# Analysis of EMG signals during posture maintenance

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**Abstract.** In this paper, the possibility to improve the poor signal to noise ratio (SNR) of shoulder muscle activity signals is investigated. This activity is measured with Electromyography (EMG). An improved ratio makes these EMG signals suitable to validate the present neuromusculoskeleton model. In previous research, force disturbances (consisting of a summation of many sine waves) were used to perturb the arm which resulted in reflex activity. However, poor SNR in the EMG signals were found. In this study, it is shown that either a reduced number of sine waves or a decrease in bandwidth of the force disturbances intensifies the reflex activity and therefore improves the signal to noise ratio in the EMG signals. Now it appears to be possible to qualitatively validate the present neuromusculoskeleton model. Further quantitative research is recommended to yield more insights.

## Introduction

Humans have two mechanisms to suppress external force disturbances: the intrinsic muscles visco-elasticity and reflexive feedback, both directed by the Central Nervous System (CNS). In sequel to previous research of the 'Delft Shoulder Group' this study will focus on the reflexive feedback system only, but now by making use of the Electromyography (EMG) signals.

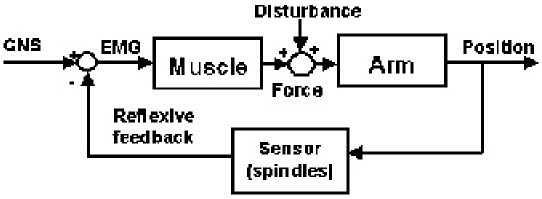

**Figure 1**. Simplified model of muscle system

Sensors in the muscle, i.e. muscle spindles, measure position and velocity that are fed back to the muscle via the spinal system, generating reflex activity (Fig. 1). In previous experiments (Van der Helm et al., 2002) the neuromusculoskeleton (NMS) model, including reflexive feedback, was quantified by measuring hand reaction force and hand position. Analysis of reflexive feedback can also be done with an EMG model based on the relationship between hand position and EMG signals. It is then possible to validate the NMS model and create more insights. However, the high level of noise in EMG signals makes them unsuitable for identification.

*This study investigates the possibility to improve the poor SNR, to proceed on using EMG signals to validate the neuromusculoskeleton model.*

## Methods and experimental set up

In this experiment, force disturbance are applied to the arm to excite the muscle spindles. In the experimental set up (Fig. 2) the subject sits in a chair and firmly holds a handle with the right hand. Unpredictable (to prevent anticipation by the subject) force disturbances in horizontal direction are applied to the handle while the subject's task is to minimize the position deviations. To assist the subject a monitor displays the position of the handle. During the experiment, the position of the handle and the reaction force of the arm are measured. In addition, the activity of four shoulder muscles[1] is measured using EMG.

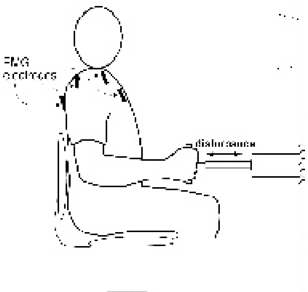

**Figure 2**. Experimental set up.

In previous experiments, the disturbances consisted of a summation of all possible sine waves in a wide band (WB) frequency range of 0.2Hz to 20Hz. This resulted in a poor SNR in EMG signals.

To distinguish the muscle activation (as a result of spindles activity) from the noisy EMG, the former is intensified. This is done by two modifications:

**1.** decrease the number of sine waves (N) in a WB signal to increase the power per sine wave, resulting in higher spindle activity.

**2.** decrease the frequency range to a narrow band (NB) disturbance to increase the spindle gain and muscle activity. This effect has been shown in previous experiments (Van der Helm et al., 2002).

In conformity with the modifications, two types of disturbances have been created (five of each type, see Table 1).

During the experiment each disturbance is repeated four times, giving 40 trials lasting 30 seconds each. The trials are applied in random order to 4 subjects (two men), all right handed. To counter fatigue, subjects are allowed at least 10 seconds rest between the trials and 15 minutes rest after 20 trials.

To remove any initial transient response only the last 26 seconds of each trial are used for further processing. The four EMG signals are normalized, rectified and lumped taking in account the principal action of the muscles. The four repetitions of one disturbance are averaged in time-domain to improve the data. All time signals are Fourier transformed to the

**Table 1**.Applied force disturbances

| Narrow Band Width | | Wide Band Width | |
|---|---|---|---|
| Band width | Nsin | Band width | Nsin |
| 0.5 - 1.6 | 5 | 0.5 - 20 | 5 |
| 0.5 - 2.1 | 7 | 0.5 - 20 | 10 |
| 0.5 - 2.6 | 9 | 0.5 - 20 | 20 |
| 0.5 - 3.2 | 11 | 0.5 - 20 | 40 |
| 0.5 - 3.7 | 13 | 0.5 - 20 | 128 |

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[1] **1**. Four muscles enable motion in horizontal direction: m.deltoideus anterior, m. deltoideus posterior, latissimus dorsi, m. pectoralis major

frequency domain. Coherence, the degree of correlation between two signals, is estimated using spectral densities and taken as a measure of SNR (see Appendix). The system's Frequency Response Function (FRF) of the arm is estimated using spectral densities of the input, output and disturbance (see Appendix).

## Results and Discussion

Coherences between the WB disturbance and position ($G^2_{DX}$) are shown in Figs. 3A - 3C for N=5, 20 and 128. All the figures show a high level of coherence, although it is seen that lower N results in a slightly better coherence. Figures 3D - 3F show that the coherences between disturbance and EMG ($G^2_{DEMG}$) decrease substantially for increasing N. Especially Figure 3F shows a deteriorated and unsteady coherence. These characteristics conform to the principle of reducing power per sine wave. For all NB frequency ranges $G^2_{DX}$ and $G^2_{DEMG}$ are high (not shown). This result was expected as spindle gain increases with decreasing frequency range (Van der Helm et al., 2002).

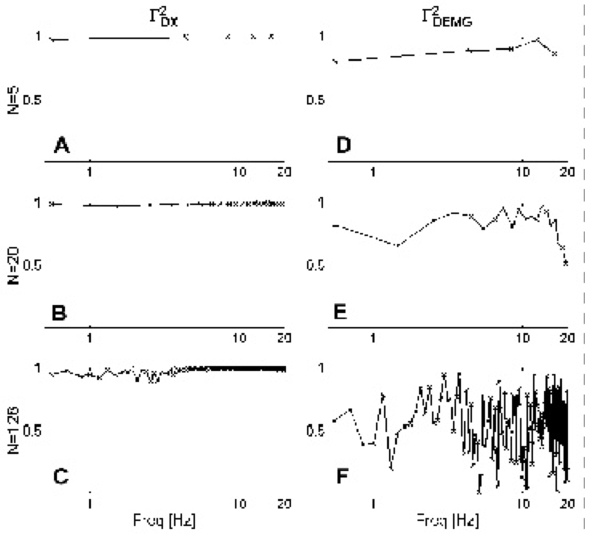

**Figure 3.** Coherences of WB disturbances

A Bode plot of the FRF (N = 20) relating the position to the reaction force ($H_{FX}$) is pictured in Fig. 4A and 4B (solid lines). Other N behave equally, but they are less reliable: on the one hand higher N resulted in unsteady $H_{FX}$ due to less coherence, on the other lower N improved coherence but resulted in less measurement points in the frequency spectrum. These solid lines have a slope of –2 and a phase lag of approximately 180° can be recognized, suggesting an integrating second order system. Overshoot in the gain occurs at the eigenfrequency of 3Hz. The phase change of 150° instead of 180° is due to damping of the hand (Van der Helm et al., 2002). The dotted lines represent $H_{FX}$ calculated using the NMS model and with its parameters adjusted on cursory inspection to fit the measured data (solid lines). It is seen that both lines coincide.

In Figs 4C - 4D, the solid lines show the gain and phase relationship of the measured EMG signals and positions ($H_{XEMG}$), these figures approximate a second order *differentiating* system. The phase for higher frequencies is descending, due to a time-delay in $H_{XEMG}$ (caused by the spinal system) so that the expected phase lead for a differentiation system does not occur.

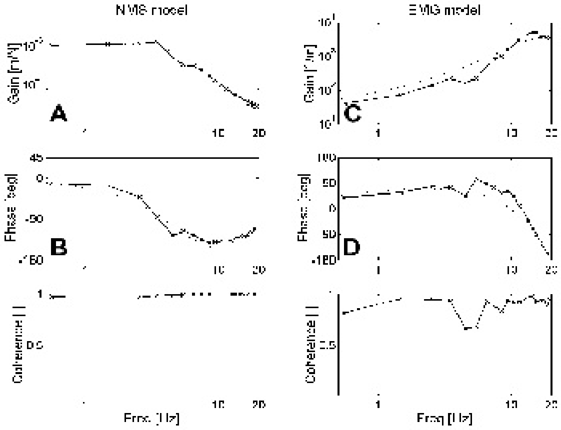

**Figure 4.** Bode plots of *measured* data of $H_{XEMG}$ and $H_{FX}$ at WB disturbances (*solid lines*) compared to *modeled* data of $H_{XEMG}$ and $H_{FX}$ (*dotted lines*)

The dotted lines represent the $H_{XEMG}$ calculated using a *new EMG model*. For these calculations the same parameter values are used as above. It is seen that these lines also coincide with the measured data (solid lines).

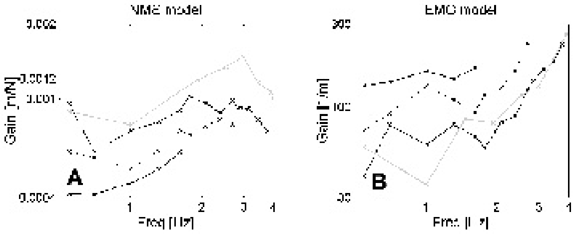

**Figure 5**. Gains of $H_{XEMG}$ and $H_{FX}$ at NB disturbances: end frequencies at 1.6 Hz (*solid lines*), 2.6 Hz (*dotted lines*) and 3.7 Hz (*dashed lines*) compared to the WB disturbance for N=40 (*gray lines*).

The gain decreases in Fig. 5A for narrower bandwidths, due to the above mentioned higher activity of spindles, which stiffens the system (i.e. lower gain in Bode plot). The gain increases in Fig. 5B, also due to the higher activity of spindles. In both figures the gray line represents the gain of a WB disturbance (N=40). It is shown that the WB disturbance has less spindle activity.

## Conclusions and recommendations

Concluding the above, it is readily demonstrated that:

**1.** it is possible to substantially improve the SNR in EMG signals by either reducing the number of sine waves or by narrowing the frequency range.

**2.** both $H_{XEMG}$ and $H_{FX}$ show higher level of spindle activity for NB disturbances than for WB disturbances.

**3.** measured data of $H_{XEMG}$ and $H_{FX}$ coincide with modeled data of $H_{XEMG}$ and $H_{FX}$. Therefore the EMG model qualitatively validates the NMS model.

We recommend further research to *quantitatively* validate the NMS model with the EMG model, yielding more results and insights.

# Appendix

### Coherence

The coherence between two signals is a frequency domain measure of the degree of correlation between the signals. If the two signals are independent, at a given frequency, the coherency between them is zero at this frequency. If one signal can be related to the other by considering them as input an output of a linear time invariant system, then the coherence is one. Coherence is taken as a measure of the signal to noise ratio.

Defined coherences:

$$\Gamma^2_{DX} = \frac{\left|S_{DX}\right|^2}{S_{DD}S_{XX}}$$

$$\Gamma^2_{DEMG} = \frac{\left|S_{DEMG}\right|^2}{S_{DD}S_{EMGEMG}}$$

### Frequency response function (FRF)

The frequency response function is a representation of the system's response to sinusoidal inputs at varying frequencies. The output of a linear system to a sinusoidal input is a sinusoid of the same frequency but with a different magnitude and phase. The frequency response is defined as the magnitude and phase differences between the input and output sinusoids. Usually, behaviour of FRFs is pictured in Bode plots, showing magnitude and the phase.

Defined FRFs:

$$H_{FX} = -\frac{S_{DX}}{S_{DF}}$$

$$H_{XEMG} = -\frac{S_{DEMG}}{S_{DX}}$$

### References

Van der Helm FCT, Schouten AC, De Vlugt E, Brouwn GG (2002): Identification of intrinsic and reflexive components of human arm dynamics during postural control. J Neurosci Meth (accepted).