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發展協調障礙兒童步行時之肌電訊號分析與類神經網路應用(2/2)

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摘要

在學齡時期有一群兒童外表正常，沒有神經方面疾病、發展遲緩和智能不足，但動作發展上卻有著協調障礙存在，就稱為發展協調障礙。美國精神醫學學會將之定義為「可完成的動作和協調性顯著地遜於同等年齡和智商能力之兒童，以致嚴重地妨礙了理論上同年齡可完成的日常活動的症候群」。在日常生活中的各種活動中，最常使用到的節律性活動之一即為走路，也是需要骨骼肌肉系統與神經系統互相密切配合，才有平穩且協調性的步行動作完成。肌電訊號量測提供步態分析中，肌肉收縮模式的了解。因此，本研究的目的為研究發展協調障礙兒童在跑步機上走路時肌肉收縮的肌電圖訊號分析。共有四十六位兒童參與本實驗，其中包括發展協調障礙兒童二十一位、疑似發展協調障礙兒童十一位、及正常兒童十四位。利用表面電極，測量雙側之臀大肌、股直肌、腿後肌、脛前肌、及腓長肌之肌電訊號，在跑步機上走 13 分鐘，收集每分鐘之前 15 秒資料，分析變異數比例、平均頻率、及中位頻率，作為跑步機走路下肢肌肉收縮的時間空間及頻譜參數。結果顯示發展協調障礙兒童，在跑步機走路時之下肢肌電訊號的中位頻率及平均頻率比正常兒童明顯較低，可能顯示發展協調障礙兒童較易產生肌肉疲乏的現象。同時，作左右兩側肌電訊號對稱性比較時發現，發展協調障礙兒童左右兩側肌電訊號不對稱的情形比正常兒童還要多，顯示發展協調障礙兒童跑步肌走路的對稱性不若正常兒童。本實驗的結果，對於發展協調障礙的診斷與治療上，可提供更進一步的參考資訊。

關鍵詞：發展協調障礙、肌電圖、頻率分析、變異數比例

Abstract

During the early school years, a number of children present with specific coordination problems and display poor perceptual-motor skills. This condition is recognized as developmental coordination disorder (DCD), a deficit in the development of motor skills that is not directly associated with any mental retardation or physical disorder. In order to better understand the neural mechanism of motor control for the children with DCD, it would be valuable to investigate the temporospatial parameters as well as the parameters extracted from frequency analysis for children with DCD during treadmill walking with the electromyography measurement of the muscles in lower extremity. Forty six children, including 14 normal children, 11 children with borderline DCD and 21 children with DCD, were recruited in this study. Ten surface EMG electrodes were used in this study. The medial gastrocnemius, tibialis anterior, rectus femoralis, hamstring and gluteus maximum were measured bilaterally. The data were collected at the first 15 seconds of each minute within thirteen-minute treadmill walking. The variance ratio, mean frequency and median frequency were computed to compare the difference between normal children and the DCD children. The mean and median frequency values of the DCD group were substantially lower than those of normal group. It is implied that the muscles of the DCD children may have the higher risk or higher trend of muscle fatigue during long term activities. Also, the comparison between right and left sides were evaluated for bilateralism of the treadmill walking. DCD children tended to have more muscles with significant differences for the values of variance ratio during the treadmill walking. It is implied that the bilateralism of walking for the DCD group may be not as good as the normal children.

Keywords: Developmental coordination disorder, Electromyography, variance ratio, frequency analysis

Introduction

During the early school years, a number of children present with specific coordination problems and display poor perceptual-motor skills. Such children appear to have no physical disability but takes such as hand-writing, or intercepting moving objects highlight their difficulty. This condition is formally recognized as developmental coordination disorder (DCD) by the American Psychiatric Association (1987). Developmental coordination disorder (DCD) affects approximately 6% of children in Mainstream primary education. It is often associated with educational, social and emotional problems that may continue beyond adolescence. These children are physically awkward or clumsy and slow to learn motor skills but this cannot be explained by intellectual deficits or identifiable physical or neurological disorders. These children are identified after referral for perceptural-motor intervention (Hoare et al., 1991) or by screening of the population of school children using a battery of tests (Mon-Williams et al., 1994). Children who are clumsy or have coordination problems early in life may continue to have motor problems as teenagers and some may have other developmental consequences such as poor academic outcome or low self-esteem (Henderson, et al., 1992).

The act of walking is the fundamental to the performance of human lower extremity. It is also the most frequently used rhythmic exercise in everyday living. Also, human ambulation is one of the basic components of independent functioning that is commonly affected by either disease progress or injury. A mature walking needs intimate cooperation and proper function of nerve along with musculoskeletal system. In general, human gait analysis, either performed on overground or treadmill, is composed of description of movement pattern, mechanics of gait, and gait development from children to aged. In gait analysis, electromyography (EMG) provides researchers a reasonable way of accessing the muscle synergy pattern during locomotion. In order to better understand the muscle contraction of lower extremities and the neural mechanism of motor control for the children with DCD, it would be greatly valuable to investigate the muscle synergy pattern for children with DCD during walking and to compare these findings with normal children's.

EMG can be analyzed quantitatively in the time and frequency domains during human locomotion. The electrical activity of a muscle can be expressed quantitatively

by the root-mean-square or integrated values in the time domain. These values have been suggested to show a linear relationship with isometric force when recorded from muscles with predominantly uniform fiber composition. Also, the linear envelope of EMG in time domain is commonly expressed as the muscular activity during one specific motion. The bilateralism of muscle contraction can be analyzed by the bilateral EMG linear envelope patterns. The frequency analysis is frequently performed to specify the energy pattern of muscle contraction. Both approaches of EMG signal processing at time and frequency domains substantially represent the characteristics of muscle contraction during human walking. Therefore, that the bilateralism of muscle contraction, and the frequency analysis of EMG signal for the children with DCD are significantly different from that of normal children is hypothesized in this study. Therefore, the purposes of this study are (1) to analyze the bilateralism of EMG signal during treadmill walking for the children with DCD (2) to investigate the frequency analysis of EMG pattern for the children with DCD during treadmill walking. The performance of treadmill walking between the normal children and the children with DCD were compared in this study.

Materials and Methods

Theoretical Background

Electromyography (EMG) signals can be analyzed in either the time or frequency domain. In the time domain, the analysis consists of manipulating and measuring one or more characteristics of the signal that may vary with time. One can, for instance, rectify a signal, filter it, calculate its mean value, display the histogram of its amplitude, and so forth. Frequency analysis is less well understood because it requires a lengthy mathematical treatment most easily done by computer. However, it gives exclusive information on a signal. For instance, when the frequency content of a signal is known, it is easy to specify which characteristics an amplifier must have in order to amplify the signal without distortion, or to set the cutoff frequencies of filters to eliminate noise. Also, in many circumstances, frequency spectra are more easily interpreted than the original raw data. Such is the case with the EMG where the random aspect of the signal makes some form of processing necessary, such as rectification and filtering, but not always as meaningful as we would like. Thus the

principal characteristics of EMG analysis are presented in this study. The usefulness in analyzing EMG signals is applied in clinical practice and research. There are two different approaches for the EMG analysis with the DCD children during walking, mainly including the bilateralism of muscle contraction with the EMG analysis in time domain, EMG frequency analysis.

Bilateralism of EMG Analysis

Symmetry plays a key role in simplifying the control of legged robots and in giving them the ability to run and balance. In examining the process of bilateralism of treadmill walking, the variance of ratio (VR) was used in this study. VR is an index of demonstrating the variation of signal in the measuring period. The VR value, ranging from 0 to 1, is an index of similarity of signals. If signals are exactly identical, the VR value is zero. On the contrary, if signals are completely irreverent, the VR value is one. Considering that the habituation is a transition period of motor status, the VR reflects subject's attempt of changing their muscle control to adapt motorized treadmill. The VR is defined as follows.

$$VR = \frac{\sum_{i=1}^{k}\sum_{j=1}^{n}(X_{ij} - \overline{X}_i)^2 /(k(n-1))}{\sum_{i=1}^{k}\sum_{j=1}^{n}(X_{ij} - \overline{X})^2 /(kn-1)}$$

where k is the number of data point, n is the number of average cycle, the X_{ij} is the value of the j th EMG signal at the time point i, $\overline{X}_i$ is the average of the EMG values at the point i averaged j realization of the experiment, and $\overline{X}$ is the grand mean of the averaged EMG signal.

The bilateralism of EMG analysis is conducted by the comparison between the left and right sides of EMG signals.

EMG Frequency Analysis

Frequency spectral analysis involves the breakdown of the continuous EMG signal into a range of different frequency components, the power spectrum is a sort of

histogram showing the amount of power activity at each frequency. During sustained voluntary isometric contraction of the muscle at maximum and different submaximum level, the muscle fatigue causes its power spectra to shift to lower frequencies. This modification is due to an increase of the relative power in the low-frequency range and to a decrease in the high-frequency range (Shi et. al., 1992).

The mean power frequency and median frequency has been accepted as a quantitative index for describing central frequency of spectral distribution. EMG power spectrum was carried out by using a fast Fourier Transform (FFT) algorithm to obtain the power spectral density function. The median frequency was then calculated.

Mean Frequency (f_{mean}):

$$f_{mean} = \frac{\int_0^{\infty} fP(f)df}{\int_0^{\infty} P(f)df}$$

where f is the frequency and $P(f)$ is the power spectrum function.

Median Frequency (f_m):

$$\int_0^{f_m} P(f)df = \frac{1}{2}\int_0^{\infty} P(f)df$$

The mean frequency and median frequency will be evaluated at different phases of treadmill walking for 12 minutes.

Data Collection

Subjects

The subjects of 46 children, with 14 normal children, 11 children with borderline DCD (DCDB) and 21 children with DCD, were recruited in this study. The groups were matched on school, school grade, mean age and non-verbal intelligence. A range of possible clumsy and control subjects were recruited from grade 3 to 4 of one elementary school in Taichung city, approximate 9 to 10 years old. At a first step in selection, the physical education teacher nominates children from grades 3 to 4

whom they judge to perform poorly on common motor tasks. Also, the teachers of school propose the children who may serve as control subjects taking into account the factors of age, sex, grade and academic achievement. The basic data were shown in Table 1.

The Movement Assessment Battery for Children (Movement ABC; Henderson et al., 1992) is often used to identify children whose motor functioning is impaired, such as children with DCD. The battery contains three components: a teacher's checklist, an individually administered standardized test, and a set of guidelines for intervention. The test of the Movement Assessment Battery for Children (Movement ABC) were administered individually to all children. Movement ABC has been to build a useful clinical and educational tool and to incorporate into it some of the newer ideas about how to understand motor difficulties in children. It requires the child to perform a series of motor tasks in a standard way. Basically, Movement ABC consists of three clusters of test, including manual dexterity, ball skill and balance. The test yields various estimates of movement competence. The total score summarizes performance on all eight items and is interpreted in terms of age-related norms. Based on the findings of the test, children with a score below 5 percentiles were be selected to constitute the group with DCD. Any child with neurological or musculoskeletal deficit was excluded in this study.

The children with DCD accepted the intervention of the physical therapy for 12 weeks. An one-hour treatment section, twice a week, were be carried out for each child with DCD. After the completion of treatment of physical therapy, the same experimental procedure of data collection were conducted to investigate the change of EMG pattern during treadmill walking before and after treatment. This would substantially provide the insight of the improvement of the motor control for the children with DCD and better understand the effect of the therapeutic intervention. The group therapy was used to enhance the motor relearning and the social interaction among children. The goal of exercise therapy is to improve the motor coordination for the children with DCD through the game therapy, increase the capability of re-organization during motor activities, and improve the ability of the problem solving and self image.

EMG Measurement

Treadmill walking was performed for thirteen minutes at subjects' most comfortable walking speed. Each subject was allowed to preliminarily walk on treadmill for 30 seconds to be familiar with the use of treadmill. The data were collected at the first 15 seconds of each minute. Therefore, there were 14 sets of EMG data for 13-minute treadmill walking. A written consent form was signed by each participant or his/her parents before any testing starts. After having obtained the subjects' informed consent, the necessary anthropometrical and clinical information were collected. Subject information is necessary to the inertia parameters for the input of modeling. Further, the maximum voluntary contraction for each muscle was collected as the baseline of EMG normalization.

Determination of Gait Cycle

The footswitch was used for the phase determination in gait cycle. A footswitch can measure the temporal events during motion and the foot / floor contact pattern. Hence, the information derived from footswitch can be used for the time reference for gait parameters such as joint kinematics, and the descriptive tool for describing pathologies, such as foot contact patterns, the distribution of forces under the foot, the center of pressure progression. The footswitch was placed on a special location on the plantar aspect of the foot, including the heel, first metatarsal head, fifth metatarsal head and big toe. Thus, the specific phases in gait cycle, initial contact, loading response, mid stance, terminal stance, pre swing, initial swing, mid swing and terminal swing were determined. Each switch is associated with a different voltage and each voltage represents a different displacement on a graph. Any combination of placement gave a different shape of foot plot.

Equipments

The EMG activities of five main muscle groups in the lower extremities were measured bilaterally. The medial gastrocnemius, Tibialis anterior, quadriceps, hamstring and gleutes maximus were recruited in this study (Cram, 1998). The surface electrodes were used as a non-invasive approach of data collection. The

MA300 EMG data collecting system were utilized as AD converter and to control the synchronization between EMG signal and footswitch transfers the digital data onto portable computer. The sampling frequency is 960 Hz.

Data Analysis

Bilateralism

Electromyography (EMG) signals represent the motor unit action potential of the muscle during muscle contraction. The values after signal processing indicate the dynamic muscular activities during walking movement. The original raw EMG signal will be processed to a standard form, linear envelope (LE). With the transformation of raw EMG into the form of LE, the EMG signal can be correlated and compared with other physiological and biomechanical signals. The whole EMG signals processing in this study includes:

1. Filters the raw EMG with a bandpass filter (cuff of frequency 40 Hz-400 Hz) to remove motion artifact and environment noise
2. Full-wave rectification of filtered raw data
3. Render an envelop with an integrator, corresponding to low pass filter with cutting-off frequency 10 Hz, to represent a meaningful profile of muscle activity
4. EMG amplitude normalization by dividing maximum amplitude value of EMG during maximum voluntary isometric contraction

In collecting dynamic EMG, the signal may be contaminated by motion artifact or environment noise that will cause signal distortion. A feasible way to remove those disturbing noise way to purify contaminated raw EMG with a bandpass filter. On the account of linear phase and narrowest transition period, the Hamming window was employed in this study. According to Inman's study (1981), the muscle tension of isometric contraction is closely related to lower frequency component of detected EMG signal after full wave rectification. A gross estimation of muscle effort can be presented in the form of LE. The main decision to be made with the LE is the choice of the low-pass filter. A filter of low cutting-off frequency is sure to get a smoother

LE satisfying smaller variance ratio, however, at the cost of signal distortion. Hence, to get a more faithful representation of EMG data and a better alternative to variance ratio, the favorite cutting-off frequency of integrator is 10 Hz. In addition, the EMG of different trial wase normalized in time-based to 256 points to reduce variation of unequal data segmentation, and the whole movement cycle was expressed in 100%.

Statistical Analysis

For the walking condition on the treadmill, the analysis of variance (ANOVA) with repeated measurement was conducted in this study. The mean power frequency values, median frequency values, the VR values were evaluated individually in this study. To evaluate the bilateralism of muscle performance during treadmill walking, the comparison between the left and right sides was performed. To evaluate the effect of physical therapy intervention, the difference between pre-treatment and post-treatment for the children with DCD were carried out with pair-t test.

Results

Comparison between Normal Children and The children with DCD

The VR values, median frequency and median frequency were compared between these three groups, normal, borderline DCD (DCDB) and DCD groups. There was a significant difference for the VR value of the medial gastrocnemius during stance phase between different groups ($P<0.05$) (Table 2). There was a significant difference for the mean frequencies of the right medial gastrocnemius, right hamstrings and left tibialis anterior during treadmill walking between different groups ($P<0.05$) (Table 3). There was a significant difference for the median frequencies of the right medial gastrocnemius, right hamstrings and left tibialis anterior during treadmill walking between different groups ($P<0.05$) (Table 4). Basically, the findings of the median frequency and mean frequency were quite similar. Also, both the mean and median frequency values of the DCD group were substantially lower than those of normal group. Basically the lower median frequency indicates the phenomenon of muscle fatigue. It is implied that the muscles of the DCD children may have the higher risk or higher trend of muscle fatigue during long term

activities. The percentage of stance phase during treadmill walking was shown in Table 5. There was no significance between different groups. The data for normal children was 62% while the DCD and DCDB groups were 63%.

Bilateralism Analysis

The comparison between right and left sides were evaluated for bilateralism of the treadmill walking. The P values for the five groups (DCD, DCDB, normal, DCDT, DCDBT) were shown in Table 6. Comparing with other groups, DCD group had more muscles with significance (rectus femoralis, tibialis anterior and medial gastrocnemius) for the VR values during the stance phase of the treadmill walking. On the other hand, there was no bilateral significant difference of the VR values of the five muscles for the DCDB and normal groups. It is implied that the bilateralism of walking for the DCD group may be not as good as the normal children. To improve the ability of bilateralism of walking may be a therapeutic goal for the children with DCD so as to enhance their motor performance of lower extremities. Moreover, bilateral comparison of the median frequency and mean frequency was shown in Table 6. It was especially interesting that the tibialis anterior revealed significant difference between left and right sides. It is indicated that tibialis anterior might not play an important role on the control of propulsion during treadmill walking.

Effect of Therapeutic Training

The effect of therapeutic training was evaluated by comparing the difference between pre-treatment and post-treatment. Both groups of DCD and DCDB were performed in this study. The training period was three months. Obviously, there were several significances of the temporo-frequent parameters (VR value, mean frequency and median frequency) for the DCDB group between pre-treatment and post-treatment (Table 7). However, there was no significance of the temporo-frequent parameters for the DCDB group between pre-treatment and post-treatment (Table 8). It was implied that maybe three-month therapeutic training was long enough for the DCDB group but might not be long enough for the DCD group. In the future study, longer therapeutic training would be assessed to determine the optimum period of therapeutic training for the DCD group.

Discussion

A number of terms have been used to identify children with DCD. Children with awkward and clumsy movements, of sufficient severity to interfere with the performance of everyday tasks, are now recognized as representing a distinct and identifiable syndrome (American Psychiatric Association, 1994; Popper & Steingard, 1996; World health organization, 1993). Historically, the children characterized by these motor problems have been identified as having a myriad of disabilities (Polataiko, 1999), such as clumsy child syndrome (Gubbay, 1975), developmental dyspraxia (Ayres, 1972; Denckla, 1984), sensory integrative dysfunction (Polatajko et al., 1991), mild motor delay (Henderson, 1994), physically awkward, poorly coordinated (Cratty, 1994), perceptuo-motor dysfunction, and motor delay (Henderson, 1994), and developmental coordination disorder (DCD) (American Psychiatric Association, 1994). Henderson (1993), an active researcher in this field, chose to adopt the definition provided by the American Psychiatric Association in the Diagnostic and Statistical Manual of Mental Disorders (1994). The condition is there labeled Development Coordination Disorder and described as a marked impairment in the development of motor coordination that is not explicable by mental retardation and that is not due to a known physical disorder. The London Consensus Statement (Polatajkoooo et al., 1995) recommended the consistent use of the term DCD (developmental coordination disorder) and therefore this term has been widely used now to refer this disorder of motor-based performance.

Approximately 6% of children in mainstream primary schools demonstrate motor competence below normal range, although they appear both physically and intellectually normal (Sovik et al., 1986; Maland, 1992; Sigmundsson et al., 1997; Peters et al., 1999). The general ranges reported are from 5% to 10% in other literatures (Brenner et al., 1967; Gubbay, 1975; Henderson et al., 1982; APA, 1994; Mon-Williams et al., 1999).

The most commonly noted feature of the DCD population is its heterogeneity (Hulme et al., 1986; Polatajko, 1999; Wright et al., 1996). Indeed, it has been said that there is no typical clumsy child (Gorden et al., 1980). DCD is associated with many concomitant problems (Henderson et al., 1982) including learning disabilities

(Lazarus, 1990) and attention deficit disorders (Gillberg, 1998; Landgren, et al., 1998). There are however, many inconsistencies in the description of DCD in the literature and it is not known whether these inconsistencies are due to sample variation or the existence of discrete subtype (Barnett et al., 1998; Polatajko et al., 1995; Rourke, 1985).

Planning and execution of action in children with and without developmental coordination disorder were studied by Smyth et. al. (1997). Ninety-five children from six English primary schools were identified on the basis of the Movement Assessment Battery for Children (Movement ABC) as having developmental coordination disorder (DCD) and, together with age- and ability-matched controls, were given three tasks that involved proprioception in the control and discrimination of limb position, and two tasks that involved planning for end state comfort after a bar was grasped and turned. The children in the DCD group performed less well on the majority of the proprioceptive tasks, but did not differ from controls in planning of grip selection. There was an improvement in grip planning with age. The results are contrasted with research indicating that people with autism do have a difficulty with planning grip selection.

Developmental coordination disorder (DCD) occurs in a small but significant proportion of children who present with impaired body-eye coordination and show poor acquisition of motor skills. Mon-Williams et. al. (1999) investigated the visual-proprioceptive mapping ability of children with DCD from a small selected group, with particular reference to the use of vision in matching tasks. The children with DCD in this study were significantly poorer than control children on all matching tasks. They seemed to have particular difficulty in cross-modal judgements that required the use of visual information to guide proprioceptive judgements of limb position. A distinction is drawn between tasks that can be achieved purely through sensory matching and those that require body-centred spatial judgements, suggesting that it is the latter that posits a particular difficulty for children with DCD.

Developmental coordination disorder (DCD) affects 6% of children in mainstream primary education (Peters et al., 1999). Concerned for children who find it difficult to acquire the movement skills required of them in everyday life has increased dramatically. It is often associated with education, social and emotional problems that may continue beyond adolescence. However, in the past, such children

received little help from either the medical or educational profession, unless their motor problems were perceived as being causally related to other problems. Clinical evaluation is hampered by the lack of use of standardized tools, variable research experience amongst therapy clinicians, and a dearth of peer reviewed journal in which to publish clinical findings.

Locomotion is the process by which the people move itself from one geographic position to another. Human walking is a progress of locomotion in which the erect, moving body is supported by first one leg and then the other. Locomotion includes starting, stopping, changes in speed, alterations in direction, and modification for changes in slope (Rose et al, 1994). As the moving body passes over the supporting leg, the other leg swings forward in preparation for its next support phase. These events, however, are transitory activities that are superimposed on a basic pattern. In walking and running, this pattern can be defined as rhythmic displacement of body parts that maintains the people in constant forward progression. If walking is a learned activity, it is not surprising that people displays certain personal peculiarities superimposed on the basic pattern of bipedal locomotion. Walking is such a fundamental and essential work in the activity of daily living. Based on the literature review, there are lots of studies regarding the motor planning, proprioception and perception for the children with DCD. However, there are quite few researches regarding the investigation of muscle performance pattern through the analysis of EMG signal during ambulation for the children with DCD. Therefore, in order to better understand the muscular performance of the walking for the children with DCD, this study focused on two aspects for the children with DCD during walking (1) EMG analysis in time domain – the analysis of bilateralism (2) EMG analysis in frequency domain. The central nervous system should have the capability to transform a kinematic plan into the appropriate activation patterns. Representation of this transformation, aside from adding to the fundamental understanding of locomotor control, also has implications for practical realizations of artificial control systems for use in physical medicine and rehabilitation. Moreover, for therapists to develop effective treatment strategies for the DCD children, it is important that they understand the nature of the motor coordination problems in children with DCD. With this study, the muscle activation pattern in gait revealed quantitatively and compared with the normal children. The findings would be beneficial to better understand the

etiology of DCD and helpful to the clinical intervention for the children with DCD.

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Table 1: Basic data of the children subjects (M: male; F: female)

	DCD	DCDB	Normal
Average Age	9.5	9.5	9.4
Gender	M10 F11	M5 F6	M7 F7
Body Weight	32.5 kg (21-53)	36.5 kg (range, 24-61)	31.1 kg (range, 25-39)
Body Height	134.8 cm (range, 120-156)	137.5 cm (range, 125-149)	136.1 cm (range, 128-142)
Movement ABC Score	17.8	12.1	6.5

Table 2: The VR values for the normal, DCD, DCDB groups (GM: gluteus maximus; RF: rectus femoralis; HS: hamstrings, TA: tabialis anerior; MG: medial gastrocnemius)

VR			Normal		DCDB		DCD	
Muscle	Side	Phase	Mean	SD	Mean	SD	Mean	SD
GM	Left	Stan	0.40	0.12	0.43	0.17	0.43	0.24
		Swin	0.67	0.13	0.65	0.17	0.69	0.17
	Right	Stan	0.35	0.10	0.44	0.23	0.36	0.21
		Swin	0.63	0.12	0.67	0.16	0.66	0.18
RF	Left	Stan	0.67	0.20	0.76	0.09	0.69	0.20
		Swin	0.72	0.14	0.81	0.13	0.75	0.18
	Right	Stan	0.64	0.16	0.72	0.16	0.62	0.21
		Swin	0.73	0.09	0.81	0.10	0.74	0.12
HS	Left	Stan	0.56	0.12	0.67	0.14	0.59	0.18
		Swin	0.92	0.12	0.94	0.11	0.91	0.11
	Right	Stan	0.60	0.14	0.68	0.12	0.57	0.17
		Swin	0.90	0.12	0.94	0.08	0.88	0.14
TA	Left	Stan	0.78	0.11	0.82	0.11	0.77	0.16
		Swin	0.55	0.14	0.60	0.17	0.51	0.16
	Right	Stan	0.75	0.08	0.77	0.16	0.67	0.14
		Swin	0.93	0.08	0.99	0.08	0.94	0.10
MG	Left	Stan*	0.68	0.11	0.72	0.09	0.59	0.16
		Swin	0.83	0.14	0.88	0.10	0.81	0.19
	Right	Stan	0.71	0.11	0.70	0.09	0.65	0.10
		Swin	0.80	0.08	0.90	0.09	0.80	0.17

*: significant difference between different groups ($P<0.05$)

Table 3: The mean frequencies (Hz) for the normal, DCD, DCDB groups (GM: gluteus maximus; RF: rectus femoralis; HS: hamstrings, TA: tabialis anerior; MG: medial gastrocnemius)

meanF		Normal		DCDB		DCD	
Muscle	Side	Mean	SD	Mean	SD	Mean	SD
GM	Left	188.09	17.07	171.89	27.08	174.42	24.76
	Right*	186.82	13.43	176.93	26.29	166.36	25.66
RF	Left	185.06	15.96	176.18	20.91	169.71	26.06
	Right	188.49	13.57	181.72	22.37	173.78	25.15
HS	Left	174.76	28.75	167.09	13.96	160.84	19.81
	Right*	178.35	11.49	177.11	15.76	166.92	15.32
TA	Left*	129.72	8.97	123.48	9.26	117.50	8.36
	Right	157.20	12.12	167.41	24.11	156.48	15.80
MG	Left	163.54	11.11	156.72	14.35	156.06	13.93
	Right	164.26	12.10	160.28	10.96	157.85	11.25

*: significant difference between different groups ($P<0.05$)

Table 4: The median frequencies (Hz) for the normal, DCD, DCDB groups (GM: gluteus maximus; RF: rectus femoralis; HS: hamstrings, TA: tabialis anerior; MG: medial gastrocnemius)

medianF		DCDN(14)		DCDB(11)		DCD(21)	
Muscle	Side	Mean	SD	Mean	SD	Mean	SD
GM	Left	155.33	25.40	129.29	42.50	133.84	37.41
	Right*	151.79	21.05	138.31	43.86	123.02	33.98
RF	Left	149.38	27.24	133.06	34.96	126.14	38.73
	Right	155.32	21.89	143.33	35.08	131.59	39.09
HS	Left	142.50	42.65	128.37	18.58	117.52	28.11
	Right*	145.39	15.72	140.14	23.44	125.99	20.67
TA	Left*	94.73	8.88	85.78	9.42	82.27	7.44
	Right	122.57	18.11	135.02	32.60	119.94	23.85
MG	Left	132.94	19.58	124.49	22.09	124.44	19.08
	Right	134.73	19.46	129.19	16.15	126.60	16.91

*: significant difference between different groups ($P<0.05$)

Table 5: The percentage of stance phase in gait cycle for three groups

Normal		DCDB		DCD	
Mean	SD	Mean	SD	Mean	SD
0.62	0.03	0.63	0.03	0.63	0.03

Table 6: the p values for the comparison between left and right sides (DCDT: post-treatment of the DCD group; DCDBT: post-treament of DCDB group)

VR - stance phase					
p value	GM	RF	HS	TA	MG
DCD	0.279	0.025	0.474	0.022	0.028
DCDB	0.831	0.251	0.709	0.33	0.361
DCDN	0.455	0.589	0.436	0.37	0.1
DCDT	0.1	0.142	0.072	0.009	0.626
DCDBT	0.033	0.591	0.007	0.72	0.587
VR - swing phase					
p value	GM	RF	HS	TA	MG
DCD	0.531	0.605	0.332	0	0.731
DCDB	0.448	0.894	0.966	0	0.49
DCDN	0.102	0.896	0.583	0	0.4
DCDT	0.002	0.526	0.889	0	0.348
DCDBT	0.002	0.428	0.451	0	0.99
Mean Frequency					
p value	GM	RF	HS	TA	MG
DCD	0.101	0.573	0.252	0	0.496
DCDB	0.263	0.497	0.013	0	0.227
DCDN	0.377	0.549	0.661	0	0.81
DCDT	0.792	0.974	0.005	0	0.616
DCDBT	0.377	0.245	0.001	0.004	0.011
Median Frequency					
p value	GM	RF	HS	TA	MG
DCD	0.174	0.628	0.265	0	0.514
DCDB	0.232	0.445	0.07	0.001	0.264
DCDN	0.203	0.538	0.806	0	0.677
DCDT	0.942	0.804	0.003	0	0.564
DCDBT	0.319	0.351	0	0.006	0.011

Table 7: The p values for the comparison between pre-treatment and post-treatment for the DCDB group (GM: gluteus maximus; RF: rectus femoralis; HS: hamstrings, TA: tabialis anerior; MG: medial gastrocnemius; L: left side; R: right side)

DCDB - DCDBT	VR – stance phase	VR – swing phase	Mean frequency	Median Frequency
GM – L	0.000	0.01	0.026	0.027
GM – R	0.001	0.374	0.067	0.145
RF – L	0.171	0.022	0.566	0.54
RF – R	0.192	0.157	0.483	0.695
HS – L	0.188	0.276	0.006	0.006
HS – R	0.246	0.038	0.138	0.157
TA – L	0.111	0.662	0.254	0.189
TA – R	0.714	0.716	0.884	0.914
MG – L	0.703	0.000	0.365	0.086
MG - R	0.062	0.002	0.308	0.824

Table 8: The p values for the comparison between pre-treatment and post-treatment for the DCD group (GM: gluteus maximus; RF: rectus femoralis; HS: hamstrings, TA: tabialis anerior; MG: medial gastrocnemius; L: left side; R: right side)

DCD - DCDT	VR – stance phase	VR – swing phase	Mean frequency	Median Frequency
GM – L	0.119	0.092	0.651	0.864
GM – R	0.001	0.224	0.751	0.588
RF – L	0.487	0.808	0.957	0.809
RF – R	0.413	0.979	0.946	0.999
HS – L	0.069	0.566	0.002	0.002
HS – R	0.361	0.943	0.325	0.459
TA – L	0.696	0.922	0.657	0.989
TA – R	0.336	0.127	0.42	0.31
MG – L	0.052	0.283	0.593	0.882
MG - R	0.254	0.601	0.427	0.999

Self-Evaluation

The current working items to be finished in this study were listed as follows:

1. To develop an EMG analytic model of the lower extremity for the children with DCD
2. To investigate the bilateralism of EMG signal for the children with DCD during treadmill walking.
3. To compute the frequency analysis of EMG signal for the children with DCD.
4. To compare the difference of EMG pattern and features extraction between the normal children and the children with DCD
5. To compare the difference of EMG pattern and features extraction before and after therapeutic intervention for the DCD children.
6. To find the significant biomechanical factors and parameters to represent the motor performance for the children with DCD.

A computer software for the evaluation of the children with DCD was developed in this study. The strategy for measuring EMG patterns in lower extremity during walking was established. Feature extraction regarding the EMG analysis both in time and frequency domains was also investigated. A study of this nature regarding the walking of the children with DCD would provide valuable information both to the biomechanical engineer and clinician for the improvement of the basic knowledge. Methods similar to those described in this study can be used in the evaluation for the children with other motor disturbance and thereby provide an objective rationale and analytic application. Further, contributions to the literature on biomechanics of walking pattern will ultimately help improve the motor performance of activities of daily living and reduce the risk of falling or sports injury.

The findings of this study may aid the examiner in exploring a more knowledgeable approach in evaluation, leading to an accurate diagnosis and appropriate treatment for the children with DCD. The information of possible factors leading to the coordination disorder was analyzed for the improvement of coordination. The findings of the comparison before and after therapeutic

intervention would provide as the guideline for the program of therapeutic exercise in physical therapy. The finding of this project would outline new information concerning the etiology of the DCD, and finally, to utilize this information in producing a scientific rationale for new type of rehabilitative treatment for the children with DCD.