THE PENNSYLVANIA STATE UNIVERSITY
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DEPARTMENT OF KINESIOLOGY

VISUAL INFORMATION INFLUENCES POSTURAL TREMOR

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Abstract

The dynamics of postural finger tremor is typically investigated with natural vision of the finger. Here we investigated the effects of different types of visual information feedback on postural tremor and on inter-limb postural coordination. There were 4 visual information conditions of postural finger tremor from either the dominant hand only or from both hands. The visual conditions were: 1) no vision; 2) natural vision; 3) augmented vision with instantaneous acceleration on a computer display; and 4) augmented vision with instantaneous and past acceleration on a computer display. Acceleration was measured with a 3D accelerometer on the distal phalanx of the index finger(s). Tremor amount and variability did not change across visual information conditions. However, removing visual feedback increased tremor regularity in the one hand condition. In the two-hand condition the artificial visual information increased the irregularity of the combined tremor variability. The no-vision condition showed a more in-phase relationship between digits than natural vision or artificial vision with past information. The findings showed that augmented visual information increased tremor irregularity and facilitated adaptive coupling in two-hand tremor.

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Acknowledgments

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Introduction

The dynamics of postural finger tremor has traditionally been assessed with the subject using information from natural vision to control finger position. Many studies with this approach have shown that there are multiple central and peripheral mechanisms that contribute to finger tremor (Elble & Koller, 1991; Stiles & Randal, 1967). However, the role of vision in regulating tremor is less well understood, including the relative influence of different kinds of augmented visual information (Beuter et al. 1995; Morrison and Newell 1996; Stephens and Taylor 1974; Sutton and Sykes 1967; Vasilakos 1998; Keogh et al. 2004). There are predominantly 3 categories of experimental methods that have been used to investigate the influence of visual information on tremor: 1) comparing natural vision to no vision (Feys et al. 2006; Carignan et al. 2009); 2) introducing artificial visual information typically through a computer aided representation (Feys et al. 2004); and 3) manipulating the gain of the augmented visual information feedback (Carignan et al. 2009; Stephens and Taylor 1974; Morrison and Keogh 2001). The findings on the effect of augmented visual information in postural tremor are inconsistent.

In constant isometric force control, gain and contraction strength were shown not to change tremor dynamics (Stephens and Taylor 1974). Reducing feedback intermittency also failed to produce an effect (Feys 2004). However, augmenting feedback via aiming at a distant target with a laser has produced changes in tremor amplitude and time-dependent structure. Tremor amplitude and irregularity increased with gain of visual feedback (Morrison and Keogh 2001; Keogh et al. 2004). However, gain did not reduce tremor amplitude because EMG activity and the 8-12Hz peak of the power spectrum also increased (Keogh et al. 2004).

In studies comparing no vision to artificial visual information, subjects successfully reduced tremor when provided with artificial feedback (Feys 2006; Carignan et al. 2009, Carrie 1966). The power spectrum broadened dependent on the degree of subjects' success in reducing tremor, and all spectral peaks in the most successful group decreased (Carignan et al. 2009). The lesser-improved group's spectrum only showed a reduced mid range peak (8-12Hz), and the unimproved group's power spectrum did not change significantly. These effects in the frequency domain of tremor can be attributed to gain of visual information. Deviating from an optimal gain that varies individually increases tremor (Beuter et al. 1995; Rooks et al. 1993; Vasilakos et al. 1998).

Symmetry in motor pathways has led to the hypothesis that inter-limb coupling should occur when completing similar tasks contra-laterally (Daneault et al. 2010; Morrison et al. 2008; Lauk et a. 2009, Rethjen et al. 2000). Contrary to this hypothesis, only a low coherence has been found in the frequency domain of postural tremor (Daneault et al. 2010). In contrast, very high coherence—up to 0.99—has been observed in orthostatic tremor (Farkas 2006, Hellwig 2003, Morrison 2008, Lauk 1999).

The purpose of this experiment was to investigate how different types of visual information feedback influence the dynamics of tremor. In 2 experiments, vision was manipulated in 4 conditions providing different types of visual information feedback. In increasing order of information, they are: 1) no vision; 2) natural vision; 3) augmented visual feedback of instantaneous acceleration on a computer display; and 4) augmented visual feedback of instantaneous and past acceleration on a computer display. The visual information feedback conditions were tested in postural finger tremor of the dominant hand only (Experiment 1) and of both hands (Experiment 2).

The visual conditions provide different types of information about the control of postural tremor. It was hypothesized that as the amount of information in the visual feedback increases, the power spectrum of finger tremor will broaden with the low frequency peak proportionally increasing. This result would suggest that subjects used the visual information to control tremor. The amount of tremor amplitude and variability was expected to follow a similar pattern showing a positive correlation between complexity and the amount of available information. In the two-finger postural task it was hypothesized that the limbs will act more tightly coupled in low information feedback conditions.

Experiment 1

Methods

Participants

Twelve healthy individuals (age = 20.9 ± 1.16 years, 6 female and 6 male) volunteered to participate in this study. Participants gave informed consent to the experimental procedures that had been approved by the University Institutional Review Board.

Apparatus

Participants were seated facing a 14-inch laptop monitor with their dominant arm pronated on the table. The hand was positioned as a fist with the palm pronated and supported on the table and the index finger extended at the MCP and IP joints. The forearm was resting on the table to minimize tremor in the more proximal arm segments. A EGAXT3 triaxial accelerometer (Entran Devices) was fixed on the nail of the index finger with athletic tape. The connecting wire was draped over the arm and shoulder of the arm of interest and was also secured to the body with athletic tape.

Output was amplified through Coulbourn S series strain gauge bridge amplifiers. Sampling frequency was 200Hz. The monitor was approximately 60 cm away from participants and 100 cm from the ground during the testing.

Procedures

Experimental Design. The participants' task was to maintain the finger posture shown in Figure 1. They were instructed to pronate the arm and support the forearm and palm with a table. They were to make a fist and extend the index finger at the MCP and IP joints. The task was tested under four conditions with different types of visual information feedback available.

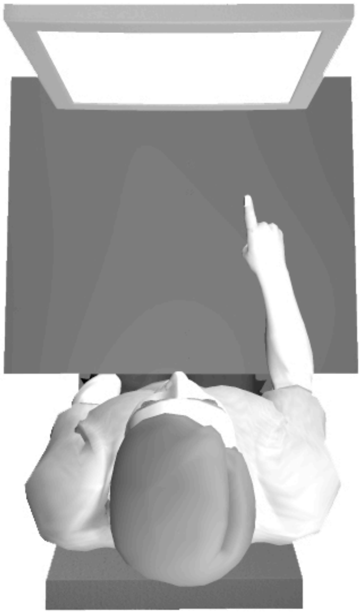


Figure 1: Subjects were instructed to assume the posture above. A table supports the dominant arm and palm while the index finger is extended.

The conditions tested were: 1) no visual feedback (eyes closed); 2) normal visual feedback (eyes open, watching finger); 3) computer enhanced visual feedback (watch instantaneous acceleration on monitor); and 4) computer enhanced visual feedback (watch instantaneous and past acceleration on monitor). Each condition was composed of ten 30s trials. Subjects practiced each condition with two 20s trials before testing began.

Data Analysis

Task Performance. The absolute mean and standard deviation of tremor were calculated for each trial to quantify the amount and variability of tremor.

Tremor Characterization. Approximate entropy (ApEn) and spectral analysis were conducted to analyze the structure of tremor. ApEn provides a measure of the regularity of output, where a value close to 0 is a completely regular waveform (e.g. a sine wave) and a value close to 2 is completely irregular (e.g. white noise) (Pincus 1991). The output was also analyzed in the frequency domain by spectral analysis. Low frequency peaks (2-4Hz) were interpreted to represent descending processes of volitional control. Mid-range frequency peaks (8-12Hz) correspond to physiological tremor. High frequency peaks (18-25Hz) correspond to mechanical oscillations (Elble and Koller 1990). ApEn and spectral analysis were completed for each trial and processed with Matlab v7.10.0.

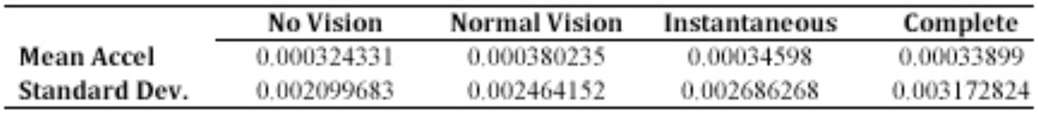
Statistical Analysis.

The dependent variables described above were analyzed using a repeated-measure ANOVA on feedback conditions. A significance level of $p < 0.05$ was used for all analyses. The Bonferroni method was used during post-hoc pairwise comparisons. All statistical analyses were completed using SPSS v18.0. The dependent values are reported as means (± standard errors) unless otherwise noted.

Results

Amount of Tremor Variability

One-way repeated-measure ANOVA of visual feedback performed on both the mean and standard deviation showed no effect of visual information feedback on tremor variability. The condition means and standard deviations are shown in Table 1. There was no significant difference between conditions.



	No Vision	Normal Vision	Instantaneous	Complete
Mean Accel	0.000324331	0.000380235	0.00034598	0.00033899
Standard Dev.	0.002099683	0.002464152	0.002686268	0.003172824

Table 1: The absolute mean and variability (SD) of finger tremor as a function of condition. Values are in units of $m.s^{-2}$.

Structure of Tremor Variability

Time Domain. Figure 2 illustrates the results of a one way repeated measures ANOVA (vision) that found an effect in the structure of acceleration variability in the time domain [$F(1.91, 21.01)=1.323$, $p<0.05$]. Post hoc analysis revealed that ApEn was significantly lower without vision than with normal vision ($p<0.05$).

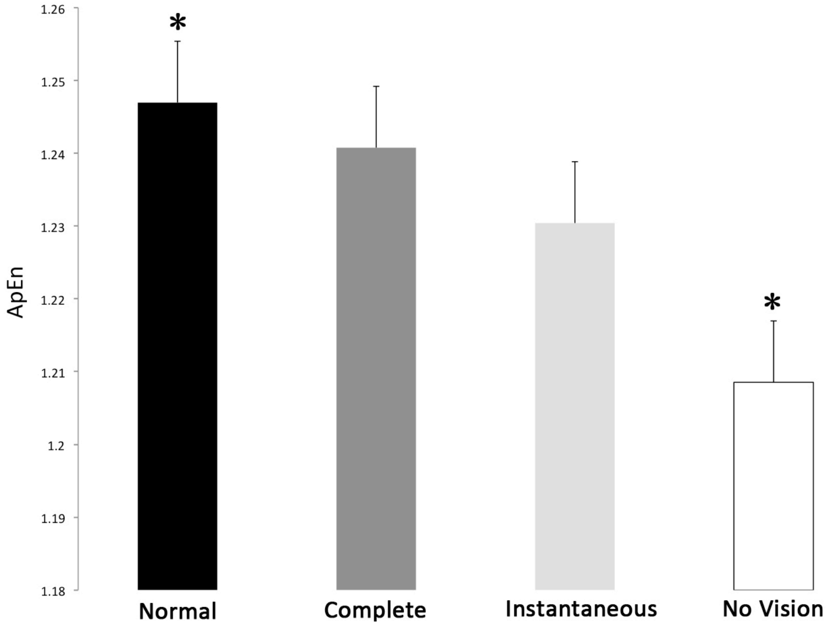


Figure 2: Regularity in acceleration output (ApEn) as a function of visual condition. The asterisk denotes a significant difference between the normal and no vision conditions.

Frequency Domain. In the power spectrum, peaks appeared in different frequency bandwidths [F(1.16, 180.35)=167.46, p<0.01]. Post hoc tests showed that peaks in the natural vision conditions occurred in the same frequency bandwidths (p=1.000), which were at higher frequencies than those of the instantaneous computer feedback condition but less than those of the complete history condition (p<0.01).

Experiment 2

Experiment 2 was designed to investigate how visual information affects inter-limb coordination of tremor. The same subjects tested in Experiment 1 participated in this study. The experimental setup was identical to Experiment 1 except that an accelerometer was also placed on the index finger of the non-dominant hand, and subjects were asked to maintain a finger posture with both hands. Subjects' task and instructions remained the same. The computer feedback conditions showed the absolute average of both fingers' acceleration.

Analysis

In addition to the analyses performed in Experiment 1, phase and coherence analyses were conducted to determine the coupling between fingers as a product of visual information. Phase compares the frequency of oscillations at each point in time and coherence describes the association between each digit's power spectrum. Cross ApEn was used in place of ApEn to examine irregularity in the coupling of tremor in both digits (Pincus and Singer 1996).

Results

Amount of Tremor Variability

As in Experiment 1, a one-way repeated-measure ANOVA of visual feedback was performed on both the absolute mean and on the standard deviation of tremor. There was no effect of the type of visual feedback on tremor variability (p-values>0.05).

Structure of Tremor Variability

Time Domain. Repeated measures ANOVA showed an effect of vision on the structure of acceleration variability (cross ApEn) [F(2.03, 20.25)=9.08, p<0.05]. Figure 3 illustrates that post hoc analysis revealed acceleration variability to be more irregular during both computer aided visual conditions than under normal vision conditions (p<0.05).

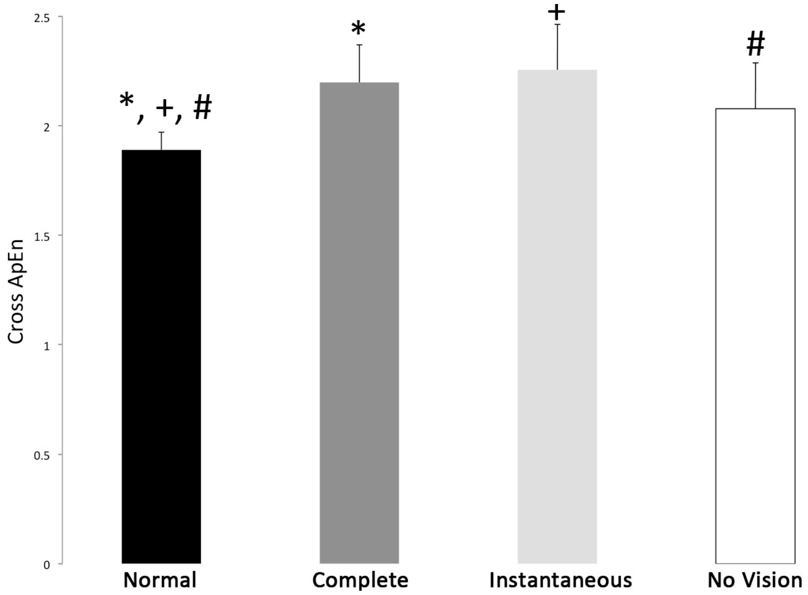


Figure 3: Regularity in acceleration output (cross ApEn) as a function of visual condition. The symbols denotes significant differences between conditions.

Phase and Coherence

There was an effect of vision on phase [F(2.28, 54.82) = 7.79, p<0.01]. Post hoc tests revealed that phase was lower in the no vision condition than in both the normal vision and the complete vision conditions (p=0.000). Across conditions, the fingers accelerated in-phase at low frequencies (0.2-.04rad at 2-4Hz). Statistical analysis showed no effect of vision on coherence [F(1.17, 27.96)= 1.38, p>0.05]. In all conditions, coherence was highest at low frequencies (0.158-0.172 at 2Hz) and approached 0 at higher frequencies.

Statistical analysis revealed an effect of vision on the location of peak in the power spectra [F(1.16, 246.24)=155.34, p<0.01]. Post hoc tests showed that the instantaneous computer feedback condition exhibited peaks in the lowest frequency bandwidths as in Experiment 1 (p=0.000). The complete computer feedback exhibited peaks in the next lowest bandwidths (p=0.000). The natural vision conditions exhibited peaks in the highest bandwidths with the no vision condition exhibiting the most right shifted power spectrum peaks.

Discussion

The study investigated the effect of augmented visual information on tremor dynamics of a single digit and of inter-limb coupling of finger tremor across two hands. Acceleration of tremor was recorded and analyses were performed in the time and frequency domains.

Contrary to the hypothesis that variability and amplitude would show a positive correlation with the amount of information in visual feedback, no correlation was found. Past studies have had varying success in finding a correlation. Some observed the expected positive correlation (Duval 2009; Morrison and Keogh 2001; Carignan 2009) and others have not (Stephens and Taylor 1974; Feys 2001; Daneault 2010). It has been proposed that the gain of tremor may be too low to see a consistent relationship between visual information and tremor amplitude (Legge 1981; Regan 1983). Finger tremor in neurologically healthy individuals is on the order of ±2mm (Harwell and Ferguson 1983; Vasilakos 1998), which may be too small of a fluctuation to effectively act on. However, whether or not subjects can use such fine detail may depend on training: novices cannot use low gain information, but experts like microsurgeons can (Beuter 1995; Vasilakos 1998).

While the magnitude of tremor variability did not change with the amount of visual information in augmented feedback, there were changes in the time-dependent structure of tremor variability. In Experiment 1, variability in the normal vision condition was more irregular (higher ApEn) than in the no vision condition. In Experiment 2, variability in both of the computer-aided feedback conditions was more irregular (higher cross ApEn) than in the normal vision condition. The findings in Experiment 2 are consistent with irregularity in output increasing with feedback availability (Beuter 1989; Slifkin and Newell 2000; Hong 2008). The findings suppport an inverted-U relationship similar to that found in isometric contractions where there is an optimal level of feedback and deviating from it increases movement irregularity (Slifkin and Newell 1999, 2000).

In the frequency domain, the power of acceleration output was redistributed under the different visual conditions. In both Experiment 1 and 2, the acceleration power spectra of the computer feedback conditions were shifted towards lower frequencies compared to the natural vision conditions, which suggests these feedback conditions were involved in greater levels of voluntary control (Freund and Hefter 1993). This effect has been attributed to increased synchronization at the motor unit (Carignan 2009), cortex (Babiloni 2004), and cerebellum (Houweling 2008) levels during finger movements that require attention and provide visual feedback.

Experiment 2 analyzed the inter-limb dynamics of tremor with phase and coherence analyses. While phase fluctuated as a function of frequency, overall coupling was lowest in the no vision condition. This finding is consistent with past research that found coupling to be negatively correlated with visual information (Vaillancourt 2002; de Oliveria 2005). To explain this, it has been suggested that separate central oscillators may control each limb (Morrison 1996, 2000). While this does not account for the non-significant difference between the conditions providing visual feedback, the lack of an effect in this study is consistent with a failure to produce a change in phase by providing displacement feedback (Daneault 2010).

Coherence was highest at low frequencies—peaking at 2Hz—but fairly low overall. Coherence has been shown to be low in all tremors except for orthostatic tremor (Lauk 1999). Further, others have found little data to support inter-limb coupling in tremor (Morrison and Newell 1996, 1999, 2000; Marsden 1969).

Conclusions

Visual information had no effect on the absolute mean or variability of tremor. However, increasing visual information affected tremor regularity in an inverted-U fashion with a peak at normal vision. In Experiment 2, visual information had minimal impact on inter-limb dynamics. Overall, the findings show that visual information does not influence tremor amplitude but does increase tremor irregularity and coupling in two-hand tremor.

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