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Identification of Static and Dynamic Properties Induced by Hip Changes to Flexion Withdrawal Reflex in Chronic Human Spinal Cord Injury*

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Abstract

The aim of this study was to investigate the static and dynamic properties of the flexion withdrawal reflex modulated by hip changes in human spinal cord injury. The influence of the hip position and passive movement were tested in six subjects with chronic spinal cord injury. Each subject was placed in a supine position and lower limb was fixed with the knee at 23.7±16.0 degrees flexion and the ankle at 33.3±5.2 degrees plantar flexion. A train of 10 stimulus pulses were applied at 200Hz to the skin of the medial arch to elicit the nociceptive flexion reflexes. From results of the regression analysis, activation of flexor muscles (tibialis anterior and illiopsoas) during static hip angle changes has a linear relationship with respect to hip angle ($P<0.05$). As the hip flexion angle increases, the EMG activity decreases. A significant linear relationship was also found between the reflex activity of flexor muscle (illiopsoas) and hip angular velocity during both hip flexion and hip extension movement ($P<0.05$). In order to validate the reflex response, we compared the static and dynamic gains of estimated activation with measured electromyogram of tibialis anterior. From this study, we postulate that flexor muscle activities of nociceptive flexion reflex have linear relationship with hip angle and angular velocity.

Key words: Flexion Withdrawal Reflex, Linear Model, Spinal Cord Injury

1. Introduction

Flexor withdrawal reflexes, first described by Sherrington [(1)] at the beginning of the twentieth century, consist of spinal reflexes producing flexion of the limb in response to activation of a variety of afferents including muscle group II, III and IV, joint and cutaneous afferents [(2)]. While flexor reflexes are most commonly tested using an electrical stimulus applied to the cutaneous innervation of the foot [(3)], they can also be elicited in spinal cord injury (SCI) using imposed movements of the ankle, particularly when passive loading of the muscles is produced [(4)]. Similarly, flexor reflexes are produced in response to electrical stimulation of the ankle flexors [(5)], confirming the convergence of muscle and cutaneous afferents onto flexor reflex pathways in human SCI. Because of the convergence of many afferents onto a common spinal reflex, we postulate that the excitability of the flexor reflex triggered by the nociceptive stimulation of the foot will depend on limb position in subjects with chronic SCI. This concept is consistent with reports from individuals with chronic SCI who indicate that flexor spasms are problematic at night, when lying flat in bed, but less pervasive when in a seated position.

The advantage of the withdrawal reflex is that it provides a balanced hip flexion that is

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difficult to attain with stimulation of individual hip flexors. Therefore, nociceptive flexor reflex has been used for producing or assisting the swing phase of gait cycle in SCI patients through functional electrical stimulation (FES) system [6]. Clinically applied FES systems have been based on both open-loop control through a trial-and-error approach and close-loop control to improve the performance of neuroprosthetic devices. However, it is difficult to determine the optimal stimulation pattern that is required to obtain the desired limb motion because the human body consists of a complex multi-joint system having highly nonlinear neuromuscular properties.

For several decades, researchers have studied the identification of the input–output properties of electrically stimulated muscle responses [7] and have developed mathematical models for lower limb dynamics in paraplegic patients [8, 9]. Unfortunately, a mathematical model of the flexion withdrawal reflex, which can play an important role in producing flexion of lower limb during the swing-phase in simple reciprocal ambulation of paraplegic persons, has not been studied, to date. Therefore, it is important to investigate the relationship between hip conditions (position and angular velocity) and the reflex response elicited by nociceptive electrical stimulation of the foot in order to restore motor function in patients with upper motor neuron lesions.

The aim of the present study was to identify the influences of hip position and angular velocity on the activation levels of the hip and ankle muscles during flexion reflexes using linear regression model from measurements of moment response to noxious stimuli applied to the skin of the foot. The activations of the hip and ankle flexor muscles elicited by nociceptive stimulus were calculated from the measured moment responses using Hill-based muscle model. A linear regression analysis was carried out for each of the six individuals to determine the static and dynamic gains of nociceptive flexor reflexes. To validate the linear model of flexor reflexes, we compared the estimated activation levels with the measured electromyogram (EMG) responses of ankle flexor muscle. The characteristics of the flexion reflex on hip position and movement have important implications in the clinical management of spasticity and can be used to improve the development of lower limb neuroprostheses in neurologically injured patients during gait.

Nomenclature

a: activation level of muscle
F_m: muscle force
f_l : length-tension relation of muscle
f_v : velocity-tension relation of muscle
r: moment arm of muscle
α : pennation angle
θ : joint angle
$\dot{\theta}$: joint angular velocity

Subscripts

h: hip joint
TA: tibialis anterior
IP: iliopsoas

2. Methods

2.1 Subjects

Six subjects were recruited into this study through the inpatient and outpatient physical therapy clinics of the Rehabilitation Institute of Chicago. Inclusion criteria included SCI and a history of spasms reported by the subject and/or physical therapist. All participants had complete SCI (American Spinal Injury Association (ASIA) Scale A) at levels ranging

from C5 to T6, as summarized in Table 1. Subject consent was obtained and all procedures were conducted in accordance with the Helsinki Declaration of 1975 and approved by the Institutional Review Boards of Northwestern University, Chicago, Illinois and Marquette University, Milwaukee, Wisconsin.

Table 1: Clinical features of subjects

Subject	Level of Injury	ASIA Impairment Scale	Age (years)	Time post injury (years)
A	C5	A	33	1
B	C6	A	33	1
C	T3	A	46	5
D	T6	A	18	1
E	C5	A	24	5
F	T4	A	37	2

2.2 Experimental setup

The test apparatus consisted of a leg brace with moment transducers aligned with the axes of rotation of the ankle, as shown in Fig. 1. The foot was placed in a footplate and secured using clamps placed on the dorsum of the foot and on the heel. The hip-knee and knee-ankle links were adjustable to fit a wide range of leg sizes. The entire leg brace was affixed to the motor of a Biodex Rehabilitation Testing System 2 (Biodex Medical Systems Inc., Shirley, NY). Hip moment, position, and velocity signals were recorded from the transducers on the Biodex. In addition, ankle moment was recorded from reaction moment meter (S. Himmelstein and Co., Hoffman Estates, IL) incorporated into the leg brace. Surface tibialis anterior (TA) EMG was recorded by Active Delsys electrode (model DE2.1, Delsys Inc., Boston, MA), which was applied to lightly abraded, degreased skin over the respective muscle belly. The signal was amplified (x 1,000) and filtered (20–450 Hz; Bagnoli-8, Delsys Inc.). The signals were sampled at 1,000 Hz using the same computer system used for acquiring the position and moment data. Flexion reflexes were elicited by electrical stimulation through bipolar surface electrodes (Blue Sensor, Medicotest, Rugmarken, DK) placed 1 cm apart at the foot sole and a constant current stimulator (Model DS-7A, Digitimer Stimulator, Hertfordshire, UK).

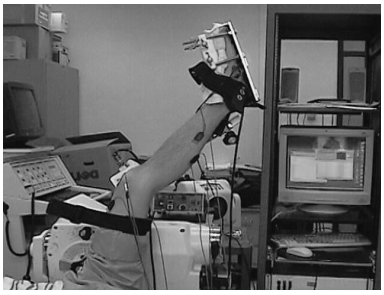


Fig. 1 Experimental apparatus for testing flexor reflexes

2.3 Procedures

Tests of flexion reflexes were conducted with subject supine during imposed static and dynamic hip movements. Each subject was placed in a supine position and lower limb was fixed with the knee at 23.7±16 degrees and the ankle at 33.5±5.2 degrees, corresponding to approximately the joint position at the initiation of swing. The hip was aligned with the axis of the Biodex motor and the brace was adjusted to align the ankle with the moment meter. Stimuli were applied with the hip held isometrically in three positions: flexed (70deg), extended (10deg) and in the midposition (40deg). Additionally, the response was measured to stimuli applied at midposition during 30deg/s constant velocity flexion and extension

movements, initiated from the full flexed or extended posture by the Biodex system.

2.4 Identification of Flexion Reflex Using Hill-Based Muscle Model

To investigate the influence of the hip position and hip movement on the flexion reflex, we assumed that the neural response of flexion reflex was a linear function of hip angle and angular velocity. Muscle activation levels of flexor muscles were estimated using measured moment data. Active muscle force (F_m) generated by flexion reflex triggered by foot stimulation was modeled with Hill-based contractile elements consisting of three factors describing the length-tension, the force-velocity property, and activation of muscles [10, 11].

$$F_m = aF_m^o f_l(\tilde{l}_m) f_v(\tilde{v}_m) \quad (1.1)$$

$$\tilde{l}_m = l_m / l_m^o, \ \tilde{v}_m = v_m / v_m^o \quad (1.2)$$

where a is activation of muscle fiber, F_m^o is peak isometric muscle force, l_m^o is optimal muscle fiber length and v_m^o is maximum shortening velocity, f_l is the length-tension relationship, and f_v is the force-velocity relationship.

Muscle moments of hip and ankle joint were calculated from muscle force multiple by muscle moment arm (r_m) and pennation angle (α).

$$\tau = F_m \cos(\alpha) r_m \quad (2)$$

For simplification, two major flexor muscles having important effects on flexion withdrawal reflex of lower limb were considered in order to investigate the reflex properties. These muscles are iliopsoas (IP) for hip flexion and TA for ankle dorsiflexion. Comparisons of the calculated reflex activity with measured TA EMG (rectified, smoothed EMG) were used to confirm the validity of using moment response to estimate the muscle activity of flexor reflex.

2.4.1 Static Property of Nociceptive Flexor Reflex

In order to identify static and dynamic properties of flexion reflex, we modeled the activation level of each muscle as combination of linear model of hip angle (θ_h) and angular velocity ($\dot{\theta}_h$).

$$a = B_0 + B_1\theta_h + B_2\dot{\theta}_h \quad (3)$$

where B_1, B_2 are static and dynamic gains of flexion reflex, respectively. Under isometric condition, activation level of each muscle was simplified to Eq. (4). We postulated that the hip proprioceptors, including the hip joint afferents and hip muscle afferents converged with the cutaneous afferents from the noxious foot stimulation onto common spinal neuronal pathways to result in a flexion withdrawal reflex that was modulated by hip joint angle [12].

$$a = B_0 + B_1\theta_h \quad (4)$$

First, we examined the ankle joint where we assumed that the ankle moment could be attributed to activation of the TA muscle, which remained the same length during changes in hip angle. The ankle joint moment was given by Eq. (5) as follows:

$$\tau_{ankle} = (B_0^{TA} + B_1^{TA}\theta_h) \times F_{TA}^o f_l(\tilde{l}_{TA}) \times \cos(\alpha_{TA}) \times r_{TA} \quad (5)$$

Note that the muscle activation, a, was incorporated into the B coefficients. We determined the estimated muscle activation level using peak measured ankle moment data for individual subjects. The static gain of the hip angle (B_1^{TA}) was then calculated for each subject using a linear regression of the isometric data at the three tested hip angles.

A similar analysis was then applied to the measured TA EMG data in order to validate the analysis. A linear regression of the TA EMG was then used to calculate the static gain for each subject. These gains were then compared to the B values obtained from the moment analysis.

Hip joint response is more complicated than ankle joint because length of hip flexor

muscle is also changed according to hip angle. We determined the estimated muscle activation level using peak measured hip moment data. Hip joint moments are given by Eq.(6).

$$\tau_{hip} = (B_0^{IP} + B_1^{IP}\theta_h) \times F_{IP}^o f_l(\tilde{l}_{IP}) \times \cos(\alpha_{IP}) \times r_{IP} \quad (6)$$

The static gain of the hip angle (B_1^{IP}) for hip flexor muscle was then calculated for each subject using a linear regression analysis.

2.4.2 Dynamic Property of Nociceptive Flexor Reflex

The dynamic response was measured using electrical stimuli applied at the midposition of the hip with constant angular velocity, initiated from the full flexed or extended posture. A control movement was provided to account for inertia, gravitational and hip triggered reflex moments at the hip and ankle joints. The moment response of the hip joint elicited by the electrical stimulus during passive hip movement consisted of components of the length, velocity and activation of the hip flexor muscle. Since the stimuli were all applied at the same hip angle, the dynamic gain (B_2 in Eq.3) was then estimated using a simplified equation (Eq.7). In addition, the dynamic gain was estimated separately for the hip flexion and hip extension perturbations, since both movements appeared to produce an increase in the reflex response.

$$a = B_{0d} + B_2\dot{\theta}_h, \quad B_{0d} = B_0 + B_1\theta_h \quad (7)$$

For the ankle, the joint moment was assumed to be determined as shown in Eq. (8). We then neglected the force-velocity property of TA muscle because the ankle joint was fixed. Since the stimuli were all applied at the same position, the position effect was accounted for by the constant. In order to analyze the dynamic property, a normalized data was used, normalizing the reflex moment and EMG by the mean response during the static posture.

$$\tau_{ankle} = (B_{0d}^{TA} + B_2^{TA}\dot{\theta}_h) \times F_{TA}^o f_l(\tilde{l}_{TA}) \times \cos(\alpha_{TA}) \times r_{TA} \quad (8)$$

A similar analysis was also applied to the measured TA EMG data in order to validate the analysis during hip movement. A linear regression of the TA EMG was then used to calculate the dynamic gain for each subject. These gains were then compared to the B_2 values obtained from the moment analysis.

Since the length and velocity of the IP muscle were changed during hip movement, these effects on hip moment needed to be accounted for. In this test, the IP muscle's stretch and shortening velocity were equal but different direction (muscle shortening velocity is 0.022m/s) during angular velocity of hip joint (30deg/s). The hip joint moment during the hip movement was given from Eq. (9). Net peak moment of hip joint was calculated by subtracting moment with stimulation from without stimulation at the mid-position of hip (hip angle=40deg) during different movement. Again, the peak hip flexion moment used for the calculation of dynamic gain was normalized by the mean hip moment produced during the isometric test.

$$\tau_{hip} = (B_{0d}^{IP} + B_2^{IP}\dot{\theta}_h) \times F_{IP}^o f_l(\tilde{l}_{IP}) f_v(\tilde{v}_{IP}) \times \cos(\alpha_{IP}) \times r_{TA} \quad (9)$$

A linear regression of the hip flexor muscle was then used to calculate the dynamic gain for each subject.

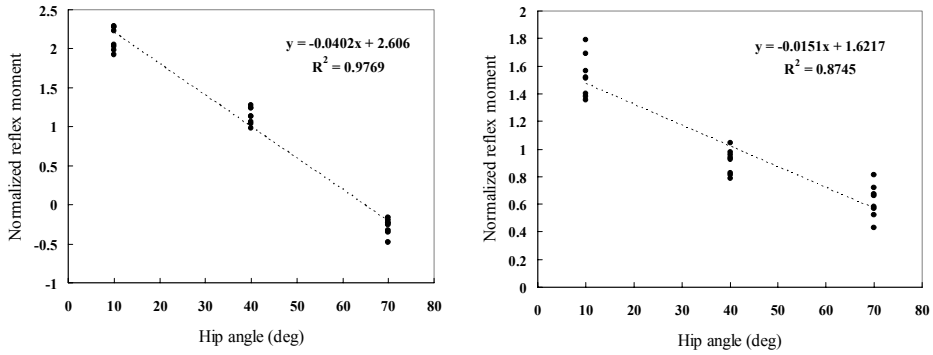
2.5 Statistics

A linear regression analysis was carried out for each of the six individuals to determine the static and dynamic properties of nociceptive flexor reflex. Regression function fitted by the method of least squares, analysis of variance for significance of regression, and the coefficient of determination (R^2) were determined for each subject under isometric and passive hip movement conditions. $P < 0.05$ was considered statistically significant for all statistical tests.

3. Results

3.1 Identification of Static Flexion Reflex under Isometric Conditions

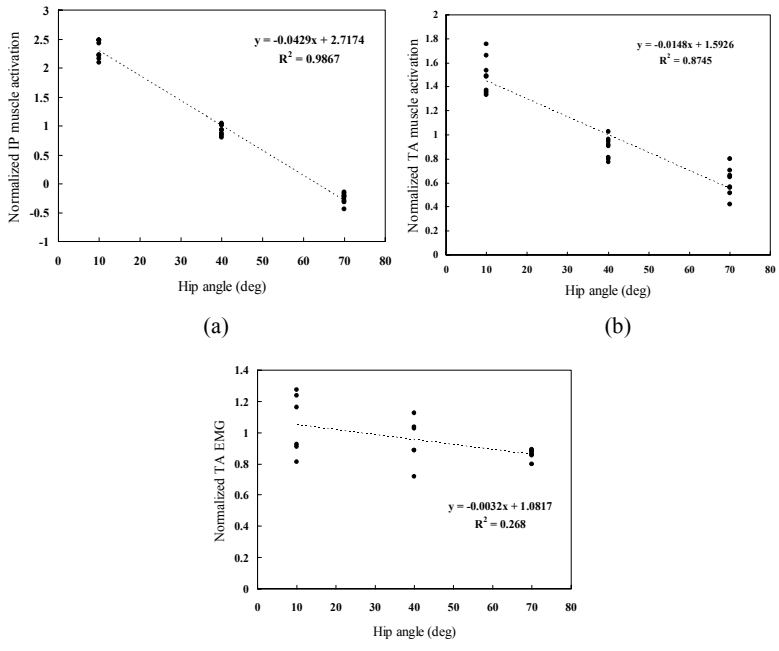
Figure 2 contains a plot of the estimated regression function of reflex moment normalized by the mean response during isometric conditions, as well as the original data for subject D. The linear regression curves show that increasing hip angle resulted in a decrease of the reflex moment at the hip and ankle joints. The reflex moments had a stronger correlation at the ankle (R^2=0.8745) and hip joint (R^2=0.9769).



(a) (b)

Fig. 2 The data and least squares regression line between normalized reflex moment and hip angle for subject D. (a) The reflex moment at the hip joint, (b) The reflex moment at the ankle joint

The relationship between the reflex activity of flexor muscles and hip angle were calculated by using Hill-based muscle model from measured reflex moment. In subject D, the regression lines fitted by the method of least squares and scatter of the data points between reflex activity of flexor muscles and hip angle are illustrated in Fig. 3. The regression lines show that the reflex activities of flexor muscles tended to decrease with the hip angle. By comparing the R^2 values, a strong correlation was found between reflex activation and hip angle (R^2=0.9867 for IP, R^2=0.8745 for TA). The corresponding fitted line of measured TA EMG was consistent with the calculated activations in that they had a tendency to decrease at large hip flexion as shown in Fig. 3(c).



(a) (b)

(c)

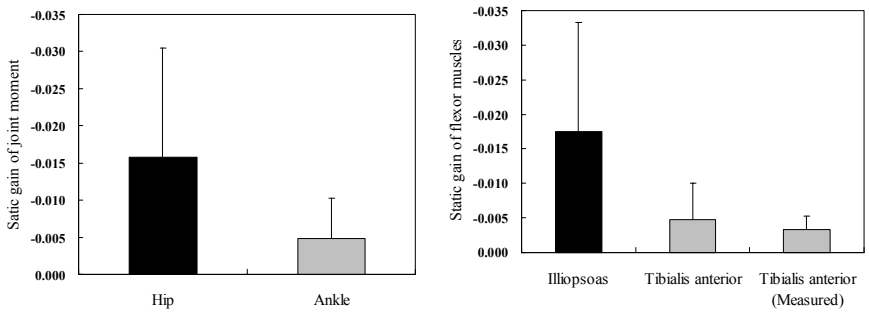
Fig. 3 The data and least squares regression line between activities of flexor muscle and hip angle for subject D. (a) Calculated IP activation, (b) Calculated TA activation, (c) Measured TA EMG response

The results of the linear regression analysis of calculated reflex activity normalized by the mean response during isometric condition for individual subjects are shown in Table 2. At three different hip positions, a significant linear relationship was found between the reflex activity of hip flexor (IP) and hip angle ($P < 0.05$). At the ankle, in four subjects, the reflex response of TA muscle was also significantly affected by hip angle with the largest reflex response in the extended hip position ($P < 0.05$) and in the remaining two subjects (subject E and F) there was no significant linearity between reflex response and hip angle ($P > 0.05$).

Table 2. Results of linear regression analysis between estimated muscle activity and hip angle for individual subjects.

Subject	Tibialis anterior				Illiopsoas			
	B_0	B_1	R^2	*P*-value	B_0	B_1	R^2	*P*-value
A	1.2176	-0.0054	0.8041	<0.05	1.4234	-0.0106	0.8502	<0.05
B	1.1644	-0.0041	0.6411	<0.05	1.1701	-0.0043	0.6082	<0.05
C	1.1347	-0.0034	0.7146	<0.05	1.0381	-0.0010	0.0552	>0.05
D	1.5926	-0.0148	0.8745	<0.05	2.7174	-0.0429	0.9867	<0.05
E	1.0202	-0.0005	0.0194	>0.05	1.7408	-0.0185	0.8302	<0.05
F	1.0178	-0.0004	0.0040	>0.05	2.1071	-0.0277	0.9839	<0.05

The mean static gains of the joint moment and estimated muscle activities elicited by nociceptive stimulation are shown in Fig. 4. The mean static gains of reflex hip and ankle moment are -0.0158, -0.0048, respectively (Fig. 4(a)). The mean static gains of muscle activity which was calculated from measured moment were -0.0175 for IP, –0.0048 for TA (Fig. 4(b)). To validate the activation model, we compared the estimated activation with corresponding EMG response of TA muscle. Note that the EMG responses represent a measured activation of nociceptive flexor reflex for the ankle. Good agreement of static gain was exhibited between the estimated muscle activation and measured EMG data of TA muscle, as shown in Figure 4(b).



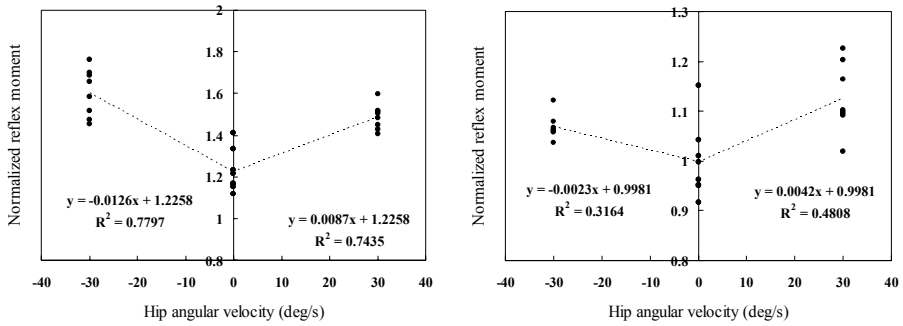
(a) (b)

Fig. 4 The static gains of joint moments and activations of flexor muscles. (a) Static gains of moment response, (b) Static gains of activities of flexor muscles

3.2 Identification of Dynamic Flexion Reflex during Passive Hip Movement

We identified the dynamic property of nociceptive flexor reflex elicited by the foot stimulation during different hip movement. Passive movement during the hip flexion was defined as positive direction and the hip angular velocity was 30deg/s. The flexion reflex response during hip movement was generally larger than the isometric response. The isometric flexor reflex response was compared to the response during hip flexion and extension, with the stimulus applied to the skin of the foot, at the identical hip angle.

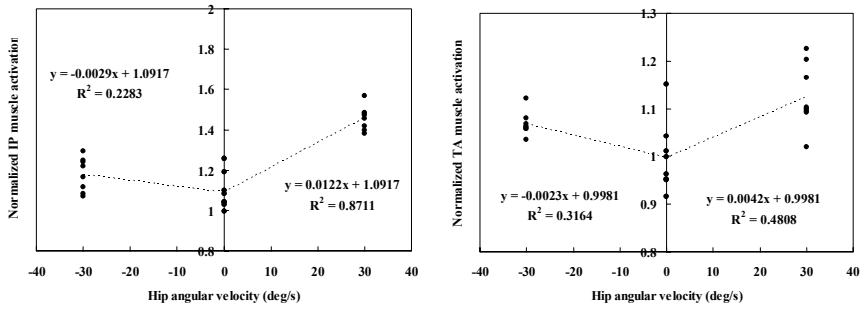
The typical responses of reflex moment for subject C, plotted versus hip angular velocity, are shown in Fig. 5. In subject C, the clear increases in the magnitude of the nociceptive reflex moment were observed with increasing speed of passive hip movement. The reflex moment of hip joint had a stronger correlation during hip flexion (R^2 =0.7435) and hip extension movement (R^2 =0.7797).



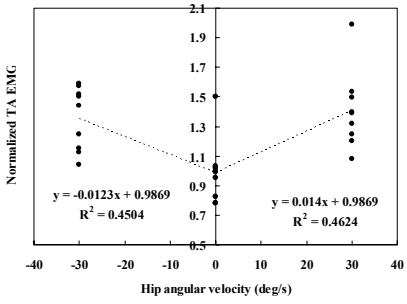
(a) (b)

Fig. 5 The data and least squares regression line between reflex moment and hip angular velocity for subject C. (a) The reflex moment at the hip joint, (b) The reflex moment at the ankle joint

The relationship between the reflex activity of flexor muscles and hip angular velocity were also calculated by using Hill-based muscle model from measured reflex moment. In subject C, the fitted regression lines and scatter diagram of the data points between reflex activity of flexor muscles and hip angular velocity are shown in Fig. 6. The regression lines show that the reflex activities of flexor muscles tended to increase with the hip angular velocity in both directions. By comparing the R^2 values, a strong correlation was found between reflex activation and hip angular velocity during hip flexion movement (R^2 =0.8711 for IP, R^2 =0.4808 for TA). The corresponding fitted line of measured TA EMG during hip movement was consistent with the calculated activation in that it had a tendency to increase at hip movement as shown in Fig. 6(c).



(a) (b)



(c)

Fig. 6 The data and least squares regression line between activities of flexor muscle and hip angular velocity for subject C. (a) Calculated IP activation, (b) Calculated TA activation, (c) Measured TA EMG

The results of the linear regression analysis, shown in Table 3, demonstrated that a significant linear relationship was found between the reflex activity of flexor muscle (IP) and hip angular velocity during both hip flexion and hip extension movement ($P < 0.05$). At the ankle, in three subjects, the calculated reflex response of TA muscle was also significantly affected by hip angular velocity during hip flexion movement ($P < 0.05$) and in the remaining one subject (subject D) there was no significant linearity between reflex response and hip angular velocity ($P > 0.05$).

Table 3. Results of linear regression analysis between estimated muscle activity and hip angular velocity for five subjects.

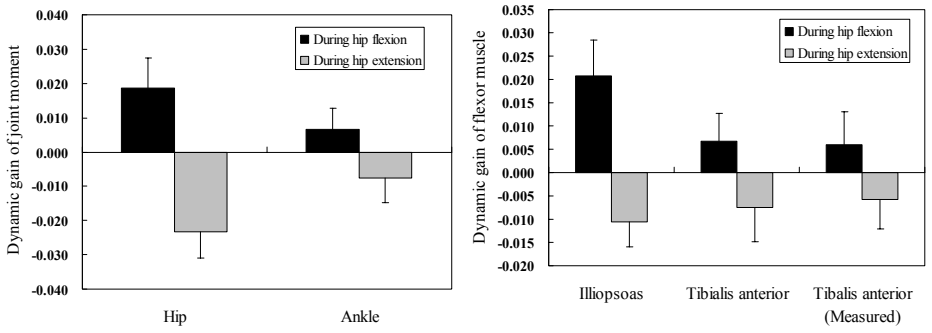
(a) During hip extension

Subject	Tibialis anterior				Illiopsoas			
	B_{0d}	B_2	R^2	*P*-value	B_{0d}	B_2	R^2	*P*-value
B	-	-	-	-	1.2176	-0.0230	0.9222	<0.05
C	0.9981	-0.0023	0.3164	<0.05	1.0917	-0.0029	0.2283	<0.10
D	0.8915	-0.0176	0.4577	<0.05	0.9302	-0.0148	0.4639	<0.05
E	0.9471	-0.0022	0.1293	>0.05	0.9404	-0.0137	0.5831	<0.05
F	1.0868	-0.0078	0.1728	>0.05	0.9598	-0.0111	0.5033	<0.05

(b) During hip flexion

Subject	Tibialis anterior				Illiopsoas			
	B_{0d}	B_2	R^2	*P*-value	B_{0d}	B_2	R^2	*P*-value
B	-	-	-	-	1.2176	0.0388	0.9598	<0.05
C	0.9981	0.0042	0.4808	<0.05	1.0917	0.0122	0.8711	<0.05
D	0.8915	0.0014	0.0070	>0.05	0.9302	0.0172	0.3906	<0.05
E	0.9471	0.0059	0.5997	<0.05	0.9404	0.0232	0.7587	<0.05
F	1.0868	0.0152	0.2606	<0.10	0.9598	0.0302	0.7171	<0.05

The dynamic gains of reflex moments and muscle activities are displayed in Fig. 7. The mean dynamic gains of reflex moment response at the hip and ankle were 0.0186, 0.0067 during hip flexion and -0.0234, -0.0075 during hip extension, respectively (Fig. 7 (a)). The mean dynamic gains of estimated activations in TA and IP muscles were 0.0067, 0.0207 during hip flexion, -0.0075 and -0.0107 during hip extension, respectively (Fig. 7 (b)). As shown in Fig. 7(b), dynamic gains of estimated muscle activation of TA matched well with the measured EMG at both directions, i.e. during flexion and extension of the hip.



(a) (b)

Fig. 7 The dynamic gains of joint moments and activations of flexor muscles. (a) Static gains of moment response, (b) Static gains of activities of flexor muscles.

4. Discussion

4.1 Static Flexion Reflex under Isometric Conditions

One explanation for the larger nociceptive flexor reflex response in an extended hip posture is that the reflex pathways receive convergent inputs from the skin afferents of the foot and the proprioceptive afferents of the hip. The proprioceptive signals from the hip apparently altered the flexor reflex of both the ankle and hip joints. The altered ankle activity suggests a possible neural coupling of the hip flexor group II afferents and the cutaneous afferents from the skin of the foot onto the flexor reflex pathways, since the mechanics of the ankle muscles are isolated from the posture of the hip.

The enhanced ankle activity and TA EMG suggest that the static afferents of the hip flexors provide a general excitatory drive to the flexor reflex pathways. A convergence of muscle group II afferents onto flexor reflex pathways has been established in the cat [13]. This convergence was first demonstrated by Lloyd [14], who showed that activation of group II muscle afferents alone could evoke flexion reflexes. Similarly, convergence of muscle group II afferents onto traditional flexor reflex afferent pathways has been demonstrated in the cat spinal cord [15]. These observations in cats are consistent with the results of the current study, suggesting that group II afferents from the hip flexors may converge onto human spinal cord interneurons incorporated into the flexor reflexes originating from cutaneous afferents of the foot.

Another functional explanation for the effects of hip flexor afferents on flexion reflexes arises from observations of the modulation of locomotion by hip flexor afferents in the cat; in particular, hip flexor afferents play an important role in initiating swing. The potential effects of hip afferents on swing initiation were first reported in chronic spinal cats walking on a treadmill [16]. In this preparation, manual manipulations of the limb initiate swing during an imposed extension of the hip, regardless of the state of the contralateral leg. While flexor muscle afferents of many muscles of the leg play a role in modulating swing[17], the influence of the afferents of the sartorius (a hip flexor/knee flexor) may be particularly potent[18].

4.2 Dynamic Flexion Reflex during Passive Hip Movement

An imposed movement of the hip, in either direction, appeared to provide an excitatory drive to the nociceptive flexor reflex pathways in the current experiments. This excitatory drive might be associated with group Ia afferent feedback, activated by the stretch of the hip muscles during the imposed movement. Unlike the isometric conditions, in which the effects were associated exclusively with stretch of the hip flexors, the modulation of the response due to movement did not appear to depend on the movement direction. In particular, ankle flexors increased their response during both flexion and extension movements. These observations suggest that movement of the hip produces a nonspecific excitation of the flexor reflexes, and possibly a general excitation of all spinal neurons.

The increased flexor reflex response during passive movement may involve reflex feedback from muscle group Ia afferents. An increased response to cutaneous stimuli is produced by imposed movements of the ankle in SCI [19], similar to the effects of hip movements in the current study. Generally, the modulation of the electrocutaneous reflex response during cyclical movements has been associated with the locomotor pattern generator [20] rather than with reflex modulation, implicating a different role for dynamic afferent feedback on electrocutaneous reflexes during movement. Our results suggest that movement itself enhances flexor reflexes, probably through an intraspinal interaction between dynamic muscle spindle afferents (group Ia) and skin afferents.

5. Conclusion

A significant linear relationship was found between reflex activities of flexor muscles and hip conditions (hip angle, angular velocity). The input-output model of nociceptive flexion reflexes can be used to develop the functional electrical stimulation system of the lower limb of paraplegics in order to restore swing motion.

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