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A Behavior Study of the Effects of Visual Feedback on Motor Output

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Abstract— **Visual feedback is a crucial factor that impacts the motor function, and a number of parameters, such as gain, delay and frequency, all play a role in regulating the motor output. In this paper, we conduct a behavioral study on 12 volunteers to determine the effects of visual feedback in the physical movement by measuring the grasp force output under different visual feedback gain levels. To this end, two force tracking tasks with different incremental/decremental rates of the force have been designed, and the force deviation and the error rate from the 12 participants are recorded when they are exposed to different visual gains. Further statistical analysis on the experimental data reveals that the gain of visual stimuli has a significant influence on the force output. For the same force tracking task, visual feedback with high gain tends to enhance the regulation of force production. The results also suggest that different visual feedback gains may be mapped onto different cortex function areas governing different motor tasks.**

I. Introduction

The human motor system refers to the many parts of our bodies that work together to enable us to act and move, and the motor function is controlled through complicated neural mechanisms. By adjusting kinematic parameters (range of movement, speed or acceleration of movement) and kinetic parameters (force production and force variety), the central-neuro-system can smoothly and accurately control motor output. Studies through EEG recordings have suggested that the amplitude of Movementelated Cortical Potential (MRP) has a strong correlation with the movement parameters [1], [2], and force level and force fluctuation can lead to some changes of cortical electrical activities [3], [4]. External stimulus, such as haptical sensing and visual sensing, can influence the motor function significantly. However, up to date, the mechanisms concerning how the external sense regulates motor cortex activity have not been well understood, and the role of visual feedback on the execution of motor function particularly requires to be explored further. Recently, some results about the effects of the visual feedback parameters including gain (scaling displayed on the screen), delay period, and frequency on the motor output, have been reported [5]. These research works indicate that the gain and variable frequency of force can influence the motor output significantly, and visual feedback is crucial to movement skill learning and motor function rehabilitation.

In the literature, force tracking is a typical experiment used to explore the effects of visual feedback on motor function. However, there is no systematic research on the visual feedback effect to force output. This motivates us to conduct a behavioral study to evaluate the correlation between the sensory and the motor systems, hereafter referred as the visual sensory and force production. In specific, we have designed a special force track experiment, in which the impacts of the force varying rate and the gain of visual feedback have been investigated. To reduce the learning effect, force track curves have been arranged in a pseudo-random manner.

II. Method

A. Subject

Twelve healthy graduate students and staff members (seven males and five females, mean age 28.5 years) from the University of Surrey in UK voluntarily participated in this study. Among these 12 participants, ten claim themselves right-handed, and the rest two are self-claimed left hand persons. All participants have either normal or corrected vision, and none of them has reported history of head or hand traumas or neurological disorders. Each subject signed informed consent prior to testing, and all experimental procedures were conducted in line with the ethic policies and protocols of University of Surrey. All participants answered an exit questionnaire after testing.

B. Apparatus

In this experiment, we developed a customized grip force measuring system which includes a grip bar, a force detection unit, and a visual feedback display. The grip bar is a customized wood bar with an embedded FS force sensor (manufactured by HoneyWell Co. Ltd). When a person grips the bar, the force produced by hand can be detected by the force sensor. To sample the force data in real-time, a commercial multi-function DAQ card (ADLINK Co.), PCI-9112 has been used. This PCI card provides a 12-bit A/D resolution, up to 110 ksps sampling rate, 16-CH singleended or 8-CH differential analog signal inputs, and multi-level programmable gains. The functional block diagram of this apparatus is illustrated in Fig. 1.

Detected grip force amplitude will be immediately displayed on a monitor, and the data will be also saved on a hard disk for off-line analysis. In this apparatus, the software program for data detecting is coded using

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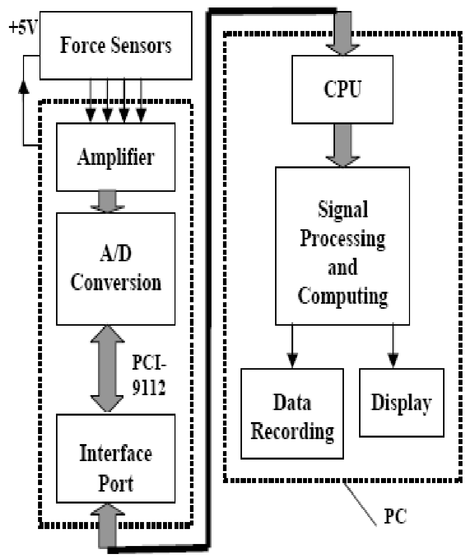

Fig. 1. Functional block diagram of the experimental apparatus

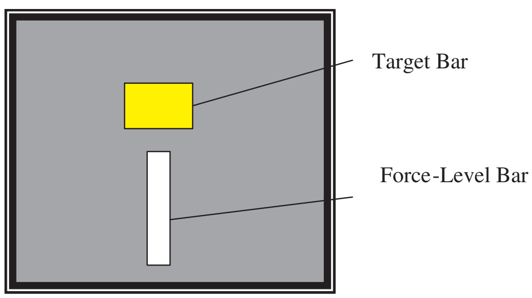

Fig. 2. Design of experiment sequence

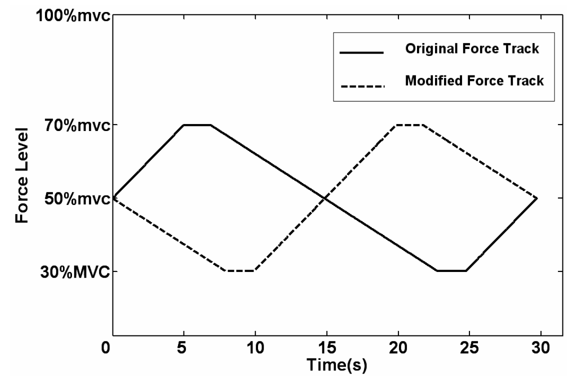

Fig. 3. Pre-specified track for force-time varied slowly

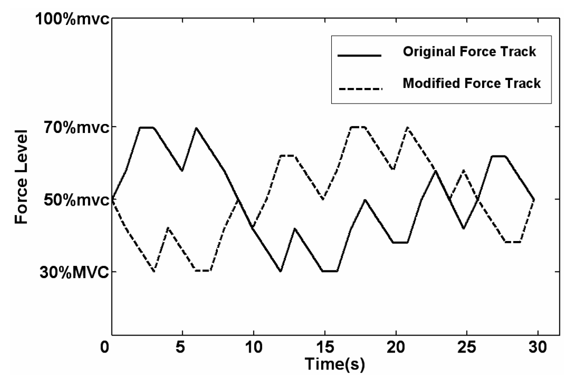

Fig. 4. Pre-specified track for force-time varied quickly

the mixture of Presentation (http://nbs.neuro-bs.com/) and Matlab (http://www.mathworks.com). When the strength of the detected grip force varies, the height of the bar on the screen that indicates the force level would increase or decrease accordingly in real-time. A typical experimental scene displayed on the screen illustrated as Fig. 2.

C. Experiment scheme

During the experiment, a participant will be required to continuously grip the custom-made bar, and he/she needs to track a pre-designed moving target bar displayed on the screen (Fig. 2). When the participant tracks this moving target, his/her grip force output varies with respect to the visual feedback stimulation in a continuous time fashion.

1) Target Moving Track Design: In this experiment, two factors, the gain of visual feedback and the force-varying speed, are examined. The force varying track, which coincides with the target moving route in this experiment, is illustrated in Figs. 3 and 4. To compare the force levels among different participants, Maximum Voluntary Contraction (MVC) of each participant is measured, and the absolute values of the force fall into the range of 30%MVC to 70%MVC. To keep the initial and final force at a comparable level in different blocks, the force track starts and ends at the same force level, 50%MVC.

To reduce the learning effect between different blocks, the fast force track and the slow force track have been modified to include four and two modes, respectively, as exemplified by the two modified force tracks shown as the dashed lines in Figs. 3 and 4.

2) Experiment Design: In this experiment, there are a total of 4 conditions to be considered: (i) two factors, the gain of visual feedback and the force varying speed, and (ii) two levels defined for each factor, fast (F) and slow (S) for grip force, whereas high-gain (H) and low-gain (L) for visual feedback gains. These conditions are respectively numbered as H_F, L_F, H_S, and L_S, in Table I. Each of these four conditions presents one scenario in each testing session, and these conditions are ordered randomly. The 1st, 2nd, 3rd and 4th conditions are denoted as C1, C2, C3 and C4, respectively.

To avoid the fatigue effect experienced by a participant, between the tests of C1 and C2, a 5-second resting period has been allowed. A 1-min rest is inserted between C2 and C3, and another 5-second rest between C3 and C4. The timing diagram of the four tests is given in Fig. 5. In each of the 4 conditions, there are 8 blocks, denoted as B1, B2, ..., B8, and each of the 8 blocks has the same visual feedback gain and force varying speed. Each block lasts 31 seconds, and

TABLE I

FOUR SPECIFIED EXPERIMENT CONDITIONS

		Force varying speed	
		Fast (F)	Slow (S)
Visual feedback gain	High (H)	H_F	H_S
	Low (L)	L_F	L_S

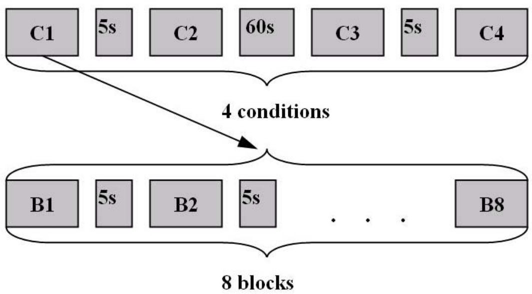

Fig. 5. Design of experiment sequence

a 5-second rest period is inserted between any two blocks (Fig. 5). Altogether, it would take about 20 min. for each participant to complete the whole test in our experiment.

3) Experiment Procedure: When the experiment is in session, a subject is allowed to sit comfortably on a chair, and the distance between the screen and the subject is set to be 50 cm. The participant is required to grip the aforementioned wood bar with his/her dominant hand, and MVC needs to be pre-measured before a testing session starts. To increase the contrast, the screen background has been set to black during the testing phase, and the moving target has a rectangle shape made of 80×30 pixels (a 17-inch LCD monitor is actually used in this study).

Test of each condition and each block will be performed as follows.

- At the beginning of each block (Bi in Fig. 5), the target bar (Fig. 2) appears in the middle area of the screen for 1 second, and this would be considered as the initialization period for the subject.
- After this 1 second, target bar will move vertically according to the pre-defined force track, and the subject is now required to adjust his/her force strength to change the height of force-level bar (Fig. 2) to track the target bar. When the force output is moderate, the upper half of force-level bar overlaps within the target bar, and the target bar turns to green. The target bar becomes red when force output is too strong or too weak. In this case, the upper half of force-level bar is outside of the target bar.
- After the completeness of one condition (8 blocks in total) and before the start of next condition, an indication of HF, HS, LF or LS is displayed on the screen to alert subject about the next condition he/she will be tested upon.

4) Data Sampling: The data of force strength produced by subject's dominant hand has been sampled in real time. Also,

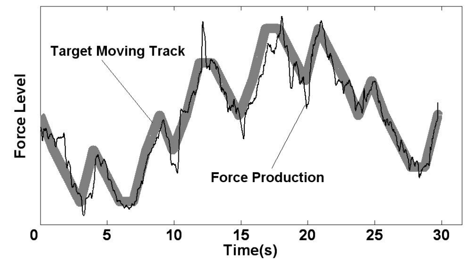

Fig. 6. The comparison of specified force level and actual force output

the force level is displayed as a rectangle with appropriate height, and the force data are saved for off-line analysis simultaneously. Beside the force data, the system records the order of experiment block sequence. The target moving track is also recorded.

III. EXPERIMENT RESULTS AND BEHAVIOR DATA ANALYSIS

In the testing session, the participant needs to adjust his/her force production to track the moving target. An example that illustrates both the target moving track and the actual force output is provided in Fig. 6. Here the thick line in grey represents the target moving track (same as the predesigned force varying curve), and the thin line in black is a recorded grip force output.

To evaluate the effects of visual feedback on force production, the accuracy of force strength, defined as the ability to control the force level within the target range, has been studied. In our experiment, this ability is quantified by computing the error rate and deviation. The error rate can be calculated as

$$S_{error-rate} = \sum_{i=0}^{N} ER(i) \quad (1)$$

where $S_{error-rate}$ denotes the sum of error. If sampled force level $F(i)$ located inside the target force range, the value of $ER(i)$ is 1; otherwise, the value of $ER(i)$ is 0. The deviation of force output can be obtained as

$$S_{deviation} = \sum_{i=0}^{N} D(i) \quad (2)$$

where Deviation $S_{deviation}$ denotes the sum of deviation, and $D(i)$ is the absolute value of difference between ith sampled force output and the mean value of target force range.

According to the experiment session discussed above, a participant would undergo 4 conditions or equivalently 32 blocks (Fig. 5). We calculate the error rate and the deviation of each condition for any subject firstly. Then, the averaged values of error rate and deviation have been computed within all 12 subjects. Furthermore, we use the statistic software SPSS to evaluate how the gain of visual feedback and force varying speed influence the ability of motor control.

From the recorded results, we have found that the deviation of a low gain condition (L_S and L_F) is less than that

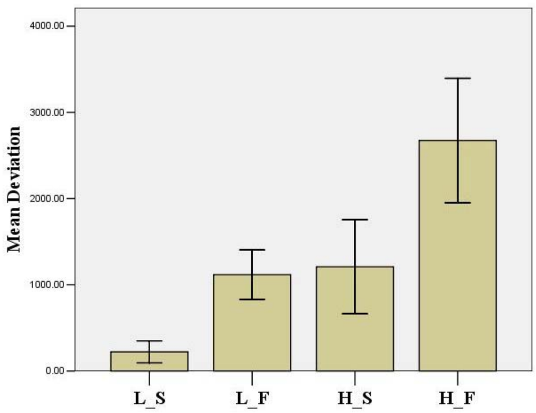

Fig. 7. Comparison of 12-participant force output deviation

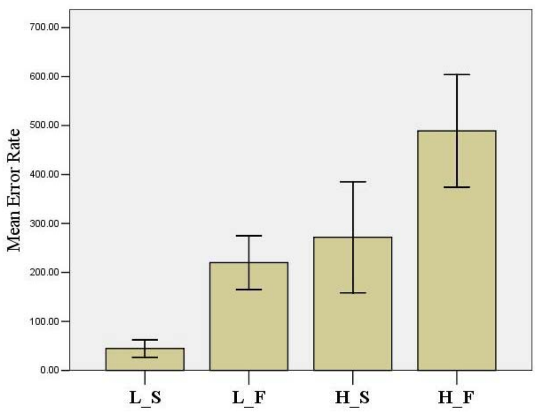

Fig. 8. Comparison of 12-participant force output error rate

of a high gain condition (H_S and H_F), and similar results have been found for the error rate. In the same gain condition (low or high), the deviation of fast condition (L_F and H_F) is much larger than that of slow condition (L_S and H_S), and similar results have been found for error rate as well. The statistical results are reported in Figs. 7 and 8.

IV. DISCUSSION

By comparing and analyzing the behavior data obtained from the experiment, a few interesting phenomenon have been discovered. For the same speed of force varying, different gains of visual feedback would cause different effects on the control accuracy of force strength. Under lower visual feedback gain, the force output of participants tends to be more accurate than when they are exposed to higher gains.

On the other hand, the results of SPSS analysis indicate that, for the slow condition (L_S and H_S), when subject receives visual feedback stimulation with different gains, the deviation and the error rate of force production are vastly different. The corresponding statistical parameters are $F(1, 11)$ = 13.09 ($p < 0.004$) and $F(1, 11)$ = 20.2 ($p < 0.001$) for deviation and error rate, respectively. For the fast condition (L_F and H_F), different gains for visual feedback stimulation result in different deviations and error rates as well. The statistical parameters are $F(1, 11)$ = 31.5 ($p < 0.001$) and $F(1, 11)$ = 55.6 ($p < 0.001$) for deviation and error rate, respectively.

As a matter of fact, gain of visual feedback can be used to strengthen or weaken the effects of visual stimulation when force strength varies. Take L_S and H_S conditions as examples. For the same absolute force change, because of different visual feedback gains, the force change is amplified under H_S condition, and so is the error of force output. This can induce subject to adjust his/her force strength more frequently, and consequently, the error rate of force output and deviation degree would be exaggerated. Similar results are obtained for H_F and L_F conditions. From above discussion, one can see that the gain of visual feedback is an important factor for the control of the force output, and the increased gain can speed up the regulating procedure.

V. CONCLUSION

A few sense stimulations are related to motor function, and visual feedback is a key factor to control the motor output. Some researches suggested that visual feedback is helpful to rehabilitation training on the patient after stoke, and some behavior parameters induced by visual stimulation can be used to evaluate the impairment degree of Parkinson patient [6], [7]. In this study, we have conduct a behavioral study concerning the effects of visual feedback on the control of force output, and the results have indicated that the increased visual gain can improve the ability of force control. Our future research work is to combine the function brain imaging and the behavior methods to acquire an even better understanding of the relationship between the visual feedback and the motor output.

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