Nudge and Shove: Frequency Thresholding for Navigation in Direct Brain-Computer Interfaces

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ABSTRACT
Direct control of a computer from the human brain has been made possible by the development of an implanted electrode. This paper describes new paradigms of computer screen navigation adapted for neural signal control.

Keywords
Brain-computer interfaces, neural signal control, navigation

INTRODUCTION

People with *locked-in syndrome* are completely paralyzed and unable to speak, but are cognitively intact. A *neurotrophic electrode* implanted in the motor cortex has been shown to provide locked-in patients with the ability to control a computer cursor directly with brain signals [1]. Imagined hand movements cause the electrode to activate digital signal processing and device drivers which simulate the movement of a mouse on the patient's computer screen. The system is designed to respond to increases in frequency of the neural signal; if the signals are tonic or decreasing the cursor does not move. Learning curve data shows that patients can learn to control the cursor through increasing the frequency of their neural signals [2]. Although the cursor movements mimic a mouse, neural signals are continuous rather than discrete, causing the control paradigm for neural signals to be significantly different than moving a mouse manually. This observation led to exploration of ideas for improving the speed and accuracy of neural signal navigation in the form of *frequency thresholding*, adding semantics to the frequency level of neural signal activity.

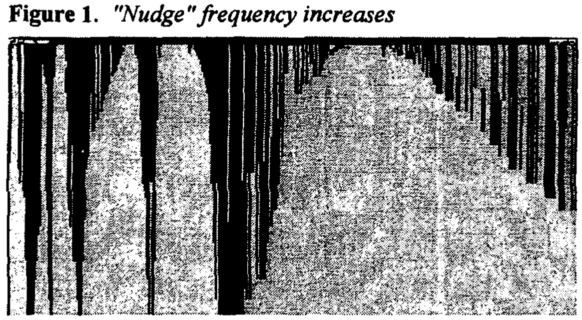
NEURAL SIGNAL NAVIGATION

The current patients have two implanted electrodes; initially one to activate cursor movement in the horizontal direction and one to activate movement in the vertical direction. Initial patient trials described in [2] and [3] involved physical 2-D navigation of a computer screen to select targets from an iconic communication program *(TalkAssist)* or a virtual keyboard. Neural signals were used to move the cursor to the target, and then either an EMG switch on residually active muscles or a dwell (holding over the target for a specified amount of time) was used to select the icon. Patient performance was measured for speed and error rates as reported in [1].

FREQUENCY THRESHOLDING

In navigating to a designated target on the screen, we observed that the patient could regulate the signal frequency according to the distance the cursor needed to travel. For example, if the target were close to the cursor, the patient would "nudge" the cursor along in a series of small signal frequency increases. If the distance to be traveled was large, such as across the entire screen, the patient generated a large frequency increase (which we termed a "shove") which resulted in rapid cursor movement. The figures below show a visualization of the patient's neural signals, the horizontal axis representing time during the trial, the length of the bar indicating the level of frequency increase and the color of the bar indicating which direction (x or y) the signal indicated. Figure 1 depicts a series of "nudges", small increases in frequency, when the patient was attempting to navigate to the next icon in a vertical line of icons.

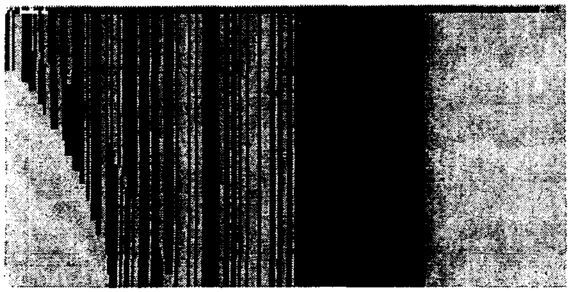
Figure 1. *"Nudge" frequency increases*



The patient increases the signal frequency but quickly relaxes the signal in order not to pass the target.

Figure 2 shows a "shove", a large frequency increase in which the patient was targeting the last icon on a horizontal row of icons. This resulted in the cursor moving rapidly to the distant target.

Figure 2. *"Shove" frequency increase*

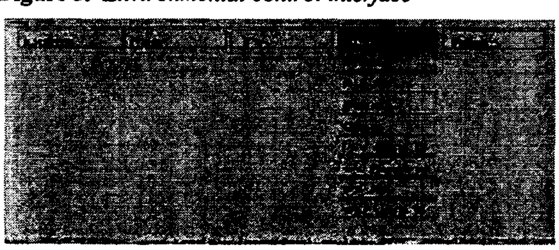


The significance of this data is that not only can neural signals be simply increased or decreased to control a cursor, but the frequency level of the signals can also be controlled. This provides a proportional signal that can be interpreted in different ways in order to provide more accurate and efficient interaction with a computer.

IMPLICATIONS FOR LOGICAL NAVIGATION

Unconstrained physical navigation of a computer screen is difficult for a neural signals user because of the accuracy required to select a target. One way of increasing this accuracy is to constrain the motion of the cursor to significant targets, such as icons [4]. Increases in frequency move the cursor automatically to the next target rather than requiring the cursor to travel linearly across the screen. This type of navigation is termed *logical* rather than physical, and requires specialized applications that respond to logical events. The drawback of logical navigation is that the user may have to traverse all of the targets to reach the one desired. Frequency thresholding, however, can improve the performance of logical navigation by providing two or more different events to the application. For example, Figure 3 shows an environmental control interface developed for neural signals. Each device is represented by a vertical pull-down menu containing commands. A "nudge" moves the cursor to the next selection in the command list, and a "shove" moves the cursor to the next device.

Figure 3. *Environmental control interface*



This means that the patient does not have to navigate the entire command list in order to reach a desired command. The "shove" in this case effects a mode switch in the environmental controller.

There are many applications for this mode switching capability for logical navigation. For example, a "nudge" could be used for navigation within a logical keyboard, and a "shove" could change modes to an email program to send the composed message. We have implemented a web browser that allows the patients to "nudge" along a list of URLS to view, or "shove" to a control mode containing save and print commands. This mode-switching paradigm is generalizable to a wide range of user interfaces.

FUTURE WORK

Although further experimentation is required, it is possible that even finer control of signal frequency can be achieved than the binary "nudge" and "shove". Multiple frequency levels could provide even greater control of computer applications, for example in the environmental controller a different signal frequency could be used to indicate each device, bypassing the navigation across the horizontal axis. We plan to continue patient trials using signal visualization and biofeedback to train the patients to gauge the signal frequency, and to experiment with logical control. We currently have FDA approval and funding from the NIH to implant six more patients within the next two years, and will continue to collect patient training data.

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