Feature extraction for movement disorders of neurological patients based on EMG signals

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Abstract

In this study, we extracted feature parameter for movement disorders of neurological patients using a wrist movement. Specially, based on EMG signals, we captured feature patterns of movement disorders for Parkinson's patients and cerebellar patients from the motor commands level. As an experimental task, we asked subjects to perform smooth pursuit wrist movement, in which the subjects follow a smoothly moving target with a cursor. We recorded movement of the wrist joint and EMG signals of four wrist prime movers with surface electrodes. The participants included eight patients with cerebellar diseases, four patients with Parkinson's disease and eight normal controls. We succeeded to extract two feature parameters from the EMG signals of the four wrist prime movers, Variability of Total Contraction (VTC) and Directionality of Muscle Activity (DMA), which characterize the pathological patterns of muscle activities for the neurological disorders. We found that these feature parameters, if combined appropriately, are useful to characterize complex patterns of muscle activities in a way easy to be recognized visually. In other words, the high-dimensional parameter space is also useful to evaluate effects of a medical treatment as a shift toward or away from the normal control in the parameter space. Consequently, it is expected that our proposed methods will be useful for a navigation system of medical treatments or rehabilitation based on Information Technology (IT) in the future.

Keywords: Movement Disorders, Feature Extraction, EMG Signal, Motor Commands

1 Introduction

Movement disorders is a major sign of neurological disorders [18], [17]. So, feature extraction of the movement disorders for neurological patients is essential for identifying evidence-based treatments. So far, some researchers tried to extract the feature parameter for the neurological disorders using arm movements [12], [14], [11]. They captured some features of movement disorders in patients with neurological diseases based on movement kinematics. The problem here is that the movement kinematics, in general, cannot specify its causal muscle activities (i.e. motor commands) due to the well-known redundancy of the musculo-skeletal system [4]. Thus, in order to understand central mechanisms for generation of pathological movements with the feature parameter, it is necessary to extract the feature for the causal anomaly of motor commands directly, rather than the resultant movement indirectly [3], [10], [2]. For that purpose, we developed a system to analyze the relationship between movement disorders and abnormal muscle activities for wrist movements, and identified causal relationship between wrist movement and activities of as few as four wrist prime movers [6]. With our method, it was possible to establish one-to-one relationship between movement disorders and causal activities of the muscles [7].

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In this study, for the next step, we propose a novel method to extract the feature parameter characterizing the movement disorders for neurological patients from the motor commands level. In particular, based on EMG signals, we captured feature patterns of the muscle activities for patients with cerebellar disorders and patients with Parkinson's disease. We extracted two feature parameters characterizing the variability and the effectiveness of muscle activities. We found that these parameters, if combined appropriately, are useful to characterize complex patterns of muscle activities for each disease in a way easy to be recognized visually. Therefore, it is expected that our proposed methods will be useful for a navigation system of medical treatments or rehabilitation based on the high-dimensional parameter space.

2 Experimental Method

2.1 Experimental apparatus

In order to extract the feature parameter for movement disorders of neurological patients from the motor commands level, we developed a system for quantitative evaluation of motor command using wrist movements [6]. In particular, we intended to analyze the causal relationship between movement disorders and abnormal muscle activities in the system. In addition, the system was also designed to be non-invasive and used handily at the bedside.

An outline of the system is shown in Fig. 1. It consists of four components, a wrist joint manipulandum, a notebook computer, a small Universal Serial Bus (USB) analog-to-digital (A/D) converter interface and a multi-channel amplifier for surface electromyogram (EMG) signal. Movement of the wrist joint is measured with 2 position sensors of the manipulandum at 2 kHz sampling rate, and the wrist position is linked to the position of the cursor on the computer display. In other words, the manipulandum worked as a mouse for the wrist joint. Consequently, we can analyze the relationship between movement disorders and muscle activities, while subjects perform various wrist movement tasks using the manipulandum.

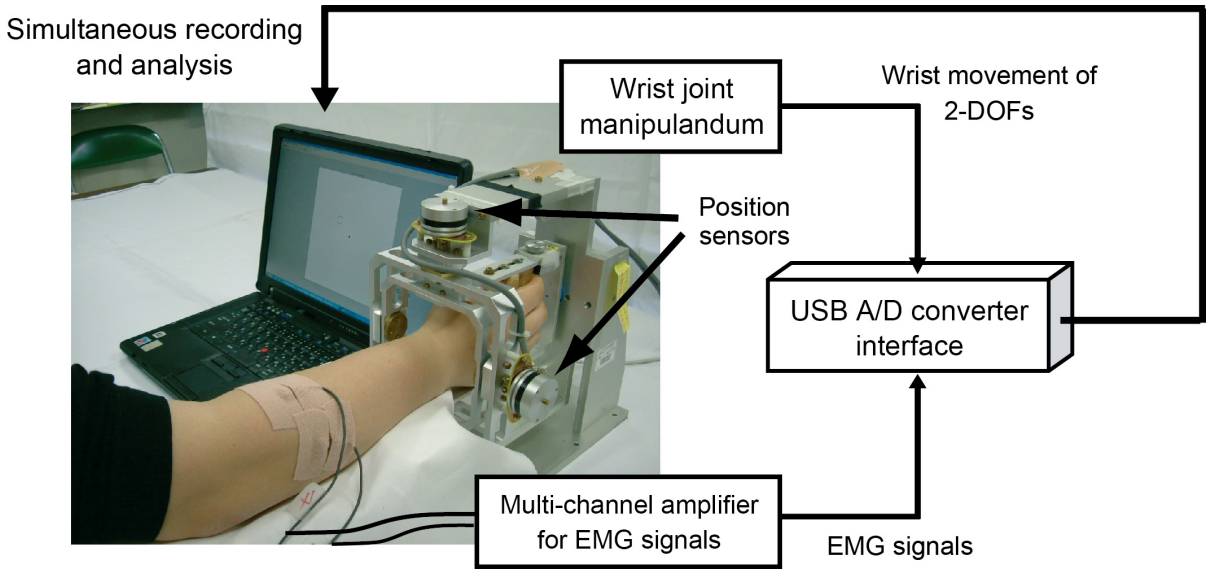

Figure 1: Outline for the quantitative evaluation system of motor command using wrist movements

2.2 Subjects and experimental task

Eight patients clinically diagnosed as cerebellar disorders (average age was 60.6, four patients were diagnosed as spinocerebellar degeneration, three patients as multi-system atrophy and one patient as multiple sclerosis), four patients clinically diagnosed as Parkinson's disease (average age was 70), and eight normal controls who didn't have any history of neurological disorders (average age was 47.4) participated as the subjects. All participants gave an informed written consent, and the local ethical committees approved this study.

As an experimental task, we asked subjects to perform pursuit wrist movements, in which the subjects follow a smoothly moving target with a cursor (Fig. 2A). Subjects sat on a chair and grasped a manipulandum with his/her right hand. The forearm was comfortably supported with an armrest. To initiate a trial, the subject placed the cursor inside the target, which was positioned at the upper left (X=-10°, Y=8°) of the screen. After a fixed hold period of 4 seconds, the target moved by making the path of the figure 2 at the constant speed (mean velocity = 6.2 deg/sec). At that time, the subjects had to enter the cursor into the moving target continuously. After practicing 2 or 3 times in order to understand this task sufficiently, each subject performed this task 5 times.

2.3 Recording muscle activities

During the task, four channels of EMG signals and two degree of freedom wrist movements were sampled and recorded at 2 kHz. EMG signals were recorded with Ag-AgCl surface electrodes and amplified differentially. We recorded the EMG signals from four wrist prime movers: extensor carpi radialis (ECR), extensor carpi ulnaris (ECU), flexor carpi ulnaris (FCU) and flexor carpi radialis (FCR). Fig. 2B shows the approximate positions of the recording electrodes. Specially, based on pulling direction for each muscle, the position of each electrode was adjusted for each subject to maximize EMG signals for a specific movement of each muscle (Fig. 2C). In a few healthy control volunteers, we confirmed effectiveness of the adjustment with high correlation between the surface EMG signals and the corresponding EMG signals recorded with needle electrodes from the same muscles identified with evoked-twitches.

2.4 EMG signals and motor commands

It is well known that EMG signals are closely correlated with activities of α motor neurons, which represent the final motor commands from the CNS. These motor commands generate muscle contraction, which results in muscle tension. It is established that a second order, low-pass filter is sufficient for estimating muscle tension from the raw EMG signal [9], [16]. However, though the low-pass filtered EMG signal is proportional to muscle tension, the proportional constant varies due to variability of skin resistance or electrode position on the muscle for each recording. Therefore, for a quantitative analysis, it is necessary to normalize the EMG signals. For this purpose, we asked the subject to generate isometric wrist joint torque for the preferred direction (PD) of each muscle. Namely, for each muscle, we set the amplitude of the EMG signals for 0.8 Nm of isometric wrist joint torque as 1. Then, the normalized EMG signals were digitally rectified and then filtered with a low-pass filter of a second order (cut-off frequency: about 3Hz) [5]. Most critically, we considered the filtered EMG signals as muscle tensions, and used them to estimate the wrist joint torque [5], [15].

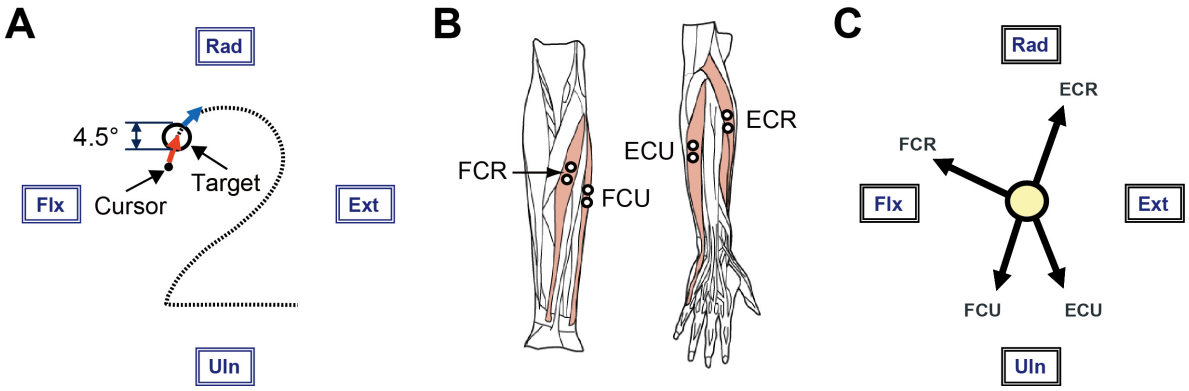

Figure 2: Experimental task and muscles recorded in this study. (A) Pursuit wrist movement as an experimental task. To make these wrist movement tasks, the subject holds the forearm in the neutral position, midway between full pronation and full supination. (B) Muscles related to the wrist joint. The four wrist prime movers whose activities were recorded: *extensor carpi radialis* (ECR), *extensor carpi ulnaris* (ECU), *flexor carpi ulnaris* (FCU) and *flexor carpi radialis* (FCR). We did not distinguish *extensor carpi radialis longus* (ECRL) and *extensor carpi radialis brevis* (ECRB), because they have quite similar actions on the wrist and their activities are indistinguishable with surface electrodes. (C) The arrow indicates the pulling direction of each muscle. Muscle pulling directions for ECR, ECU, FCU, FCR were 18.4, 159.5, 198.3, and 304.5° clockwise from UP target.

3 Result

3.1 Feature extraction for movement disorders based on EMG signals

Fig. 3 shows trajectories and EMG signals of the pursuit movement recorded from a normal control and a cerebellar patient. As shown in Fig. 3A, the normal control followed the moving target very smoothly, by activating the proper muscle corresponding to the movement direction

In contrast, in case of the cerebellar patient (Fig. 3B), the pursuit movement was continuously disturbed by improper timing of agonist selection and/or co-contraction of both agonists and antagonists. In other words, the pursuit trajectory for the cerebellar patient was not smooth, showing an irregular stepwise tracking pattern which conformed to a position tracking pattern [1].

In order to perform a pursuit wrist movement in an experimental task of this study, it is desirable to change muscle activities smoothly, because the target moves smoothly. In addition, it is also desirable to maximize contrast between activities of agonist and antagonist muscles to minimize energy consumption for a movement. Therefore, in order to capture feature patterns in the pursuit movement directly from motor commands, we extracted two feature parameters characterizing the variability and the effectiveness of muscle activities: "Variability of Total Contraction" (VTC, Fig. 4A) and "Directionality of Muscle Activity" (DMA, Fig. 4B) in this study.

3.1.1 Feature parameter 1: Variability of Total Contraction(VTC)

VTC represents temporal variability of muscle activitites, as illustrated in Fig. 4A. We first calculated amplitude of torque for each muscle using equation (1).

$$|\vec{T}_{Muscle}| = \sqrt{(a_x^{Muscle})^2 + (a_y^{Muscle})^2} \times e_{Muscle}(t) \tag{1}$$

where, a_x^{Muscle} (≥ 0) and a_y^{Muscle} (≥ 0) denote the parameters for the musculo-skeletal system of the

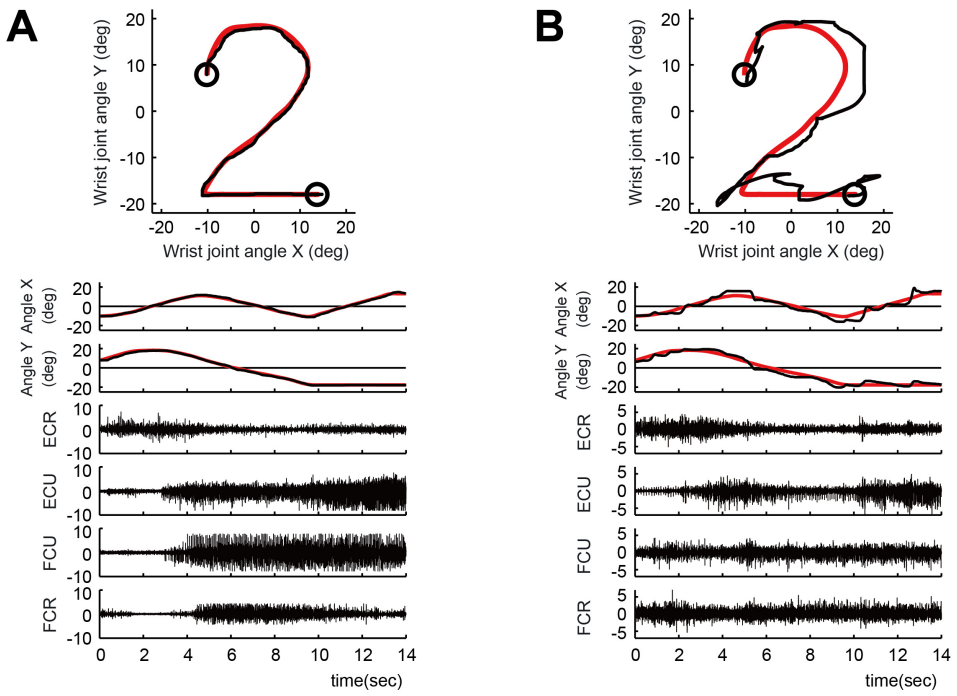

Figure 3: Trajectories and EMG signals for the pursuit movement. (A) An example for a normal control. The inset demonstrates a trajectory of the wrist joint for a pursuit movement. The top two traces show X-axis and Y-axis components of the wrist joint angle. Red lines and black lines indicate the trajectories of a target and the wrist movement, respectively. The bottom four traces show EMG signals of ECR, ECU, FCU, FCR. (B) A corresponding example recorded from a cerebellar patient.

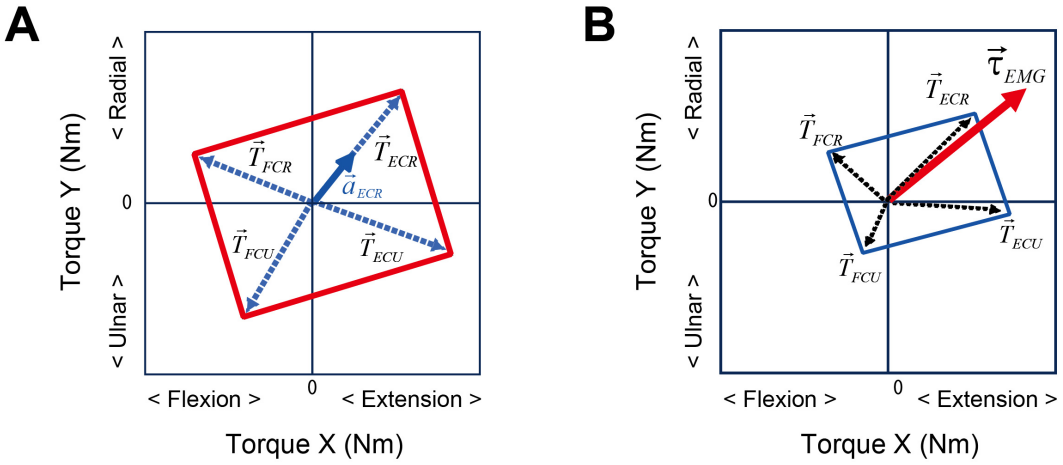

Figure 4: Illustration for two feature parameters, Variability of Total Contraction (VTC) (A) and Directionality of Muscle Activity (DMA) (B) (Modified from [8]).

wrist joint, which convert muscle tension into the X-axis component and the Y-axis component of the

wrist joint torque respectively. $e_{Muscle}(t)$ represents the muscle tension of each muscle.

$$VTC = \frac{\int \left(\sum_{Muscle=1}^{4} \left| \frac{d(|\vec{T}_{Muscle}|)}{dt} \right| \right) dt}{t} \tag{2}$$

Then, as described in equation (2), we calculated the instantaneous variability of the torque for the four muscles. Finally, the VTC was calculated by averaging the absolute value of the variation with movement duration t to normalize it for movement duration.

3.1.2 Feature parameter 2: Directionality of Muscle Activity (DMA)

DMA was evaluted as the ratio of wrist joint torque to the total muscle torque as shown in Fig. 4B and equation (4). We first calculated the wrist joint torque from four muscle activities as follows:

$$|\vec{\tau}_{EMG}| = \sqrt{(g_x(t))^2 + (g_y(t))^2} \tag{3}$$

where, $g_x(t)$ and $g_y(t)$ represent X-axis component and Y-axis component of the wrist joint torque estimated from the four muscle tensions.

$$DMA = \frac{\int \frac{|\vec{\tau}_{EMG}|}{\sum_{Muscle=1}^{4} |\vec{T}_{Muscle}|} dt}{t} \tag{4}$$

Then, as described in equation (4), we calculated the ratio of the wrist joint torque to the sum of the torque of the individual muscles, and finally, the DMA was calculated by averaging the ratio for movement duration t as a nomalization.

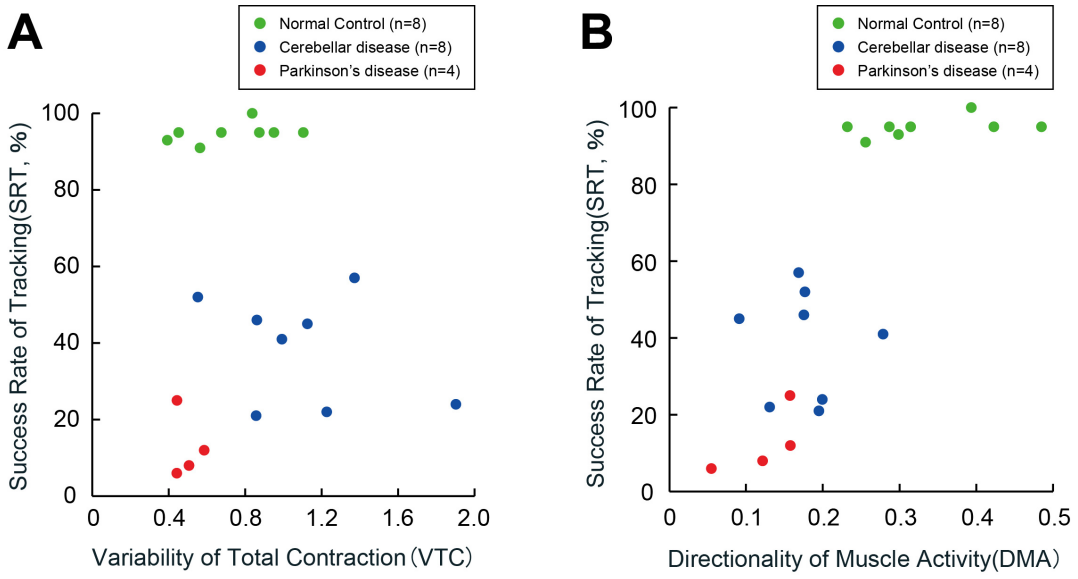

Figure 5: VTC and DMA for neurological disorders and normal controls (Reproduced from [8]). (A) Variability of Total Contraction (VTC). (B) Directionality of Muscle Activity (DMA). SRT indicates the rate (%) of the cursor within the target for the pursuit movement.

3.2 VTC and DMA in the feature parameter of neurological disorders

In order to evaluate usefulness of VTC and DMA, we calculated these feature parameters for patients with cerebellar atrophy and patients with Parkinson's disease, as well as for normal control subjects. Fig. 5 shows the results for each disease.

The VTC indicates variability of muscle activities. Therefore, if there are a number of abrupt changes in the muscle activities, the VTC gets higher. For instance, in case of cerebellar patients (Fig. 3B), muscle activities keep fluctuating intensely due to the cerebellar ataxia. As a result, as shown in Fig. 5A, VTCs for the cerebellar patients tend to be higher than control subjects with much smoother muscle activities (see Fig. 3A). In contrast, VTCs for patients with Parkinson's disease tend to be smaller due to faint modulation of muscle activities.

The DMA represents directionality of muscle activities, and thereby indicating contrast between activities of agonist and the antagonist muscles. By definition, if agonists are activated selectively with complete suppression of antagonists, DMA gets highest. In contrast, DMA is low in case of co-contraction with comparable activities for agonists and antagonists. As a result, as shown in Fig. 5B, DMAs for cerebellar patients are usually very low due to significant co-contraction (see Fig. 3B). On the other hand, in case of patients with Parkinson's diseases, DMAs are also low due to poor modulation of agonist activities.

Overall, VTC or DMA captures feature patterns of the muscle activities for patients with cerebellar disorders and patients with Parkinson's disease. Moreover, it is possible to make more detailed characterization of pathological muscle activities by combining these parameters (Fig. 6). If we use more useful parameters in combination with VTC and DMA, it will be possible to make more sophisticated evaluation of movement disorders in a high dimensional space of feature parameters that quantify patterns of muscle activities. Consequently, it could be possible to evaluate effects of newly developed treatments for neurological diseases in the parameter space.

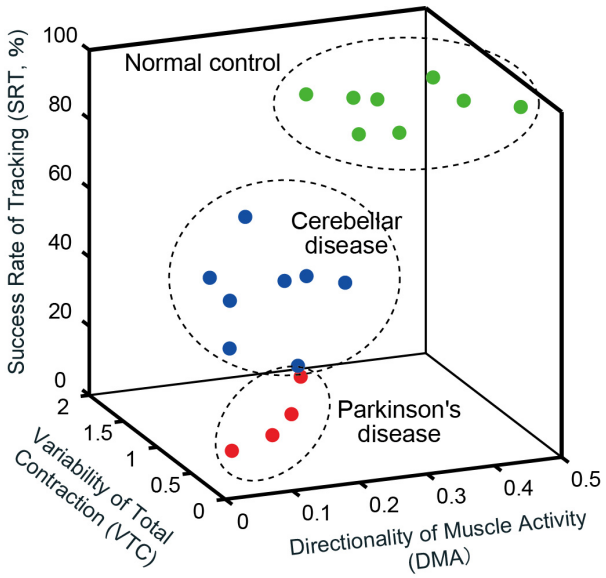

Figure 6: Comprehensive assessment of muscle activities (i.e. motor commands) for neurological disorders and normal control (Reproduced from [8]). Green, blue and red points indicate normal controls, cerebellar patients and Parkinson's patients, respectively. Note that it is easy to separate from each subject group in the 3D parameter space.

4 Discussion and Conclusion

In this study, we proposed new feature parameters to make a quantitative evaluation for movement disorders of neurological patients based on the EMG signals. In particular, we captured characteristic patterns of the muscle activities with two parameters, Variability of Total Contraction (VTC) and Directionality of Muscle Activity (DMA). We found that these feature parameters, if combined appropriately, are useful to characterize complex patterns of muscle activities in a way easy to be recognized visually. In the following discussion, we will focus on two points: 1) How effective our proposed method is; 2) application of our proposed method.

Some researchers tried to extract the feature parameter for the neurological disorders using arm movement in various conditions [17], [12], [14], [11]. For instance, by analyzing the position, velocity and acceleration of arm during a circular movement on the digitizer, Nakanishi et al. (1992) extracted the feature parameter for the movement disorder of the arm movement in patients with neurological disorders including cerebellar deficits and Parkinson's disease, such as latency in movement onset, slow movement, inaccuracy in achieving a target (dysmetria), and so on [12], [14], [11], [3]. However, their analysis was limited to the movement kinematics. Unfortunately, the movement kinematics cannot specify its causal muscle activities due to the well-known redundancy of the musculo-skeletal system [4]. In other words, completely different sets of muscle activities (causes) end up with the same kinematics (results). Thus, in order to understand central mechanisms for generation of pathological movements with the extracted feature parameter, it is essential to capture causal anomaly of the motor commands directly, rather than to observe the resultant movement indirectly [10], [2]. For that purpose, we identified abnormal components of agonist selection for wrist movements from muscle activities of the four forearm muscles [6], [7]. For the next step, in the present study, we further extended our analysis to quantify the pathological patterns of muscle activities. Specially, we found two feature parameters characterizing pathological patterns of the muscle activities (Fig. 5). In addition, we found that these parameters, if combined appropriately, are useful to characterize complex patterns of muscle activities for different movement disorders in a way easy to be recognized visually (Fig. 6). The high-dimensional parameter space is also useful to evaluate effects of a medical treatment as a shift toward or away from the normal control in the parameter space. It is expected that our proposed methods will be useful for a navigation system of medical treatments or rehabilitation based on the motor commands.

In this study, we proposed a new method to identify causal muscle activities for movement disorders of the wrist joint. However, there are twenty-four muscles in the forearm that have significant effects on the wrist joint. If we had to record activities of all these muscles to reconstruct the movement kinematics, we would have to use a number of (i.e. twenty-four pairs of needle electrodes and it would take painful hours for just placing the electrodes. In this study, we proposed a new method to determine abnormal components of agonist selection for various wrist movements by recording activities of as few as four forearm muscles without pain. Consequently, with our proposed method and extracted feature parameters, it is easy to analyze central mechanisms for generation of pathological movement. In fact, we confirmed the effectiveness of our proposed method, identifying the causal abnormality of muscle activities for the cerebellar ataxia and Parkinson's disease (Fig. 5 and Fig. 6).

So far, our method is limited to examine the wrist movement, rather than the whole arm. Nevertheless, the wrist joint is suitable to examine important motor functions of the arm. Basically, not only six wrist muscles but also eighteen finger muscles are relevant to control the two degrees of freedom of the wrist joint [13]. This anatomical setup allows the wrist joint a uniquely wide variety of motor repertoires. For instance, the wrist joint plays an essential role in hand writing which requires the finest precision of all the motor repertoires. It should be emphasized that its role is not just a support for finger movements. On the other hand, the wrist is also capable to generate and/or transmit considerable torque as seen in the arm wrestling. Overall, our method is capable to examine wide range of natural or disordered movements

by the wrist joint. However, in future, it is desirable to expand our method to analyze movements of any body part including the whole arm or gait.

Our proposed method is not limited to analysis of motor deficits. We will further apply this method to evaluation of rehabilitation or guidance of treatment for neurological diseases. As a first step, we examined feature parameters characterizing pathological patterns of muscle activities and demonstrated their usefulness to evaluate pathological muscle activities. These parameters, if combined appropriately, are useful to characterize complex patterns of muscle activities in a way easy to recognize visually. The high-dimensional parameter space is also useful to evaluate effects of a medical treatment as a shift toward or away from the normal control in the parameter space. In other words, based on Information Technology (IT) including tablet system, we can apply this method to the navigation system for medical treatments in the future. We are now preparing to use this system for evaluation and navigation of rehabilitation in the tablet system. We expect that an earliest sign of favorable or infavorable effects of rehabilitation emerges as subtle changes in muscle activities long before visible changes in movement kinematics using the tablet system at home. Our method may be also useful for evaluation of treatments currently available like the deep brain stimulation therapy or available in a near future, such as gene therapies whose targets are in the central nervous system and whose effects appear as, probably, slow renormalization of the motor commands.

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