MODULATION OF FORCE STRUCTURE VIA VISUAL SCALING OF FAST TIME SCALE PROCESSES

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INTRODUCTION

Long-range temporal correlations (i.e. 1/f processes) have been observed in human motor behaviors (e.g. isometric force control [1]). It has been shown that control of the high frequency components of force output is degraded, possibly due to the latency of sensorimotor feedback, tremor, and visual information scaling (i.e. smaller visual scaling in high frequency force components [2]).

This study investigated whether selectively increasing the visual scaling of the high frequency force components enhances the control of the faster time scale processes under different force targets. A related question was whether and how the control of the low frequency force components will be changed. Thus, we examined the hypothesis that increased visual scaling in the high frequency components improves the control of high frequency force bandwidth but the effect of this manipulation on the control of the low frequency components was more open.

METHODS

Eleven right handed young healthy individuals participated in this study. They gave informed consent that was approved by the University IRB. Participants were seated in a chair facing a LCD monitor, with their right dominant hand pronated on the table. Through isometric abduction, the lateral side of the index finger pressed on a load cell. The force was sample at 40 Hz.

The Maximum Voluntary Contraction (MVC) was recorded. The participants were instructed to adjust their force to match a red target waveform displayed on the monitor. A yellow trajectory representing their force was displayed in real time to the subjects. Four types of waveforms were used as force targets: 1) straight line; 2) 0.8 Hz sine wave; 3) pink noise; 4) brown noise. The mean amplitude of the force target was 20% of participant's MVC and the amplitude was ±5% of MVC.

During the experiment, the high frequency components of the force feedback were amplified by a scaling (scaling = 0, 2, 4, 6, 8). Two frequency ranges (4-8 Hz and 8-12 Hz) were separately manipulated with scaling. The experiment consisted of 4 blocks of trials, with one type of force target in each block. Each block contained 10 conditions (5 Scaling × 2 Frequency ranges), the order of which was randomized across subjects. Participants had 3 consecutive 20 s trials at each condition.

RESULTS AND DISCUSSION

The force structure was assessed by using a spectral slope analysis, where a linear regression was performed on the logarithmic power spectrum (Fig. 1). In the constant target condition, statistical analysis revealed that the slope decreased with

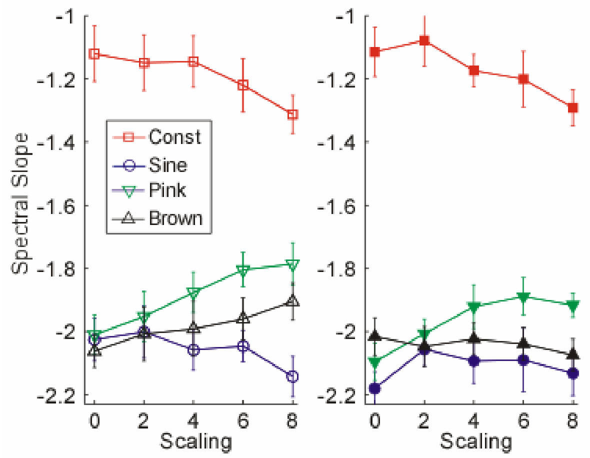

Figure 1: Spectral slope. Left panel: the 4-8 Hz bandwidth amplification condition, and the mean slopes are represented by open symbols. Right panel: the 8-12 Hz bandwidth amplification condition, and the mean slopes are represented by solid symbols. Error bars represent standard error across participants.

increasing scaling [$p = 0.001$]. In contrast, in the pink noise target condition, the slope increased when scaling increased [$p = 0.001$]. In the brown noise target, the slope increased significantly in 4-8 Hz bandwidth amplification condition [$p = 0.015$]. No significant change of slope was found in the sine wave target condition [$ps > 0.05$].

The sum of normalized power (SoP) of three frequency bandwidths covering 4 Hz range (0-4 Hz, 4-8 Hz, and 8-12 Hz) was calculated to provide more detailed information concerning where in the frequency range the changes occurred (see Fig 2). In the constant target condition, statistical analysis showed that the SoPs of 0-4 Hz in the 4-8 bandwidth amplification condition decreased with increasing scaling [$p = 0.004$]. The SoPs of 4-8 Hz and 8-12 Hz frequency ranges also decreased when scaling increased [$ps < 0.05$]. In the pink noise target, the SoPs of 0-4 Hz decreased significantly with increasing scaling [$p = 0.002$]. However, no significant change of SoPs in any of the 4-8 Hz and 8-12 Hz frequency ranges was found [$ps > 0.05$].

In the constant target condition, the larger ratio of decrease in the higher frequency force resulted in a higher proportion of power in the lower frequency, which lead to a steeper spectral slope. However, in

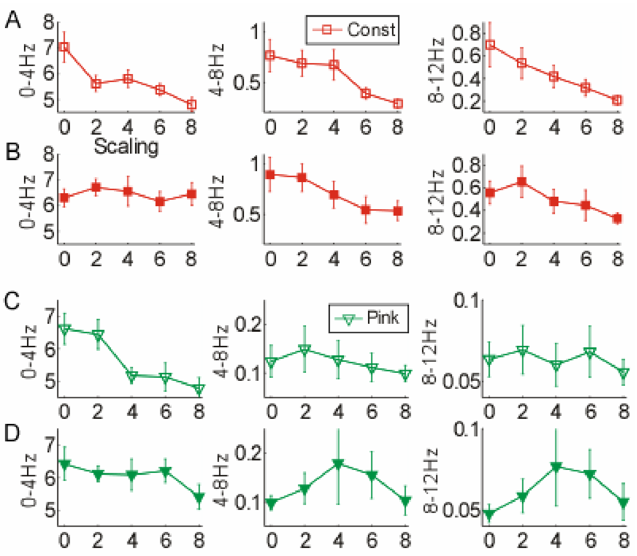

Figure 2: Sum of power (SoP) of three frequency ranges. The left column: the SoP of 0-4 Hz, the middle column: the SoP of 4-8 Hz, and the right column: the SoP of 8-12 Hz. Open symbols represent 4-8 Hz bandwidth amplification condition (Panel A & C), solid symbols represent 8-12 Hz bandwidth amplification condition (Panel B & D).

the pink noise target, the increased slope with increasing scaling was mainly contributed by a decrease of power in 0-4 Hz. The amplification of power in high frequency ranges in visual feedback had no significant effect on changes of SoP in the sine wave and brown noise targets.

The results showed that increased visual scaling in the high frequency components facilitated the control of high frequency force (i.e. reduced power in high frequency force in the constant target condition) and that the control of the low frequency force bandwidth was also changed (i.e. decreased power in 0-4 Hz in the constant target and the pink noise target conditions).

The visual scaling manipulations in the sine wave and brown noise target conditions had no effect on the force structure. This result may be explained by the fact that the slower time scales dominate the force output (steeper slope), therefore, the fast time scales have less effect during the force control.

CONCLUSIONS

This study showed that increased visual scaling in high frequency bandwidth facilitated the control of force within the frequency bandwidth as well as in the neighboring bandwidths. Depending on the task constraints, the findings reveal that the amplification of the fast time scales feedback information can be utilized to enhance force control but this scaling modulation becomes less effective as the force frequencies increase. It is speculated that a control model based on frequency modulated error feedback mechanism may be able to predict the multi-time scale behaviors in force control.

REFERENCES

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