PREDICTION OF FOREARM MUSCLE ACTIVITY DURING GRIPPING

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INTRODUCTION

There is a strong association between upper extremity musculoskeletal disorders and jobs involving forceful grip exertions and deviated wrist postures [1]. The inherent difficulty in measuring hand and finger forces in the workplace, without interfering with a worker's normal movement patterns, has led to the use of EMG-based mathematical relationships to predict grip force [2-4]. Prediction of grip force is valuable, however, EMG collection in the workplace is an expensive and tenuous task. In addition, predicting grip force itself does not necessarily provide information on which muscles may be at risk of injury or fatigue. Accurate prediction of muscle activity without an elaborate biomechanical model would improve our understanding of muscular loading in the workplace. The purpose of this study was to predict muscle activity of six forearm muscles from grip force and posture using an existing dataset [5].

METHODS

The dataset [5] was comprised of surface EMG of 6 forearm muscles (FCR, FCU, FDS, ECR, ECU and EDC) collected during 10s static grip force contractions on each of two days. All combinations of 3 forearm postures (pronation, neutral and supination) and 3 wrist postures (45° extension, neutral, 45° flexion) were used. Grip force and EMG were collected at 4 relative effort levels (5, 50, 70 and 100% $Grip_{max}$) and an absolute force of 50 N. EMG and grip force were normalized to maximum. AEMG was calculated from the 3 Hz linear envelope EMG over a 3 s plateau at the target force and during baseline prior to each exertion.

Forward stepwise regression analyses were performed to develop equations to predict AEMG for each of the 6 forearm muscles from grip force and posture using Day 1 data, using STATISTICA (version 6.0, StatSoft Inc., Tulsa, OK). Analyses included linear, factorial and polynomial regressions. All models included the AEMG and measured grip force data from each of the five exertion levels, in each combination of wrist and forearm posture. The predictive ability of each model was judged based on the adjusted r^2 and $RMSE_{model}$ (in % MVE). The validation process used Day 2 data as input into the equations developed from Day 1 data, and were evaluated using r^2 and $RMSE_{valid}$.

RESULTS AND DISCUSSION

Second order regression models improved the prediction of extensor muscle activity over linear regression with r^2 and $RMSE_{model}$ improving by as much as 4% and 0.7%, respectively. The generic form of each equation is:

$$AEMG_i = (a_1 \cdot G)+(b_1 \cdot G^2)+ (a_2 \cdot W)+ (b_2 \cdot W^2)+ (a_3 \cdot F)+ (b_3 \cdot F^2)+c$$

where, $AEMG_i$ is percent muscle activation (i=1-6), G is relative grip force, W is wrist posture (extension = 1, neutral = 2 and flexion = 3), F is forearm posture (pronation = 1, neutral = 2 and supination = 3), and c is a constant. Coefficients were included in each model if they were significant at $p < 0.05$; most were significant at $p < 0.001$.

Posture explained less than 2% of the variance. However, when combined with grip force, inclusion of both wrist and forearm posture reduced $RMSE_{model}$ to less than 9% MVE for all equations (Table 1). Using the measured wrist angle (in degrees) resulted in weaker models than using nominal wrist posture. Forearm posture had little effect on the prediction of average finger muscle and wrist flexor activations, but improved r^2 and $RMSE_{model}$ of the wrist extensors by as much as 4.7% and 0.9% MVE, respectively.

Day 2 AEMG was predicted very well using the equations developed from Day 1 data and was often lower than the development data ($RMSE_{valid}$ vs $RMSE_{model}$, Table 1). Each target force level was also evaluated in isolation to determine the ability of each equation to predict muscle activation across the full range of grip forces. The error in predicting muscle activation was greater with increasing grip force. The RMSE for forces = 50% $Grip_{max}$ was 0.9-2.3% lower than the overall $RMSE_{valid}$ which ranged from 6.6-9.8%. The RMSE values of predicted muscle activity for grip forces above 50% were 3.7-7.3% MVE higher than $RMSE_{valid}$. Preliminary tests using verbal estimates of grip force indicate that the equations are robust, as the predictive capacity was the same as with measured grip force.

These equations provide a simple and accurate tool to predict forearm muscle loading in the workplace, and may be used to complement existing workplace screening tools.

REFERENCES

1. Silverstein, B. et al. (1986) *Br.J.Indust.Med.* **43**, 779-784.
2.Armstrong, T.J. et al. (1979). *J Biomech*, **12**, 131-133.
3. Claudon, L. (1998). *Int J Occup Safety Ergon*, **4**, 169-184.
4. Duque, J. et al. (1995). *Appl Ergon*, **26**, 61-66.
5. Mogk, J.P., Keir, P.J. (2003) *Ergonomics* **46**, 956-75.

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Table 1. Coefficients and error estimates for the quadratic equations to predict muscle activity in six forearm muscles.

Muscle	Equation coefficients							Goodness of fit and error			
	a_1	a_2	b_1	b_2	a_3	b_3	c	r^2	$RMSE_{model}$	r^2 (valid)	$RMSE_{valid}$
FCR	0.514	*	*	0.640	2.112	*	-5.143	0.823	7.1	0.842	6.6
FCU	0.550	*	*	0.501	-1.589	*	1.616	0.797	8.2	0.827	7.2
FDS	0.550	*	*	0.823	1.361	*	-5.071	0.826	7.5	0.823	7.3
ECR	0.811	-0.004	-6.68	2.420	*	-0.738	9.726	0.798	8.2	0.800	7.4
ECU	0.736	-0.002	*	0.654	-13.049	2.031	17.551	0.791	8.6	0.730	9.4
EDC	0.826	-0.004	*	1.358	*	0.264	-0.269	0.773	8.9	0.707	9.8