed consent forms that had been approved by the Human Subjects Research Committee of Ben-Gurion University of the Negev.

Evaluation of perceived effort

Subjective perceived effort was evaluated on the Borg CR-10 scale (from 0 for 'no effort' to 10 for 'maximum possible effort') for rating localized exertion (Table 1) [1]. At the start of the experiments, the scale was explained to the participants. For rating the effort level, the subjects were instructed to start by reading the written expressions describing the numbers on the Borg scale and only then to choose a number that corresponded to the written expression.

Hand gesture experiments

To simulate localized low-effort activity, two hand gesture experiments (HG1 and HG2) were performed. Each experiment consisted of eight different hand gestures (gestures 1-8 for HG1 and gestures 9-16 for HG2, Figure 1). The hand gestures were selected from a set of gestures that have been identified as good hand gestures for evaluating human-machine interactions (gestures 1-6 and 9-14) [20] and from a set of gestures that were considered to be difficult to perform (gestures 7, 8, 15 and 16). The eight specific gestures for each experiment were selected to provide diverse hand configurations and different levels of difficulty. Experiment HG1 was run a period of time prior to HG2, and the results were presented in part at the annual meeting of the Human Factors and Ergonomics Society [21].

Testing procedure

The testing procedure, was described in Korol et al. [21], and is presented here in a brief for the sake of clarity. Each subject was seated comfortably on a chair opposite a table. The Borg scale and the hand gesture illustrations were placed in front of the subject (Figure 2). During the experiment, the subject's right elbow, forearm and hand

Rating	Perceived level of effort
0	Nothing at all
0.5	Extremely light
1	Very light
2	Light
3	Moderate
4	Somewhat hard
5	Hard
6	
7	Very hard
8	
9	Extremely hard
10	Maximum possible effort

Table 1: Borg CR-10 scale for rating localized exertion.

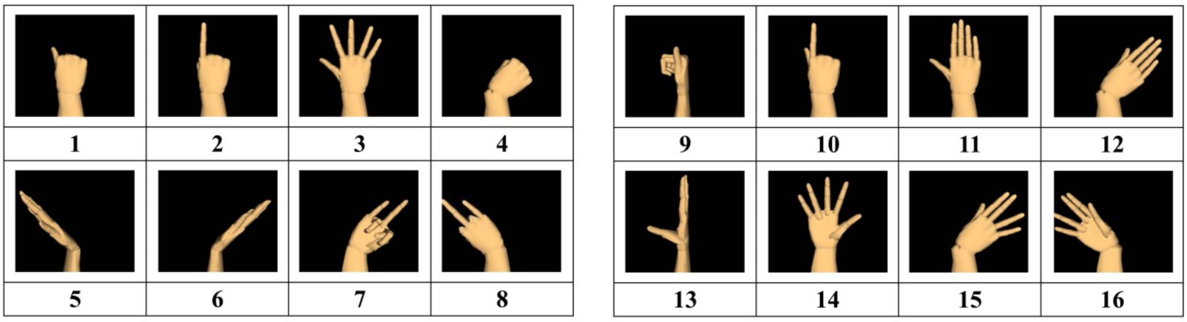


Figure 1: Hand gestures that were used in the (a) HG1 (Korol et al., 2014) and (b) HG2 experiments.

were positioned on the table top on a pad that was covered with a soft sponge (Figure 2). The subject performed eight different hand gestures as follows:

The subject held his/her hand open with the palm facing down (i.e., 'base posture') and was instructed to relax the forearm muscles to the greatest extent possible when in the base posture (EMG signals were observed online to verify muscle relaxation). Then, after receiving a spoken command, the subject performed the required hand gesture by lifting the hand and forearm just enough to perform the gesture while the elbow remained motionless on the table (Figure 2). The subject held this position for 15 seconds, and then returned to the base posture for 15 seconds of rest. This cycle was repeated three times for each hand gesture. An additional 30-second rest period was given between the different hand gestures. The Borg score for each gesture was recorded during the rest period between the repetitions. The testing procedure described above is presented in Figure 3 (block 1).

To prevent the order of the gestures from influencing the results, four different sequences of the eight gestures were used in the HG1 and HG2 experiments. These sequences were randomly assigned to the subjects in each experiment.

Handgrip force experiment

To simulate localized moderate- to high-effort activity, a 0 to 100 kilogram-force handgrip dynamometer (Takei 5001 Analogue Dynamometer, Takei, Niigata, Japan), was used (Figure 4).

The subject positioned his/her right elbow and forearm on the soft sponge pad and gripped the dynamometer handle with the right hand (as in Figure 4). During the rest period, the subject was instructed to hold the handle without applying any force and to relax the muscles to the greatest extent possible.

Each subject performed a maximum grip force test followed by four handgrip tests of 20, 40, 60 and 80% of the subject's maximum handgrip force. Each test was performed as follows. The subject held his/her hand with the palm facing down (base posture). Then, after receiving a spoken command, the subject pressed the handle with increasing force until the required force was reached. The indicator showing the grip force was hidden from the subject. Acquisition of the required force was indicated by a second spoken command. The subject was instructed to maintain the required force level for 6 seconds and then to return to the base posture for two minutes of rest [22]. This cycle was repeated twice for each force level before moving on to the next force level. The Borg score for each handgrip force level was obtained during the rest period between repetitions (each level was rated twice). Four different sequences of the grip force levels were randomly assigned to the subjects.

Maximum voluntary isometric contraction (MVIC)

After the hand gesture or handgrip sessions had been completed, each subject performed a set of tests to determine maximal isometric voluntary contraction (MVIC) for each of the six measured forearm muscles (see EMG section). The muscle testing technique of Hislop et al. [23] Korol et al., [21] for isolating specific muscles was implemented. With this technique, for each tested muscle there is a unique starting posture of the forearm and hand, from which the subject is requested to try to move his/her hand and fingers in a specific movement. While the subject was trying to perform the movement, the researcher resisted subject's movement (isometric force application). During the test, the subject was instructed to apply the maximal possible force during the contraction and was encouraged verbally by the researcher to exert the maximal force. Each isometric contraction lasted for six seconds, with a two-minute rest period between contractions [block (2) in Figure 3].

EMG measurements

The basic set-up for the EMG measurements and data processing were presented at the 2014 HFES conference [21], but are described here in a brief for the sake of clarity. Surface EMG signals were recorded from six superficial forearm muscles: pronator teres (p.t.), flexor carpi radialis (f.c.r.), flexor carpi ulnaris (f.c.u.), extensor carpi radialis brevis and longus (e.c.r.), extensor carpi ulnaris (e.c.u.) and extensor digitorum (e.d.). These muscles were chosen based on what we predicted would be the contribution of each muscle to the various hand gestures and grips that we intended to use in our experiment and the ability to measure their activity using surface EMG. The gestures and grips, in turn, were determined by the anatomical structure of the forearm [24].

EMG signals were recorded as follows. After cleaning the skin with alcohol, each of six wireless EMG bi-polar sensors (Trigno™ Wireless System, Delsys, Natick, MA, USA) was placed on the skin over the underlying belly of the particular muscle and parallel to the muscle fibers (Figure 2). The muscle belly was located manually by touching the skin over the underlying muscle during the isolation of that specific muscle, using the muscle testing technique described above (MVIC section). The EMG sensors were attached to the skin by adhesive interfaces (Adhesive Interfaces for Trigno™ Sensors, Delsys, Natick, MA, USA) and taped down with surgical tape (Medipore™ Surgical Tape, 3M, St. Paul, MN, USA).

Citation: Korol G, Karniel A, Melzer I, Ronen A, Edan Y, et al. (2017) Relation between Perceived Effort and the Electromyographic Signal in Localized Effort Activities of Forearm Muscles. J Ergonomics S6: 004. doi: 10.4172/2165-7556.1000.S6-004

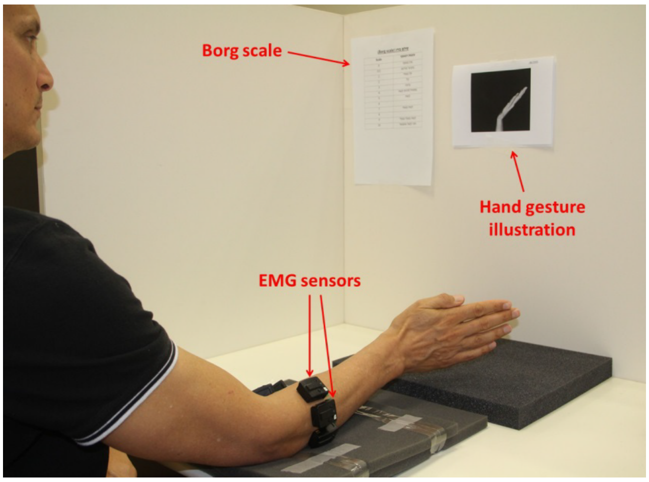


Figure 2: Hand gesture experimental setup; illustration of a subject performing a gesture.

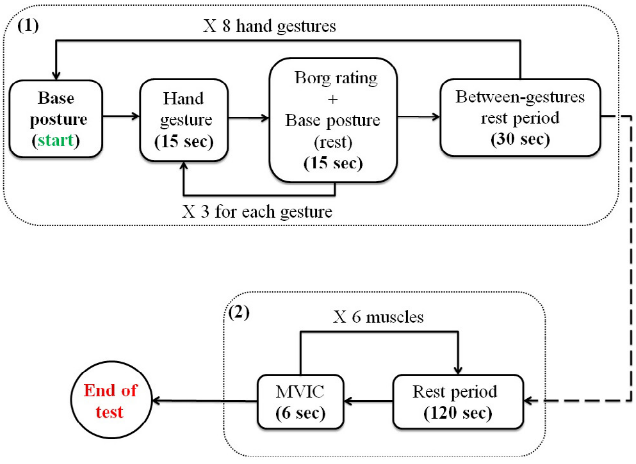


Figure 3: Experimental diagram of the hand gesture experiments. Block 1 describes the procedure of performing the hand gestures, and block 2, the testing of muscle maximum voluntary isometric contraction (MVIC).

Acquisition and processing of EMG signals

EMG signals were collected from the six muscles at a sampling rate of 2000 Hz. The signals were band pass filtered (20-450 Hz, 4th order Butterworth) with EMGWorks™ 4.1.1 (Delsys, Natick, MA, USA) acquisition software. A moving RMS of the raw EMG signals was calculated using a time window of 0.125 seconds and an overlap of 0.0625 seconds [25]. For each muscle, an average RMS (ARMS) value was calculated for the time periods of each repetition (three repetitions for each of the hand gesture experiments and two repetitions for the handgrip force experiment). For the hand gesture experiments, these periods were defined as beginning with the start of the subject's hand movement and terminating with the end of movement (immediately before the return to the base posture). At the handgrip force experiment, these periods were defined as starting from the contraction of the dynamometer's handle to the end of contraction. To compare the results between and within subjects, ARMS values for each muscle were normalized by dividing them by the maximal RMS value for each muscle [22] as obtained in the MVIC experiments:

Figure 4: Dynamometer used in the handgrip force experiment.

$NRMS_{ij}=ARMS_{ij}/MRMS_{i}$, (1)

Where $NRMS_{ij}$ is the normalized average value of the i muscle (i=1:6) in the j hand gesture/force level (j=1:8 for the hand gestures experiments and 1:4 for the handgrip force experiment); $ARMS_{ij}$ is the corresponding average RMS value; and MRMSi is the maximum RMS value of muscle i. The maximum RMS value was obtained by taking the highest RMS value during each muscle's MVIC test. Data processing was performed off-line using our custom-made code in MATLAB™ R2010b software (MathWorks, Natick, MA, USA).

Maximum and average EMG values

The surface EMG signals (normalized muscular activity=NRMS) of the six measured forearm muscles were used as the objective physiological measurement of physical exertion. The maximum and average values of the EMG signals across the six muscles were also used. The maximum values of the EMG signals were utilized to test the hypothesis that the perceived effort would be affected to the greatest extent by the muscle whose activity is closest to its maximum capability, i.e., the weakest-link theory [26]. According to this theory, a higher EMG signal value reflects a higher level of perceived effort. The second hypothesis that we sought to test was that higher RPE ratings would reflect the activation of additional muscles (e.g., two active muscles at 30% of maximum capability would be perceived as greater effort than one muscle at 30% of its maximum capability). To test this hypothesis, we used the average EMG value for all six muscles as a parameter representing the overall level of muscle activity [27].

Data analysis

The relationship between the normalized muscular activity of a subject's forearm muscles (NRMS) and his/her perceived effort, as represented by the Borg scale ratings, was examined using Spearman's rank correlation coefficient. After the relationship was determined for each of the six muscles and for the average and maximum values of the six muscles per gesture/grip, the significance of the difference between correlations was assessed using a Fisher z-transformation. Examination of the correlations was performed only as a preliminary evaluation to provide an opportunity to view the data from a simpler perspective. Later we perform a full statistical analysis using a mixed model analysis.

For the full statistical analysis, a generalized linear mixed model (GLMM) analysis that regressed Borg values on gender and EMG

(NRMS values) was implemented for three different sets of predictors: (1) gender and a combination of six muscles; (2) gender and maximum EMG values; and (3) gender and average EMG values:

$$Borg_{est}=w_g \times Gender+\Sigma (w_i \times NRMS_i) \quad (2)$$

Where $Borg_{est}$ is the model estimated Borg scale rating for a given subject; gender is the subject's gender; w_g is the gender's weight; $NRMS_i$ is the NRMS value of one of the six muscles; and w_i is its relative weight. Note that for the maximum and average models, the summation operator contains only a single variable (e.g., for the average model, $w_{avg} \times NRMS_{avg}$). In all three models, we tested for interactions between different muscles, and between muscles and gender. In addition, for the handgrip force experiment, a GLMM analysis was used to fit a model based on gender and force level (i.e., applied force divided by the maximum force that the subject generated).

The models were fitted using a manual backwards elimination procedure. Starting with a model that included all candidate variables, we then removed the least significant variable (according to the GLMM analysis). The process was repeated this process until all the remaining variables in the GLMM model were significant [28].

The influence of the subjects and gestures was defined as a random effect to allow us to generalize the model regardless of the specific subject or the particular physical activity. The goodness of fit for the models was evaluated using the R-squared coefficient, calculated according to Xu et al.:

$$R_2=1 - SS_{res}/SS_{tot}=1 - (n_1+n_2+n_3)/(m_1+m_2+m_3) \quad (3)$$

Where SS_{res} is the sum of the squared residuals (i.e., a measure of the discrepancy between the data and the model) and SS_{tot} the total sum of squares, was proportional to the sample variance. The parameters n1, n2 and n3 are the unexplained variations of the model due to between-subjects variances (n_1), between-gestures variances (n_2) and other random factors (n_3). The parameters m_1, m_2 and m_3 represent the corresponding unexplained variations (e.g., m_1 – unexplained variations due to between-subjects variances, etc.) of the intercept model (i.e., model with no fixed effects).

In the handgrip force experiment, the grip force levels were not random but fixed effects. Hence, the R-squared coefficient was calculated by:

$$R_2=1 - SS_{res}/SS_{tot}=1 - (n_1+n_3)/(m_1+m_3) \quad (4)$$

To generalize the hand grip force experiment model regardless of the specific physical activity, the grip force levels were not included in the model).

To further study the relation between the (NRMS) and Borg ratings. We also examined the possible goodness of fit that can be achieved when the specific subject is known (fitting a model to a specific subject) by eliminating unexplained variations due to between-subject variances (i.e., removing n1 in equation (3) and equation (4)). To evaluate gender differences, GLMM analysis compared normalized muscular activity (NRMS) values and Borg scale ratings for male and female subjects [29].

In addition, to test whether the fitted linear models represent a general relation between EMG (NRMS) and Borg ratings (and could therefore be used to predict Borg ratings for different types of subject and physical exertion activity), the Borg ratings in the HG2 and HF experiments (i.e., test datasets) were compared to the Borg rating predictions based on the models that were developed using the HG1 dataset [30]. These comparisons were performed using a Spearman's rank correlation between evaluated ratings and the actual measured Borg ratings in the HG2 and HF experiments. In addition to providing a basis for comparison, the Spearman's rank correlation described above was also performed for the HG2 and HF models (i.e., the models of the same test datasets).

All data analyses were conducted at the 0.05 significance level, using a statistical analysis program (SPSS™ Statistics 18, IBM, Armonk, NY, USA).

Results

The normalized muscular activity (NRMS) values and the Borg ratings in the handgrip force (HF) experiment show that that even in hand gestures activity the Borg scale could reach values higher than 5 (Hard) and that the NRMS of a muscle can be as high as half of the MVIC (Table 2).

Correlation between normalized RMS and Borg ratings

For experiments HG1 and HG2, we found significant correlations (Spearman) with the Borg score and both the maximum and average NRMS. This was true for men and women separately and for all subjects as a group [31]. There was, however, a difference between the results for men and women in the correlations of the activity of individual muscles with the Borg score. For women, the Borg score was correlated with the activity of six of the individual muscles, while in men the correlations were significant only for one (HG1) or two (HG2) of the six muscles (Table 3).

In the handgrip force experiment, all correlations were significant and higher than in the hand gesture experiments (evaluated using Fisher z-transformation) except for the extensor carpi radialis and extensor carpi ulnaris muscles (Table 3). In the handgrip experiment, the R-squared values for the males were significantly higher than those for the females for half of the muscle measurements (flexor carpi ulnaris, extensor digitorum, maximum and average values). In the hand gesture experiments, there was no difference between the correlations for males and females across all the muscles.

Prediction of the Borg scale ratings

To predict the Borg scale ratings based on normalized muscular activity (NRMS) and gender (i.e., fixed effects) for the three experiments, GLMM analysis was used. For each experiment, three linear models were utilized: (1) gender and multiple muscles; (2) gender and maximum value across the muscles; and (3) gender and average value across muscles (Table 4). The gender effect was significant in the HG1 experiment for all three models [21] but not in the other two experiments (HG2 and HF). In the six-muscle model, using the

	Borg Average (SD)	Range	Max NRMS		Avg NRMS	
			Average (SD)	Range	Average (SD)	Range
HG1 experiment	1.8 (1.1)	0-5.7	0.124 (0.074)	0.029-0.406	0.058 (0.027)	0.016-0.141
HG2 experiment	2.0 (1.1)	0-5.0	0.123 (0.093)	0.022-0.549	0.052 (0.032)	0.012-0.196
HF experiment	4.1 (2.5)	0-9.5	0.372 (0.203)	0.082-0.901	0.188 (0.105)	0.036-0.508

Table 2: Borg ratings, maximum NRMS (Max) and average NRMS (Avg).

backward elimination algorithm, we found that the same three muscles (pronator teres, flexor carpi ulnaris and extensor digitorum) had a significant effect both in the HG1 experiment and in the HF experiment. In the HG2 experiment, only two muscles (flexor carpi ulnaris and extensor carpi ulnaris) had a significant effect. Both the maximum and average NRMS across the muscles were significant as the main effects for all three experiments. Most of the interactions (between the muscles and gender) were not significant, with the exception of the interaction between gender and maximum NRMS values in the HF experiment.

For all three experiments, R-squared values were higher for the multiple muscles model and the average values model than for the maximum values model. The R-squared values in the handgrip force experiment were higher than those in the hand gesture experiments ($R_2 \approx 0.45$ vs. $R_2 \approx 0.1$-0.3).

In addition, for the HF experiment, the GLMM analysis was used to fit a model based on gender and force level. The force level had a significant effect, but gender or the interaction between them did not. The R-squared value was 0.572, which is higher than that for models based on muscle activity (R_2=0.419-0.511).

We also examined the possible goodness of fit of our models for a specific subject (i.e., fitting the model to a specific subject), thus eliminating unexplained variations due to between-subject differences [i.e., removing n1 in equation (3) and equation (4)]. The corresponding R-squared values for the models were 0.697, 0.633 and 0.849 for the HG1, HG2 and HF experiments, respectively, and 0.907 for the model based on the force level. All models were tested on the basis of the dataset of the same experiment.

Figure 6 (a-c) shows the relationships between the Borg scale ratings and the average normalized muscular activity (NRMS) values and the linear fitted models based on the average NRMS of each experiment. It can be seen that the data dispersion in the handgrip force experiment (Figure 6c) was smaller than that in the hand gesture experiments (Figures 6a and 6b). The data and the linear fitted models based on the force level (applied force divided by max force) are presented in Figure 7.

Gender differences

Significant differences, between the perceived effort ratings of male and female subjects were revealed by the HG1 (average ratings of 2.2 and 1.4, respectively) and HG2 (2.2 vs. 1.8) experiments, using the GLMM analysis (Table 5). However, these differences were not due to differences in muscular activity of males and females, since no differences in NRMS were found between genders in these experiments (Figures 8a and 8b) except for the pronator teres (HG1 experiment) where the female subjects showed higher NRMS values than the male participants (0.039 vs. 0.025).

In the HF experiment, no significant differences between genders were detected for the Borg ratings. For the NRMS, in six out of eight muscle measurements there was no difference between men and women; women had higher NRMS values than men only for the pronator teres (0.118 vs. 0.044) and for the flexor carpi radialis (0.130 vs. 0.069) muscles (Figure 8c).

Evaluation of the HG1 models on different subjects and physical activities

To evaluate whether the relation between normalized muscular activity (NRMS) and Borg ratings obtained from the first experiment (HG1) can be generalized to other conditions (i.e., experiments), the Spearman correlation was used to compare between the measured

	HG1 experiment			HG2 experiment			HF experiment		
Muscle	All	Males	Females	All	Males	Females	All	Males	Females
p.t.	0	0.009	0.182^	0.061**	0.223^	0	0.452^	0.588^	0.519^
f.c.r.	0.002	0.028	0.002	0.045*	0.03	0.054	0.434^	0.575^	0.325^
f.c.u.	0.040*	0.033	0.115**	0.145^	0.003	0.437^	0.522^	0.724^	0.295^
e.c.r.	0.078**	0.045	0.087*	0.198^	0.067	0.269^	0.181^	0.146**	0.225**
e.c.u.	0.041*	0.013	0.150**	0.149^	0.206^	0.122**	0.268^	0.374^	0.209**
e.d.	0.142^	0.100**	0.111**	0.061**	0.038	0.072*	0.433^	0.564^	0.256**
Max	0.110^	0.053*	0.134**	0.111^	0.062*	0.179^	0.472^	0.733^	0.314^
Avg	0.134^	0.074*	0.216^	0.202^	0.149**	0.286^	0.585^	0.801^	0.407^

*p<0.05, **p<0.01 and ^p<0.001.

p.t.: pronator teres; f.c.r.: flexor carpi radialis; f.c.u.: flexor carpi ulnaris; e.c.r.: extensor carpi radialis brevis and longus: e.c.u.: extensor carpi ulnaris; e.d.: extensor digitorum; Max: maximum; Avg: average.

Table 3: Spearman coefficients of determination (R_2) between NRMS and Borg ratings.

Experiment	Fixed effect	Linear model	R2
HG1	Gender+muscles	Borg=0.945 × Gender*+14.737 × p.t.^+4.467 × f.c.u.**+6.464 × e.d.^	0.295
	Gender+maximum	Borg=0.738 × Gender*+4.444 × Max^	0.196
	Gender+average	Borg=0.786 × Gender*+20.187 × Avg^	0.278
HG2	Gender+muscles	Borg=1.439^+9.777 × f.c.u.**+3.192 × e.c.u.**	0.215
	Gender+maximum	Borg=1.609^+3.108 × Max**	0.099
	Gender+average	Borg=1.435^+10.686 × Avg**	0.149
HF	Gender+muscles	Borg=9.148 × p.t*+7.158 × f.c.u.^+3.960 × e.d.*	0.478
	Gender+maximum	Borg=12.199 × Max^-2.268 × Gender × Max*	0.419
	Gender+average	Borg=20.291 × Avg^	0.511
*	Gender+force level	Borg=0.083 × Force_level^	0.572

*p<0.05, **p<0.01 and ^p<0.001.

Table 4: Linear models for predicting Borg ratings based on gender, EMG and force level*.

Citation: Korol G, Karniel A, Melzer I, Ronen A, Edan Y, et al. (2017) Relation between Perceived Effort and the Electromyographic Signal in Localized Effort Activities of Forearm Muscles. J Ergonomics S6: 004. doi: 10.4172/2165-7556.1000.S6-004

Borg scale ratings in the HG2 and HF experiments and the evaluated ratings obtained using the models developed in HG1 experiment. The coefficients of determination (R2) are presented in Table 6. The predictive abilities of the HG1 average model were very similar to those of the HG2 and HF average models (i.e., similar R-squared values). However, the other two models were not consistent; the HG1 combination of muscles model achieved similar prediction ability only in the HF experiment, while the HG1 maximum values model achieved similar prediction ability only in the HG2 experiment.

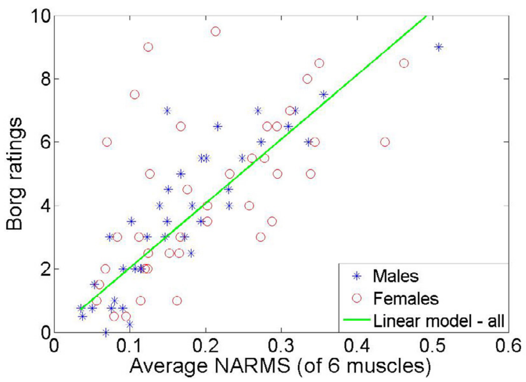
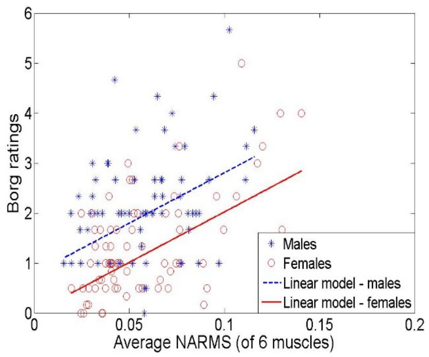


Figure 5: Correlation between normalized RMS and Borg ratings

Discussion

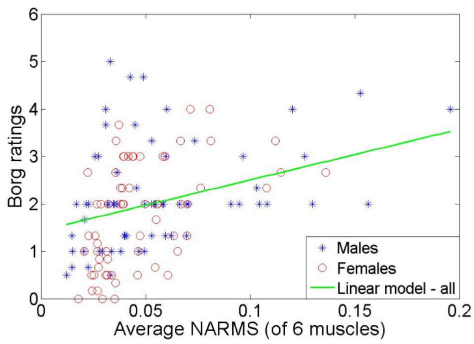
The main purpose of this study was to investigate the relation between muscle activity (i.e., EMG), applied load and perceived effort ratings (i.e., Borg CR-10) during localized effort activities of forearm muscles. The issue of gender differences in perception of effort was also studied.

When evaluating the performance of each of the EMG-based models to predict the level of perceived effort (i.e., Borg ratings), our analysis reveals that in the hand gesture experiments, higher R-squared values were obtained for the multiple muscle models than for the average values models (0.295 vs. 0.278 and 0.215 vs. 0.149 for HG1 and HG2 experiments, respectively). Yet, in the handgrip force experiment, the average model achieved a higher R-squared value (0.511 vs. 0.478). In all three experiments, both the multiple muscles and the average values models achieved higher R-squared values than the maximum values models (R2=0.196, 0.099 and 0.419 for HG1, HG2 and HF experiments, respectively). This finding suggests that our weakest-link hypothesis is not suitable for these types of activities, and that the combined activity of muscles is a better predictor. Furthermore, we believe that the average values model is better for general use since it does not require finding a specific combination of muscles. This is particularly important in light of the fact that in the past most researchers used only individual muscles as a measurement for the level of effort in physical activities [11-13].



(a) Borg = 0.786 × Gender + 20.187 × Avg;

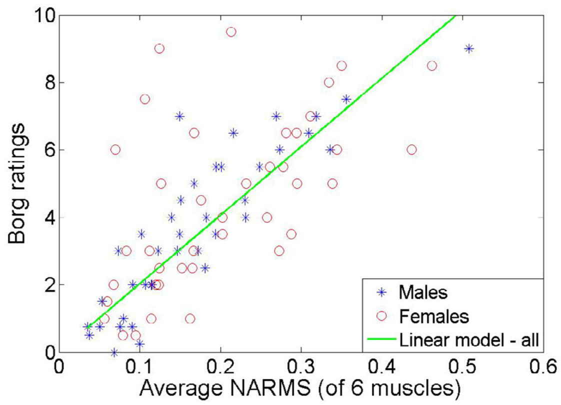
Gender: 1 = male, 0 = female. $R_2 = 0.278$



(b) Borg = 1.435 + 10.686 × Avg;

$R_2 = 0.149$.

R^2



(c) Borg = 20.291 × Avg; $R_2 = 0.511$

Figure 6: Relation between Borg ratings and average NRMS values of male and female subjects for the (a) HG1, (b) HG2 and (c) HF experiments.

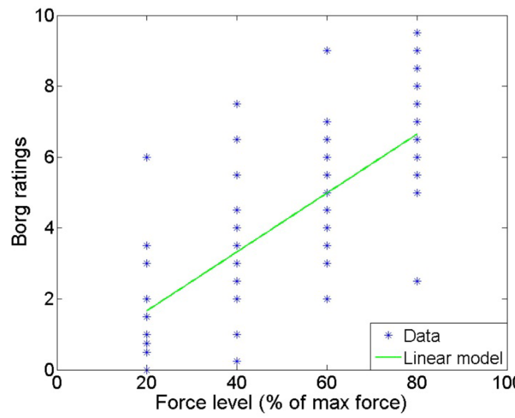


Figure 7: Relation between Borg ratings and force level (% of max force) of male and female subjects for the HF experiment. Borg=0.083 × force; R_2=0.572.

When testing the generality of the models developed using one dataset (the HG1 experiment data) to predict the perceived level of effort based on the EMG signals of different subjects and physical activities (i.e., test datasets-HG2 and HF experiments), the analysis showed that the prediction ability of the HG1 average model is very similar to the predictive abilities of the average models fitted on the basis of the HG2 and HF data.

When we further tested the relations between the EMG and perceived effort by eliminating the subjects' variance (i.e., when fitting a model to a single subject), our ability to predict the Borg ratings was much higher (the R-squared values rose from 0.278, 0.149 and 0.511 to 0.697, 0.633 and 0.849 for the HG1, HG2 and HF experiments, respectively). By fitting the data to a single subject, we eliminated variance due to, for example individual differences between two people who may perform the same level of physical exertion yet display different Borg ratings. These results indicate that muscle activity (EMG) can explain a relatively large part of the variation in the perceived effort ratings. Two observation regarding factors contributing to perceived effort can

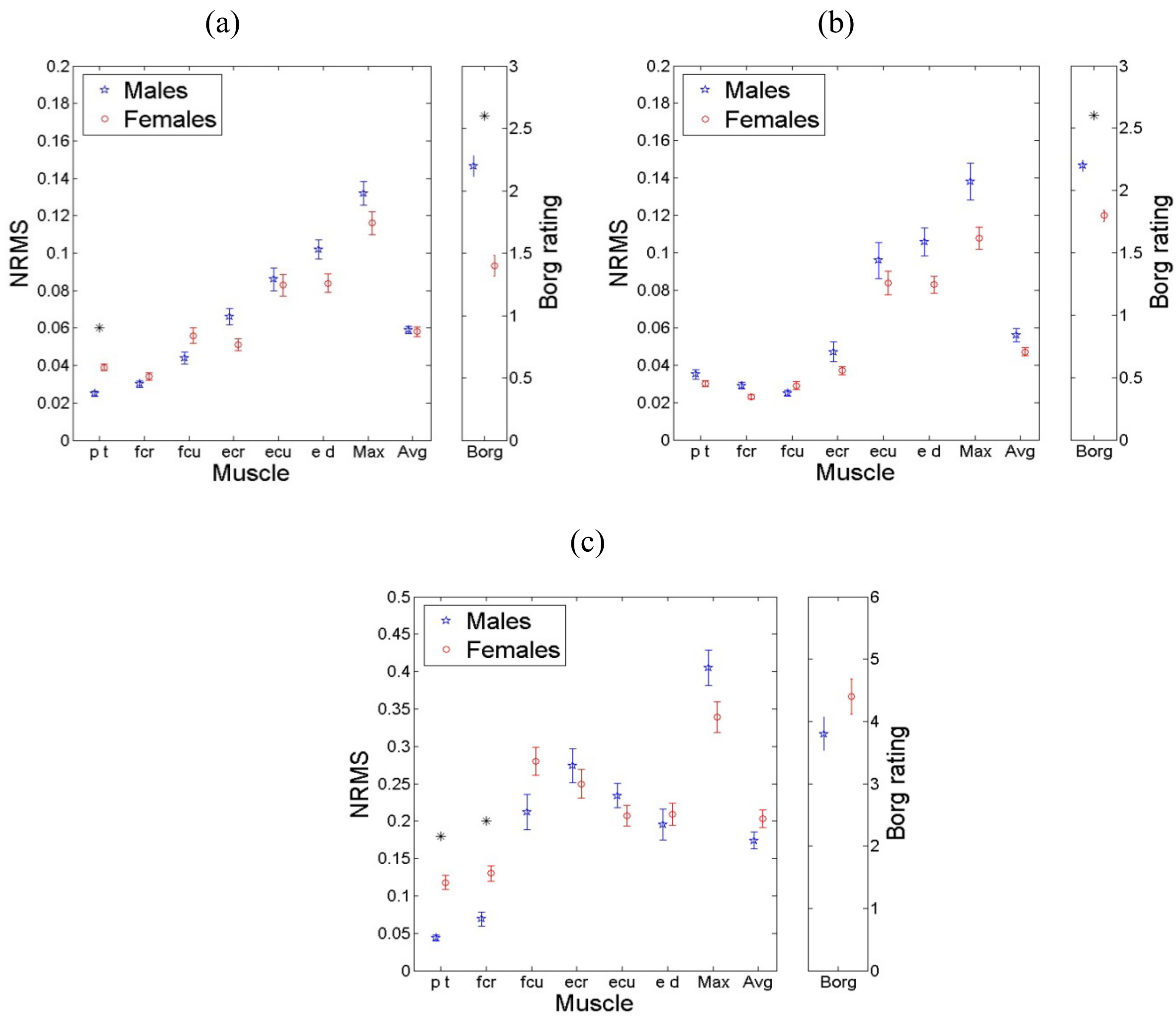


Figure 8: Average values and standard error of the mean of NRMS and Borg ratings of male and female subjects in the (a) HG1, (b) HG2 and (c) HF experiments. Significant differences between males and females are indicated with an asterisk.

	HG1 experiment		HG2 experiment		HF experiment	
Variable	Males	Females	Males	Females	Males	Females
Borg	2.2*	1.4*	2.2*	1.8*	3.8	4.4
Max	0.132	0.116	0.138	0.108	0.405	0.339
Avg	0.059	0.058	0.056	0.047	0.174	0.203
Significant differences between males and females are indicated with an asterisk; *p<0.05.						

Table 5: Maximum (Max) and average (Avg) NRMS values and Borg ratings for male and female subjects.

	HG2 experiment		HF experiment	
Fixed Effects	HG1 models	HG2 models	HG1 models	HF models
Gender+muscles	0.13	0.274	0.583	0.538
Gender+maximum	0.104	0.111	0.3	0.492
Gender+average	0.184	0.201	0.538	0.585

Table 6: Comparison between predictive abilities of the HG1 models and HG2 and HF models (models of the same test datasets), using Spearman coefficients of determination (R_2) between measured and estimated Borg ratings.

be obtained from combining our results with those of previous studies [11-13]. First, the simpler motions had higher R-squared values than complex motions (e.g., the prediction ability for knee extensors was superior to that for hand gestures and reaching tasks). Second, when fewer muscles are involved in the motion, the predictions are better [11-13] and our results).

We compared the predictive abilities of models based on load (force and torque) to those based on EMG in our experiments and in the experiments of Dickerson et al. [14]. In our experiments (handgrip force), the R-squared value for the applied load based model was 0.572 and the values for the EMG model were up to 0.511, while the respective values that appear in Dickerson et al. [14] were 0.51 and 0.27. We believe that the reason for the difference between the performances of the EMG models in the two studies might be due to the fact that in our experiment the task had less variability (hand grip vs. reaching to several different locations). This premise is in line with Dickerson et al. [14], who found that when the reaching location was part of the model, the EMG model had an average R squared value of 0.64. It should be noted here that in all three of our experiments, only about one third of the muscles that are involved in producing the motion were measured. Therefore, it is possible that if the EMG data of all the active muscles would have been taken into account, the EMG model would have achieved better results.

Our analysis regarding gender differences showed that women perceive low-effort activities (HG1 and HG2) as less of an effort than men. On the other hand, for moderate-to high-effort activities there was no significant gender difference in the perception of physical effort. This difference in perception cannot be attributed to muscular activity since no differences were found between the muscle activity of the men and women in all three experiments. Interestingly, in the low-effort (HG1 and HG2) experiments, there was no significant difference between the correlations of men and women while for the moderate to high extraction experiment (HF), the correlations for women were lower than those for the men (Table 3).

Conclusion

The findings from this study demonstrated that muscle activation level (i.e. EMG) is related to perceived effort (measured using CR10 Borg ratings) for localized hand-effort tasks. Further, while the rating levels are subjective for a given individual, by fitting a model to a single subject the model based on the EMG could explain between 63% and 85% of the variance in the effort perception. The model using the average of the muscle EMG achieved higher R-squared results than the Max EMG model (weakest link). This suggests that the perception of effort is related to the overall effort of the muscles and not to a specific limiting muscle.

Acknowledgments

This study was partially supported by the Helmsley Charitable Trust through the Agricultural, Biological and Cognitive Robotics Initiative of Ben-Gurion University of the Negev, and the United States-Israel Binational Science Foundation under Grant number 2011152.

The authors would like to thank Israel Permat for his assistance with the data analysis; Opher Donchin for his suggestion for data analysis, representation and editorial comments; and Shaul Zuares for his assistance in conducting the experiments.

References

1. Borg GA (1982) Psychophysical bases of perceived exertion. Med Sci Sports Exerc 14: 377-381.
2. Lawrence JH, De Luca CJ (1983) Myoelectric signal versus force relationship in different human muscles. J Appl Physiol 54: 1653-1659.
3. Zuniga EN, Simons G (1969) Nonlinear relationship between averaged electromyogram potential and muscle tension in normal subjects. Arch Phys Med Rehabi 50: 613-620.
4. Herberts P, Kadefors R, Högfors C, Sigholm G (1984) Shoulder pain and heavy manual labor. Clin Orthop Relat Res: 166-178.
5. Kothiyala K, Kayis B (2001) Workplace layout for seated manual handling tasks: An electromyography study. Intern J Indus Ergonom 27: 19-32.
6. McDonald A, Picco RB, Belbeck LA, Chow YA, Dickerson RC (2012) Spatial dependency of shoulder muscle demands in horizontal pushing and pulling. Appl Ergonom 43: 971-978.
7. Mork PJ, Westgaard RH (2006) Low-amplitude trapezius activity in work and leisure and the relation to shoulder and neck pain. J Appl Physiol 100: 1142-1149.
8. Skotte JH, Essendrop M, Hansen AF, Schibye B (2002) A Dynamic 3D Biomechanical Evaluation of the Load on the Low Back during Different Patient-handling Tasks. J Biomech 35: 1357-1366.
9. Agarabi M, Bonato P, De Luca CJ (2004) A sEMG-based Method for Assessing the Design of Computer Mice. Conf Proc IEEE Eng Med Biol Soc 4: 2450-2453.
10. McCloskey DI, Ebeling P, Goodwin GM (1974) Estimation of weights and tensions and apparent involvement of a sense of effort-Experimental Neurology 42: 220-232.
11. Tiggemann CL, Korzenowski AL, Brentano AM, Tartaruga MP, Alberton CL, et al. (2010) Perceived Exertion in Different Strength Exercise Loads in Sedentary, Active, and Trained Adults. J Strength Cond Res 24: 2032-2041.
12. Troiano A, Naddeo F, Sosso E, Camarota G, Merletti R, et al. (2008) Assessment of Force and Fatigue in Isometric Contractions of the Upper Trapezius Muscle by Surface EMG Signal and Perceived Exertion Scale. Gait Posture 28: 179-186.
13. Pincivero DM, Coelho AJ, Campy RM, Salfetnikov Y, Suter E (2003b) Knee extensor torque and quadriceps femoris EMG during perceptually-guided isometric contractions. JEK 13: 159-167.
14. Dickerson CR, Martin BJ, Chaffin DB (2007) Predictors of perceived effort in the shoulder during load transfer tasks. Ergonom 50: 1004-1016.
15. Demura S, Nakada M, Nagasawa Y (2008) Gender difference in subjective muscle-fatigue sensation during sustained muscle force exertion. Tohoku J Exp Med 215: 287-294.
16. Demello JJ, Cureton KJ, Boineau RE, Singh MM (1987) Ratings of perceived exertion at the lactate threshold in trained and untrained men and women. Med Sci Sports Exerc 19: 354-362.

17. Pincivero DM, Coelho AJ, Campy RM (2003a) Perceived exertion and maximal quadriceps femoris muscle strength during dynamic knee extension exercise in young adult males and females. Euro J Appl Physiol 89: 150-156.
18. O'Connor PJ, Poudevigne MS, Pasley JD (2002) Perceived exertion responses to novel elbow flexor eccentric action in women and men. Med Sci Sports Exerc 34: 862-868.
19. Koltyn KF, O'Connor PJ, Morgan WP (1991) Perception of effort in female and male competitive swimmers. Intern J Sport Med 12: 427-429.
20. Stern HI, Wachs JP, Edan Y (2008) Optimal consensus intuitive hand gesture vocabulary design. Semantic Computing, 2008 IEEE International Conference 96-103.
21. Korol G, Karniel A, Melzer I, Ronen A, EdanY, et al. (2014) Relation between perceived effort and the electromyographic signal in localized low-effort activities. International Annual Meeting Human Factors and Ergonomics Society, Chicago, Illinois, USA.
22. De Luca CJ (1997) The use of surface electromyography in biomechanics. J Appl Biomech 13: 135-163.
23. Hislop HJ, Montgomery J, Connelly B, Daniels L (1995) Daniel's and Worthingham's muscle testing: Techniques of manual examination. St. Louis, MO: WB Saunders.
24. Snell RS (2003) Clinical Anatomy: An Illustrated Review with Questions and Explanations (4th edition) Baltimore, MD: Williams and Wilkins Lippincott.
25. Lariviere C, Delisle A, Plamondon A (2005) The effect of sampling frequency on EMG measures of occupational mechanical exposure. JEK 15: 200-209.
26. Weibull W (1939) A statistical theory of the strength of materials. Generalstabens litografiska anstalts förlag 151.
27. Da Costa BR, Vieira ER (2010) Risk factors for work-related musculoskeletal disorders: A systematic review of recent longitudinal studies. Am J Ind Med 53: 285-323.
28. Rose MJ (1991) Keyboard operating posture and actuation force: Implications for muscle over-use. Appl Ergonom22: 198-203.
29. Wickens CD (2014) Effort in human factors performance and decision making. Hum Factors 56: 1329-1336.
30. Xu R (2003) Measuring explained variation in linear mixed effects models. Stat Med 22: 3527-3541.
31. Yeung SS, Genaidy A, Deddens J, Leung PC (2003) Workers' assessments of manual lifting tasks: Cognitive strategies and validation with respect to objective indices and musculoskeletal symptoms. Intern Arch Occu Environ Health 76: 505-516.