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Original Article

A comparison of muscle activity between static and dynamic arm positioning tasks with kinematic constraints

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Abstract

How the degree of freedom in the musculo-skeletal system is resolved in human has long been a major focus of motor control studies. With constraints to the environment or restrictions of movement from dynamic to static conditions, it is possible that strategies for resolving the high degree of freedom in muscle excitation may vary according to the condition. However, differences in muscle activity between static and dynamic conditions have not been examined under a constrained environment in previous studies. The aim of this experiment was to examine differences in muscle activity between static and dynamic arm positioning tasks with kinematic constraints.

Arm positioning tasks manipulating a force handle on a guide rail with kinematic constraints were performed by three subjects. As a static condition, the subjects kept the force handle at a constant position (static arm positioning task, SPT). As a dynamic condition, the subjects moved the force handle from the center to a right or left position (dynamic arm positioning task, DPT). During arm positioning tasks, electromyographs (EMGs) of six muscles in the arm were recorded. To investigate differences in EMG activity between SPT and DPT conditions, the correlation coefficient for each muscle at each position was calculated. We obtained a strong correlation coefficient for EMG activity between the two conditions in the three subjects. Therefore, it became clear that there was no remarkable difference in the correlation of EMG activity between the two tasks. From these results, it is suggested that arm movement in positioning tasks with kinematic constraints follows the same controls of motor with regard to the activation of muscles during static and dynamic conditions.

Key words

muscle activity, electromyography, arm positioning task, constraint, motor control

Introduction

Humans have a high degree of freedom in operation of the musculo-skeletal system. Even in arm pointing action between two points, there are many possible hand paths, joint angles, muscle tensions, neuron firing patterns, and so on. Such an infinite variety is said be a problem due to a large number of degrees of freedom, and has long been a major focus of motor control studies[1]. Then how have humans resolved high degree of freedom?

Soechting and Lacquaniti[2] investigated free-arm pointing movement, and they found that humans have invariant characteristics to decrease the number of degrees of freedom of the arm. Also, in arm reaching movement with kinematic constraints such as a linear rail or crank rotation, consistent patterns or optimal movement is performed, despite constraint by the physical environment[3,4]. These studies suggest that humans have resolved the high degree of freedom following a systematic manner according to constraint. On the other hand, Tax et al.[5,6] compared motor-unit activity in the

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Table 1. Physiological data of subjects

	Age (years)	Height (cm)	Weight (kg)	Length of upper arm (cm)	Length of lower arm (cm)
Subject 1	22	178	74	33	25
Subject 2	22	157	50	26	23
Subject 3	21	180	62	32	28

biceps brachii muscle during isometric contractions and voluntary movements, suggested that the central control of the biceps brachii muscle is different for force tasks and movement tasks. However, Sogaard[7] also studied during motor unit recruitment patterns during static and dynamic contractions, and indicated that motor units recruited during different contractions showed similar properties. Moreover, in a recent study by Sergio et al.[8], they showed that there was no compelling evidence of selective recruitment of neurons in specific dynamic environments in primary motor cortex. Although comparisons between static and dynamic conditions have been an object of motor control studies for a long time, there seems to be little agreement as to differences between conditions.

With constraints to the environment or restrictions of movement from dynamic to static conditions, it is possible that strategies for resolving the high degree of freedom in muscle excitation may vary according to the condition. However, differences in muscle activity between static and dynamic conditions have not been examined under a constrained environment. The aim of this experiment was to examine differences in muscle activity between static and dynamic arm positioning tasks with kinematic constraints.

Methods

Three healthy right-handed male subjects participated in this experiment. Table 1 shows the physiological data of the subjects. They had no history of motor disorders. All subjects gave informed consent to participate in the experiment.

We recorded an electromyograph (EMG) from six muscles: the anterior deltoid muscle (DAN), the posterior deltoid muscle (DPO), the brachio radialis muscle (BRD), the lateral head of the triceps brachii muscle (TLA), the biceps brachii muscle (BIC) and the long head of the triceps brachii muscle (TLO). Surface electrodes (M-00-S, NEC Medical Systems) were positioned along the ventral side of the relevant muscle after general preparation for adhesive electrodes. The EMG signal was amplified with a time constant of 0.03 s and a 100-Hz high-cut filter (BA1008, TEAC). To measure joint angles of shoulder horizontal flexion and elbow flexion, electrogoniometers (M180, Penny +Giles) were used. The EMG signal and joint angle data were transmitted to a computer with an AD converter (PCI-DAS6071, Measurement Computing). DASYLab 9.0 software (National Instruments) was used to measure the signals. The sampling frequency was set to 500-Hz.

The experimental instrument and setup seen from the upper surface are shown in Figure 1. We manufactured a custom-built instrument with a force handle (LSA-A-300NSA30, Kyowa Electronic Instruments) on a guide rail as a kinematic constraint. The force handle on the guide rail can be moved +17/-17 cm in the right or left direction in a horizontal plane, respectively, from the center at 0 cm. As a weight load on the force handle, a weight can be attached to the movable base of the force handle. To minimize friction between the

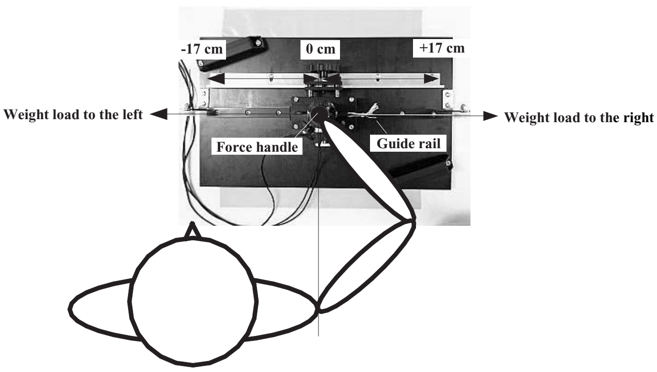

Figure 1. The experimental instrument and setup seen from the upper surface

force handle and the guide rail, ball bearings were used. The instrument was placed so that the line of the shoulder joint-handle and the guide rail were perpendicular.

The arm positioning tasks consisted of manipulating the force handle on the guide rail with a weight load corresponding to 20 N in the right or left direction parallel to the trunk under the following static and dynamic conditions: 1), maintaining a constant position (static arm positioning task, SPT), 2), movement to a right or left position from the center (dynamic arm positioning task, DPT). To measure the amount of motion during guide rail movement, we used a rotary encoder (UN-360, Muto Engineering) and a pulse multiplication counter (CNT-3921-EA10, Coco Research). The force magnitude signals from the force handle and the motion signals during guide rail movement were transmitted to the computer. The target of the SPT was to maintain positions at 0, −8, and −16 cm with a 20 N weight load to the right, and to maintain positions at 0, +8, +16 cm with a 20 N weight load to the left. The target of the DPT was to move the force handle from 0 cm to −17 cm in about 1 second with a 20 N weight load to the right, and to move the force handle from 0 cm to +17 cm in about 1 second with a 20 N weight load to the left. The distance from the shoulder to the force handle differed among subjects (50 cm in subjects 1 and 3, and 46 cm in subject 2). During the experiment, the subjects sat in a bucket seat and were fixed with a 4-point harness to restrict trunk motion. To remove the weight of the upper limb and to restrict motion of the upper limb in the horizontal plane, an arm suspension was used.

Prior to the experiment, we recorded the EMG signals during isometric maximum voluntary contractions and at rest. All EMG signals during tasks, isometric maximum voluntary contractions and at rest were subjected to full-wave rectification and smoothed by a 2nd-order Butterworth low-pass filter with a 50-Hz cut-off frequency. EMG signals during isometric maximum voluntary contractions and at rest were recorded for 5 seconds, and the middle 3 seconds of data were averaged, eliminating the first and last 1 second of the recorded periods. As EMG activities, EMG signals were normalized by the following equation according to Vasavada et al.[9],

$$\%EMG = 100 \times \frac{EMG_{task} - EMG_{base}}{EMG_{\max} - EMG_{base}}$$

where $EMG_{\max}$, EMG_{base}, and EMG_{task} denote EMG signals during isometric maximum voluntary contractions, at rest, and during tasks, respectively. EMG activities of SPT were calculated at 0 cm, −8 cm, −16 cm, +8 cm, and +16 cm positions. EMG activities of DPT were calculated at −0〜−1 cm, −5〜−6 cm, −15〜−16 cm, +0〜+1 cm, +5〜+6 cm, and +15〜+16 cm positions.

To investigate differences between SPT and DPT conditions, we calculated the correlation coefficient using the EMG activities of each muscle at each position. EXCEL statistics ver 6.0 software (Esumi) was used for calculation of the correlation coefficient.

Results

Figure 2 shows example raw data of subject 2 in the DPT with the weight load to the left. In this example, as the weight load is directed to the left, the direction of movement shifts from the center to

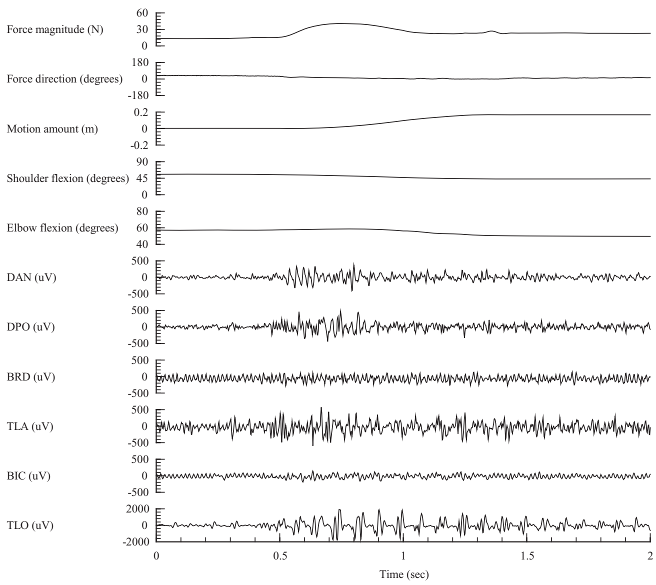

Figure 2. Example raw data of subject 2 in the DPT with the weight load to the left. DAN, anterior deltoid muscle; DPO, posterior deltoid muscle; BRD, brachio radialis muscle; TLA, lateral head of the triceps brachii muscle; BIC, biceps brachii muscle; TLO, long head of the triceps brachii muscle.

Table 2. Force magnitudes and force directions measured by the force handle

	Weight load to the right		Weight load to the left	
	Magnitude (N)	Direction (degrees)	Magnitude (N)	Direction (degrees)
Subject 1	26.4 ± 7.9	162.7 ± 9.7	22.8 ± 5.7	17.3 ± 12.8
Subject 2	22.8 ± 11.5	169.4 ± 7.8	22.4 ± 10.7	24.2 ± 28.2
Subject 3	25.4 ± 9.2	176.1 ± 15.0	23.5 ± 9.9	17.3 ± 21.6

the right. The extensors TLA and TLO were activated first, and DAN and DPO around the shoulder joint were activated next. The flexors BRD and BIC were not clearly activated. Table 2 shows force magnitudes and force directions measured by the force handle. Each value represents by the mean ± standard deviation. Since the weight load was placed in opposing right and left directions, the forces measured by the force handle appeared to reverse direction. Thus, when the weight load was directed to the right, the force direction corresponded to 180 degrees, and when the weight load was directed to the left, the force direction corresponded to 0 degrees. According to Table 2, force magnitudes were greater than 20 N, and force directions rotated clockwise with the weight load to the right and anti-clockwise with the weight load to the left. Moreover, with the weight load to the left, standard deviations of the force directions increased. EMG activities of subject 1 in the SPT and DPT are shown in Figure 3. Although there are differences in EMG activities of each muscle, the increasing and decreasing tendencies are similar between SPT and DPT conditions for each muscle at each position as shown in Figure 3. Thus, we calculated the correlation coefficient using EMG activities for each muscle at each position. Table 3 shows the correlation coefficient of EMG activities in SPT and DPT conditions. SPT −0 cm vs. DPT −0〜−1 cm, SPT −8 cm vs. DPT −7〜−8 cm, and SPT −16 cm vs. DPT −15〜−16 cm in Table 3 denote the correlation coefficient of EMG activities of SPT versus DPT

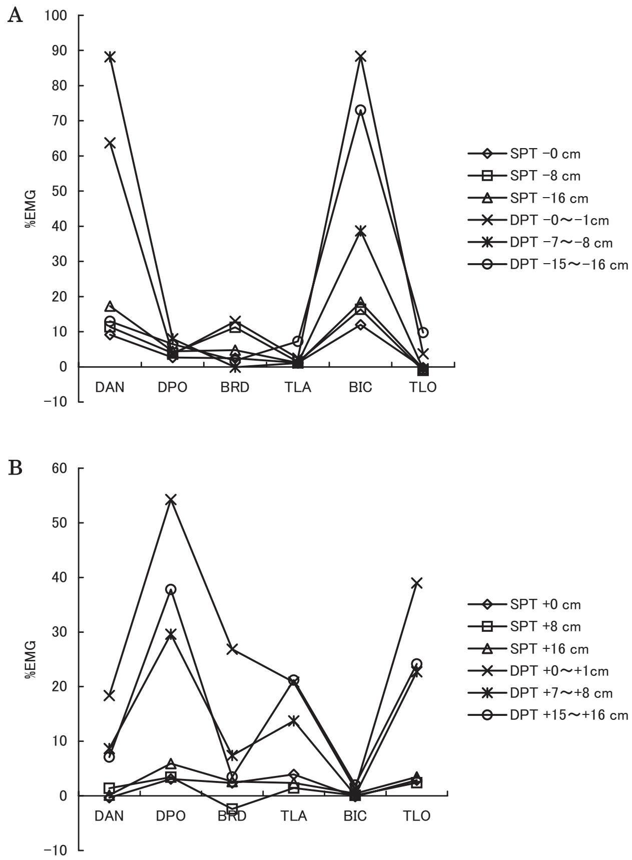

Figure 3. A: EMG activities with the weight load to the right. B: EMG activities with the weight load to the left. All data are from subject 1. SPT, static arm positioning task; DPT, dynamic arm positioning task. Abbreviations of muscles are the same as those in Figure 2.

Table 3. Correlation coefficient of EMG activities in the SPT and DPT

	Weight load to the right			Weight load to the left		
	SPT -0 cm vs. DPT -0〜-1 cm	SPT -8 cm vs. DPT -7〜-8 cm	SPT -16 cm vs. DPT -15〜-16 cm	SPT +0 cm vs. DPT +0〜+1 cm	SPT +8 cm vs. DPT +7〜+8 cm	.SPT +16 cm vs. DPT+15〜+16 cm
Subject 1	0.98	0.83	0.95	0.94	0.7	0.91
Subject 2	0.98	0.58	0.69	0.63	0.76	0.87
Subject 3	0.99	0.75	0.48	0.70	0.80	0.67

corresponding to each position with the weight load to the right. SPT +0 cm vs. DPT +0～+1 cm, SPT +8 cm vs. DPT +7～+8 cm, and SPT +16 cm vs. DPT +15～+16 cm in Table 3 denote the correlation coefficient of EMG activities of SPT versus DPT corresponding to each position with the weight load to the left. Although the correlation coefficient for SPT −8 cm vs. DPT −7～−8 cm in subject 1 and that for SPT −16 cm vs. DPT −15～16 cm in subject 3 are slightly small, the other correlation coefficients are large.

Discussion

We investigated muscle activity in kinematically constrained arm positioning tasks in which the force handle on the guide rail was maintained or moved against the weight load. By comparing EMG activities at each position in the SPT with those in the DPT, differences between static and dynamic conditions were examined. When the correlation coefficient of SPT versus DPT at the same position was calculated, we obtained a strong correlation coefficient of EMG activities among three subjects between the two conditions. Therefore, it became clear that there was no remarkable difference in the correlation of EMG activities between the two tasks. This suggests that arm movement in positioning tasks with kinematic constraints adheres to the same controls of motor with regard to the activation of muscles in static or dynamic conditions.

Arm pointing movement between two points has characteristics of a straight-line path, irrespective of the initial and final positions of the hand within the workspace[10,11]. In general, arm pointing is unconstrained movement in the external space. However, it has been suggested that in performance of this movement with the above characteristics, the central nervous system (CNS) naturally imposes various kinematic constraints, such as Liner synergy[12,13], Donders' law[14], Listing's law[15,16], and the power law[17]. Because we imposed kinematic constraints by a guide rail upon the subjects, movement in our arm positioning tasks was strictly limited. In other words, we already reduced kinematically the degree of freedom by constraints. On the other hand, although differences between static and dynamic conditions in muscle activity were not agreed with previous studies[5-7], our study with kinematic constraints indicated that there are no differences between the two conditions. According to Sergio et al.[8], there was no compelling evidence of selective recruitment of neurons in primary motor cortex of two monkeys between isometric and movement conditions. Moreover, they suggested that the task-dependent changes in M1 activity might be caused by peripheral reafferent input rather than by central feed-forward process. One explanation for similarity between the two conditions may be that the subjects did not carry out task-dependent movement, by using mainly feed-forward process with the kinematically constrained degree of freedom. Bernstein[1] has already stated 40 years ago that the CNS is able to resolve the problem of kinematic variety by reducing the effective number of degrees of freedom in a coordinated task. Thus, by effectively utilizing the number of degrees of freedom to the environment, we understood that controlling patterns in muscle excitation, that is the neural command for resolving the high degree of freedom of movement from the CNS, have invariant features whether the condition is static or dynamic.

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運動制限のある静的・動的な上肢ポジショニング課題間の筋活動の比較

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要　　旨

どのようにしてヒトは筋骨格系の自由度を決めるのかという疑問は長い間、運動制御研究に関する主要なテーマである。環境への制限あるいは動的から静的への運動の制約によって、筋活動中の自由度に対する方策が条件により変わると考えられる。しかしながら、制限された環境下での静的・動的な条件間での筋活動の違いについては先行研究で検討されていない。この研究の目的は運動制限のある静的・動的な上肢ポジショニング課題間の筋活動における違いを検討することである。

３名の被験者に運動制限のあるガイドレール上の力ハンドルを操作する上肢ポジショニング課題を遂行させた。静的な条件として、一定の位置に力ハンドルを保持するとした(SPT)。動的な条件として、中央の位置から右または左へ力ハンドルを動かすとした(DPT)。ポジショニング課題中、上肢の６つの筋の筋電図（EMG）を記録した。SPTとDPT条件間のEMG活動量における相違を検討するため、各筋に対する各位置での相関係数を計算した。３名の被験者ともに２条件間でのEMG活動量に強い相関が得られ、両課題間のEMG活動量の関係に著しい違いがないことが明らかとなった。これらの結果から、運動制限のあるポジショニング課題での上肢の運動は静的・動的中でも筋の活動には同様の運動制御が利用されていることが示唆された。