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FEATURE SELECTION OF ELECTROMYOGRAPHY SIGNALS FOR AUTISM SPECTRUM DISORDER CHILDREN DURING GAIT USING MANN-WHITNEY TEST

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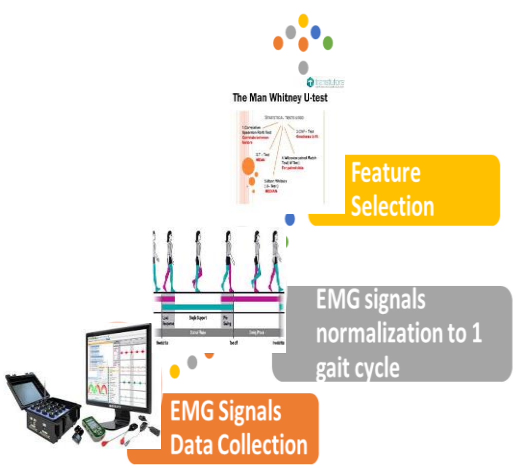
Graphical abstract



Abstract

Autism Spectrum Disorder is a lifelong neurodevelopmental impairment that affects brain growth and individual functional capabilities that associates with unusual movement and gait disturbance. The aim of this study is to investigate the significant features of EMG signals for lower limbs and arms muscle between Autism Spectrum Disorder (ASD) and Typical Development (TD) Children during walking. In this study, 30 ASD and 30 Typical Development (TD) children aged between 6 to 13 years old were asked to walk on the walkway naturally. The Electromyography (EMG) signals of Biceps Femoris (BF), Rectus Femoris (RF), Tibialis Anterior (TA), Gastrocnemius (GAS), Biceps Brachii (BB) and Tricep Brachii (TB) muscles of the ASD and TD children were recorded by using surface EMG sensors. The BF muscle is located at the posterior compartment of the thigh whereas the RF muscle located in the anterior compartment of the thigh. On the other hand, the TA muscle originates within the anterior compartment of the leg, and Gas muscle originates at the posterior compartment of the calf. Meanwhile, the BB muscle is in the front of the upper arm between shoulder and elbow, and TB muscle is a large muscle on the back of the upper arm limb. The data consists of 42 features from 7 walking phases of 6 muscles during one gait cycle were obtained from the data collection. Firstly, the data will be normalized to one gait cycle to standardize the length of EMG signals used for all subjects. Then, the feature selection method using Mann-Whitney Test is applied to find the significant features to differentiate between ASD and TD children from the EMG signals. Out of 42 features, 5 were found to be the most significant features of EMG signals between ASD and TD children, there are TA muscle at 30% of gait cycle, Gas muscle at 50% and 60% of gait cycle, and BB muscle at 10% and 80% of gait cycle with significant values of 0.017, 0.049, 0.034, 0.021 and 0.003, respectively. These findings are useful to both clinicians and parents as the lower limbs and arm muscles can be valuable therapeutic parameter for ASD children's rehabilitation plan. The findings of this research also suggest that the significant difference of EMG signals obtained can be a parameter to differentiate between ASD and TD children.

Keywords: Electromyography (EMG), Autism Spectrum Disorder (ASD), gait

Abstrak

Gangguan Spektrum Autisme (ASD) adalah kerosakan perkembangan neuro sepanjang hayat yang menjejaskan pertumbuhan otak dan keupayaan fungsi individu yang berkait dengan pergerakan luar biasa dan gangguan gaya berjalan. Tujuan kajian ini dijalankan adalah untuk menyiasat ciri-ciri penting dalam isyarat *Electromyography* (EMG) bagi otot anggota bawah badan dan juga otot lengan diantara kanak-kanak ASD dan TD semasa berjalan. Dalam kajian ini, seramai 30 orang kanak-kanak ASD dan 30 orang kanak-kanak TD yang berumur antara 6 hingga 13 tahun diminta untuk berjalan atas *walkway* secara semulajadi. Isyarat EMG bagi otot *Biceps Femoris* (BF), *Rectus Femoris* (RF), *Tibialis Anterior* (TA), *Gastrocnemius*

(GAS), *Biceps Brachii* (BB) dan *Tricep Brachii* (TB) pada kanak-kanak ASD dan TD telah direkodkan menggunakan sensor EMG jenis permukaan. Otot BF terletak pada bahagian belakang paha manakala otot RF terletak pada bahagian depan paha. Sebaliknya, otot TA berada di bahagian hadapan kaki dan otot GAS berada di bahagian belakang betis. Manakala, otot BB berada di bahagian depan lengan atas di antara bahu dan siku, dan otot TB ialah otot yang besar terletak pada bahagian belakang lengan atas. Terdapat 42 data terdiri daripada 7 fasa berjalan dan 6 otot dalam satu kitaran berjalan telah diperolehi daripada pengumpulan data. Pertama, data akan dinormalisasikan kepada satu kitaran berjalan untuk menyeragamkan panjang isyarat EMG yang digunakan untuk semua subjek. Kemudian, kaedah pemilihan menggunakan ujian *Mann-Whitney* telah diaplikasikan untuk mencari ciri isyarat EMG yang penting bagi membezakan antara kanak-kanak ASD dan TD. Daripada 42 data tersebut, 5 data merupakan ciri paling penting bagi isyarat EMG antara kanak-kanak ASD dan TD, iaitu otot TA pada 30% kitaran berjalan, otot Gas pada 50% dan 60% kitaran berjalan, dan otot BB pada 10% dan 80% kitaran berjalan dengan nilai masing-masing 0.017, 0.049, 0.034, 0.021 dan 0.003. Dapatan ini sangat berguna kepada doktor dan ibu bapa kerana otot anggota bawah dan otot lengan boleh menjadi parameter terapeutik yang berharga kepada rancangan pemulihan kanak-kanak ASD. Dapatan kajian ini juga mencadangkan bahawa perbezaan isyarat EMG yang jelas di antara kanak-kanak ASD dan TD yang diperolehi ini boleh menjadi parameter untuk membezakan antara kanak-kanak ASD dan TD.

Kata kunci: Electromyography (EMG), Gangguan Spektrum Autisme (ASD), gaya berjalan

1.0 INTRODUCTION

Autism Spectrum Disorder (ASD) is a complex neurodevelopment disorder characterized by social impairments, communication difficulties as well as restricted, repetitive and stereotyped patterns of behavior [1]. The impairment in ASD children is often developed from the early childhood, continues into adulthood. The sign of ASD begins as early as 6 months old manifested by difficulties in oral motor coordinator and muscle tone [1]. During the second half of the first year, the ASD children continue to demonstrate difficulties in sensorimotor and diminishing oral motor control. Beyond their one-year-old of age, the children with ASD usually meet the diagnostic criteria for autism through Autism Diagnostic Tools such as Modified Checklist for Autism in Toddlers (M-CHAT). The ASD children can be diagnosed through behavioral development observations including social abnormalities. Each of the behaviors associated with ASD children may range from mild to severe. These behaviors are common among those on the spectrum, but some of the behaviors may change according to the spectrum [2].

Moreover, ASD is also defined as having nerve problems on gross motor behaviors including motor coordination, gait, postural stability, arm movement and muscle tone. Numerous studies have been conducted on gait disturbance in ASD children. Provost *et al*. (2007) in their study claimed that ASD children have motor delay in their gross motor skills or fine motor skills [3]. Generally, ASD children suffer an unusual gait, whereby their gait is subtle, clumsy and wide-based [4]. While, Nobile *et al*. (2011) had revealed that the body posture of individual with ASD seems odd and unnatural, appearing floppy and rigid. They also experience difficulty in maintaining a straight line that may be caused by the abnormalities in trunk posture [5]. Some findings showed the ASD children had suffered an irregular locomotion difficulty when changing from one floor surface to another. This is manifested by high variables in oscillations of the head, shoulders and trunk [6].

The human body engages with body muscles including lower limb muscles and arm muscles. Activities of the lower limb muscles are salient in daily human movements such as walking, sitting and standing. On the other hand, muscular system of the legs and feet is for propelling, supporting and balancing the human body. The whole body is involved in locomotion, but the hip and leg muscles are the main actuators when walking [7]. Arm swing is a natural motion when humans are walking and running. During walking, the arm movement may influence the stride characteristics and activation patterns of the lower limb muscle [8]. A normal arm swing involved in human walking should shorten the contraction of the arm's muscles [9]. According to Meyns *et al*. (2013), there are two purposes of arm swing. The first is to optimise stability and the second is to minimise energy consumption during gait [10]. The arm swing also greatly affects the gait pattern depending on the speed of the human while walking and the pattern of the arm swing [11].

Electromyography is an experimental technique concerned with the development, recording and analysis of myoelectric signals. In the present day, EMG signals is well establish application in enormous area of rehabilitation and human movement detection. To the best of the authors' knowledge, most of the previous researchers using EMG on ASD children to investigate the emotional behavior, grasping action and facial expression [12]. Also, there are widely available clinical reports that mentioned that EMG signals is the best technique used to identify appropriate rehabilitation and therapy plan [13-15]. In addition, motor impairment in ASD constitutes a core characteristic which distinct for diagnosis autism symptom [16-17]. Ilias *et al*. (2016) had classify the ASD and TD children based on the gait parameters of temporal spatial, kinetic and kinematic by using Neural Network (NN) and Support Vector Machine (SVM) [18]. Their finding showed that the fusion of temporal spatial and kinematic for NN classifier and the fusion of temporal spatial, kinetic and kinematic for SVM classifier capable to discriminate between ASD and TD children with accuracy of 95% and 95.8%, respectively. Therefore, motor function in ASD children can be one of the discriminating features to differentiate the individual with autism from TD children [5, 17, 19]. Consequently, this study will use surface EMG, as it is a modern electronic device with new technique in signals processing and easy to conduct during experiment without hurting the subjects. The EMG signals of lower limbs and arms muscle of ASD and TD children will be acquired and analyzed to find the significant features of ASD children that differ from TD children during walking.

2.0 METHODOLOGY

The experimental workflow of the proposed system is illustrated in Figure 1. It consists of three stages which include EMG data acquisition, pre-processing and feature selection statistical analysis.

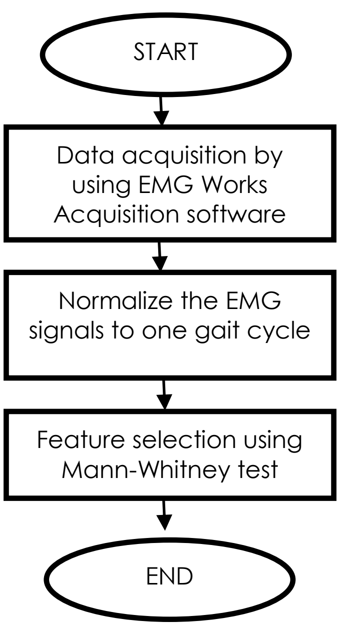
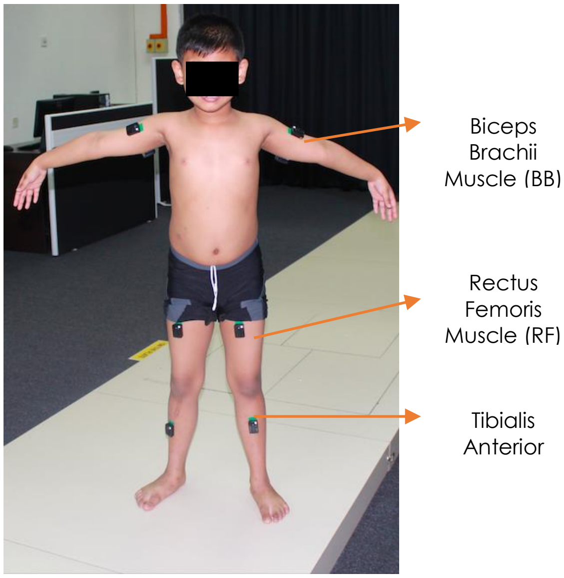


Figure 1 Overview of the proposed system

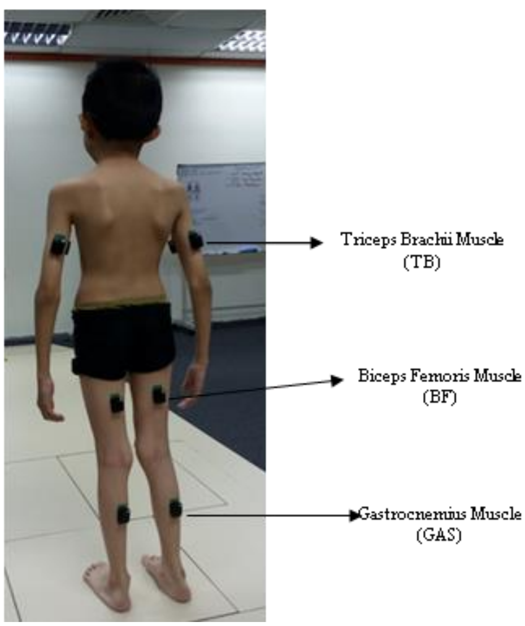
A group of 60 children consisting of 30 ASD and 30 TD children, with age ranging between 6 to 13 years old have participated in this study. The approval of the local ethics committee was obtained from the Research Ethics Committee of the Universiti Teknologi MARA (UiTM) Shah Alam, Malaysia on 29 May 2015. The ASD subjects are from National Autism Society of Malaysia (NASOM) centre in Klang, Selangor, and through personal approach by the main author via social media network. On the other hand, the TD children were recruited from the local community neighborhood near UiTM Shah Alam. Both groups of participants must be able to walk independently without any lower extremity injuries or musculoskeletal disorders. Both group of participants must also be capable to follow verbal instruction given by the researcher. For the ASD children, they must be accompanied by parents or guardians during the experimental process. The parent or guardian were explained about the procedures for conducting the experiments and all the subjects' guardians need to complete the informed consent form before participating in this study.

Before the experiment, all the subjects were required to wear special clothing that was provided in the laboratory for data capturing. The purpose of changing the cloth is to ease the process of sensor placement. General measurements such as body mass and height were recorded. Four simple steps were adopted during placing the EMG sensors to the skin in order to optimize the signal detection [20]. Firstly, the subjects were advised to remove all jewelries or other metal objects that are attached on the body as these may interfere with the experiment procedure. The second step is by cleaning the subject's skin and drying it before EMG sensors are attached. An alcohol wipe was applied on the subject's skin to remove dead skin cells which may produce high impedance, and to clean the skin from sweat and dirt [21]. Afterwards, the Delsys adhesive tape was used to attach the sEMG sensor on the subject's skin. Lastly, the Delsys surface EMG sensor was attached to the subject's skin. Lastly, the Delsys surface EMG sensor was attached to the subject's skin according to the SENIAM guidelines [22]. According to SENIAM guideline, the surface EMG sensors must be placed parallel to the muscle fibers of each tested muscle. There are 12 EMG sensors have been placed on the subject's skin to capture EMG signals from the muscles of BF, RF, TA, GAS, BB and TB as shown in Figure 2 (a) and (b).

In this study, the recording of EMG signals is performed by using EMG Works Acquisition software. This software is designed for attaining simultaneous data recording and real time monitoring of EMG. The desired sample rate used for this recording purpose is 2000Hz. During data collection, a video camera was placed to record the walking trials from the frontal view for reference purpose. The EMG Works Acquisition software and the video camera will work simultaneously for the purpose of EMG signals recording of lower limbs and arms muscle activity throughout the data collection.



(a) Anterior



(b) Posterior

Figure 2 Sensors placement

Subsequently, the EMG signals data for each muscle were normalized to one gait cycle to obtain the standardize EMG signals. This is due to the varieties of walking speed and different step length between subjects. One complete gait cycle is determined by the initial contact of the left foot until the terminal swing of the same foot. According to Romkes *et al*. (2015), there is no significant difference between left and right leg in gait parameters during normal walking process [23]. Therefore, in this study only left limbs of muscles are tested. With normalization, the foot contact event corresponded to 0% and the foot-off event corresponded to 100% of the stance phase. The normalization of gait data was computed in Microsoft Excel.

The next process was the selection of the most significant gait features between ASD and TD children by employing the statistical analysis methods. Generally, it was conducted in 2 steps. Firstly, the normality test was employed for all muscles to check the distribution of EMG signals for both groups. The normality of all normalized data was verified by using Shapiro-Wilks test as the number of subjects were small. The results from Shapiro-Wilks test obtained reveal that the EMG signals data of BF, RF, TA, GAS, BB and TB muscles have the significant value less than 0.05 ($p<0.05$), thus the distribution of the EMG signals were not normally distributed or called non-parametric. In general, Shapiro-Wilks test is more accurate and is a great test as it has revealed whether the scores are normally distributed or not [24]. From the normality test results, the EMG signals distribution was not normally distributed or called non-parametric, thus the Mann-Whitney test was implemented. The Mann-Whitney test with 95% confidence interval was performed to examine the significant difference of EMG signals distribution from BF, RF, TA, GAS, BB and TB muscles that possibly distinguish both ASD and TD children. All statistical computations were performed by using the IBM SPSS Statistics. Whereas, the significant difference of the height and weight between 2 samples was check by using independent sample T-test. In this study, seven phases of gait patterns were considered for analysis of the tested muscles, which are loading response (LR), mid-stance (MST), terminal stance (TST), pre-swing (PSW), initial swing (ISW), mid-swing (MSW), and terminal swing (TSW). The gait phases employed is shown in Table 1 below.

Table 1 Gait Phase in one Gait Cycle

Gait cycle	LR	MST	TST	PSW	ISW	MSW	TSW
Gait phases	0%-10%	10%-30%	30%-50%	50%-60%	60%-70%	70%-90%	90%-100%

3.0 RESULTS AND DISCUSSION

The demographic data for both groups of participants of ASD and TD children were presented in Table 2. The age range between ASD and TD children was comparable with mean age is 8.10 and 9.40, respectively. The standard deviation of age for TD and ASD children are 2.76 and 2.20 respectively. TD children has greater mean of height and weight compared to ASD children which the differences are 4 cm and 2.5kg respectively. The range of height for TD children is varies from 95 cm to 159.5 cm (SD 18.07) compared to ASD children which is range between 95cm to 149.7cm with SD of 13.26. However, the variation of weight for ASD and TD children are almost similar with the standard deviation of 11.14 and 11.60 respectively. Nonetheless, the findings from the T-test showed that there are no significant differences in height and weight (p-value more than 0.05) for ASD and TD children, which are 0.33 and 0.39, respectively, showed that the tested parameter of lower limbs and arms muscle in this study was comparable. An enormous number of the ASD participants are boys. There are 36 boys and 24 girls are participated. Boys are almost five times more common suffered with autism than girls [25]. Thus, the diagnosis of ASD for boys is easier than girls.

Table 2 Demographic Data of ASD and TD Children

Variable		ASD	TD
Age	Mean	8.10	9.40
(years)	SD	2.20	2.67
Height	Mean	124.5	128.5
(cm)	SD	13.26	18.07
Weight	Mean	27.5	30.0
(kg)	SD	11.14	11.60

In this work, the mean amplitude of EMG signals of the tested muscles of ASD and TD children were presented (Figure 3 – Figure 8). Figure 3 below shows the mean amplitude of EMG signals of BF muscle for ASD and TD children in one gait cycle.

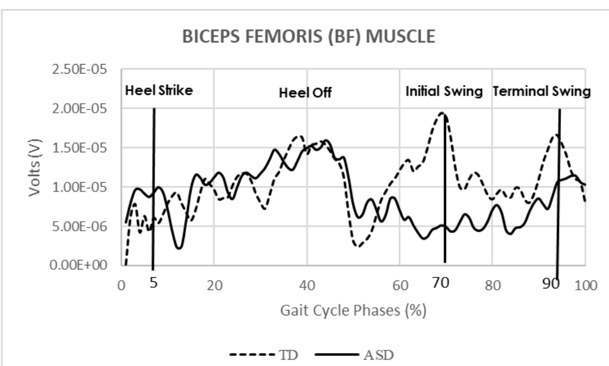


Figure 3 Mean Amplitude of EMG Signals for BF Muscle for One Gait Cycle

In the phase of loading response, it was observed that there is disparity pattern of mean amplitude of EMG signals between ASD and TD children. It was increased for ASD children, showed that the muscle of BF was extended. Whereas, for TD children, the mean amplitude of EMG signals of BF muscle during loading response was decreased, shows that the muscle of BF was in the flexed condition. Meanwhile, at 40% of gait cycle, the mean amplitude of EMG signals was increased for ASD and TD children, showed that the BF muscle was in the extended condition. However, throughout 70% of gait cycle, it can be seen that the BF muscles for TD children were in the extended condition but BF muscles of ASD children are flexed as mean amplitude of EMG signals was decreased. Nonetheless, at 90% of the gait cycle, the BF muscle of ASD and TD children was extended before it was flexed upon approaching 100% of the gait cycle.

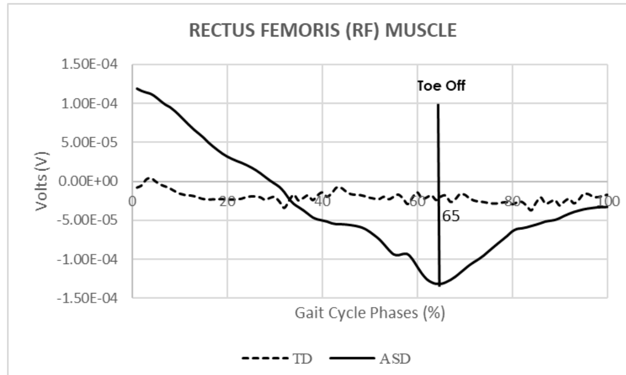


Figure 4 Mean Amplitude of EMG Signals for RF Muscle for One Gait Cycle

Figure 4 shows the mean amplitude of EMG signals for RF muscle in one gait cycle. From the figure, it has been observed that the mean amplitude of EMG signals of RF muscle of ASD children was gradually decreased starting from loading response phase until initial swing phase, means that the RF muscle was in flexed condition for all this phases while for TD children the amplitude of EMG signals of RF muscle has slight contraction intermittently starts from terminal-stance phase until terminal swing phase.

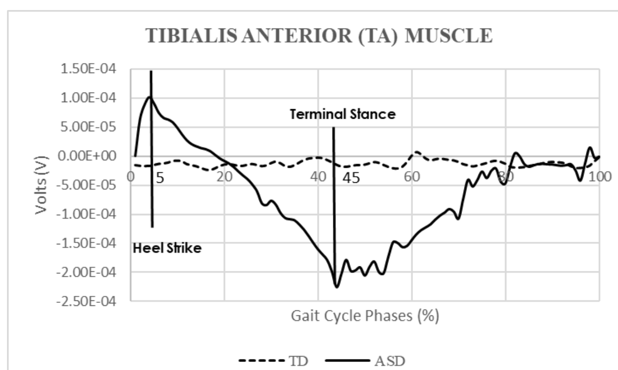


Figure 5 Mean Amplitude of EMG Signals for TA Muscle for One Gait Cycle

Figure 5 above shows the mean amplitude of EMG signals of TA muscle for ASD and TD children for one gait cycle. During loading response phase, the mean amplitude of EMG signals of ASD children was increased to the maximum point, revealed that this muscle was in the extended state. Then, the mean amplitude of EMG signals of TA muscle was gradually decreased to the minimum point at 45% of gait cycle. However, it was then increased gradually until terminal swing phase. Contrary with TD children, the mean amplitude of EMG signals of TA muscle showed slight contraction intermittently from loading response phase until terminal swing phase.

The mean amplitude of EMG signals for GAS muscle is shown in Figure 6 below. For TD children, mean amplitude of EMG signals of GAS muscle was decreased and reach minimum point at terminal stance phase, revealed this muscle was in flexed condition. However, it was gradually increased to the maximum point at 90% of gait cycle. Nonetheless, for ASD children, the GAS muscle was only showed slight contraction throughout the gait cycle.

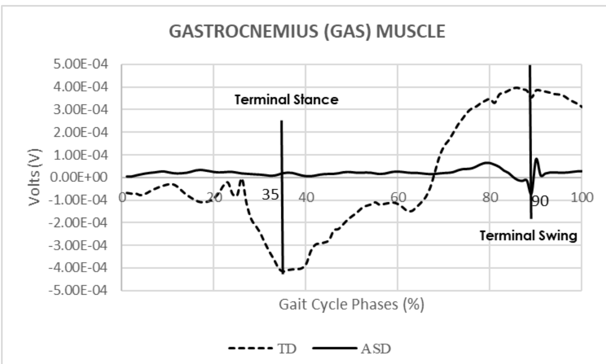


Figure 6 Mean Amplitude of EMG Signals for GAS Muscle for One Gait Cycle

Figure 7 shows the mean amplitude of EMG signals of BB muscle for ASD and TD children in one gait cycle. From the figure, the mean amplitude of EMG signals of BB muscles for ASD children was at the maximum point during loading response phase, then it was gradually decreased to the minimum point at the initial swing phase. Contrary with TD children, the mean amplitude of EMG signals of BB muscle was contract intermittently flex and extend start from loading response phase until 40% of gait cycle.

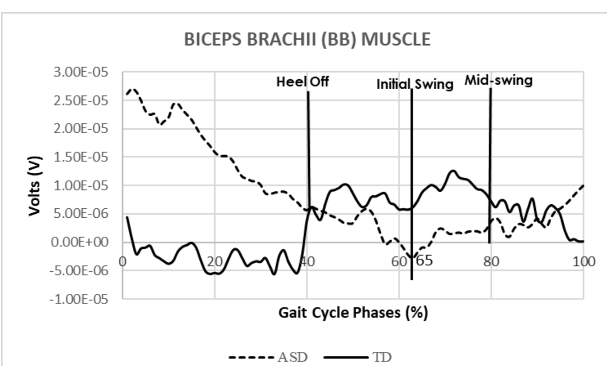


Figure 7 Mean Amplitude of EMG Signals for BB Muscle for One Gait Cycle

Then, the mean amplitude of EMG signals of BB muscle for ASD and TD children was increased, showed that this muscle was in extended condition at the phase of 65% until 80% of gait cycle. However, the contraction for ASD children observed is higher than TD children during 65% until 80% phases of gait cycle.

The mean amplitude of EMG signals of TB muscle for ASD and TD children in one gait cycle is shown in Figure 8. During loading response phase, the mean amplitude of EMG signals for TB muscle for TD children was increased, showed that this muscle was in extend condition, contrary with ASD children, the TB muscle was in flexed condition, observed by decreasing of mean amplitude of EMG signals of TB muscle.

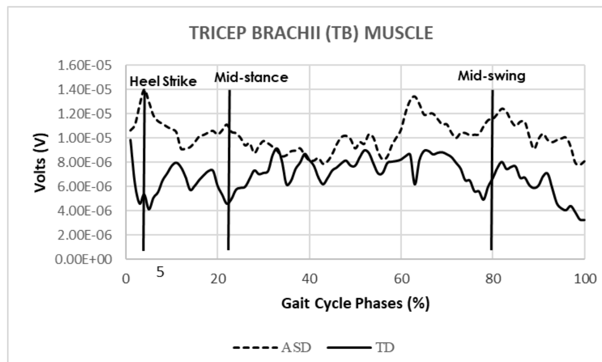


Figure 8 Mean Amplitude of EMG Signals for TB Muscle for One Gait Cycle

Also, the same contraction of TB muscle occurred during end of mid-stance phase where the TB muscle for TD children was extended and for ASD children this muscle was in flexed condition. However, the mean amplitude of EMG signals of TB muscle for both ASD and TD children was decreased from 80% of gait cycle until terminal swing phase, showed that this muscle was in flexed condition.

Statistical analysis of Mann-Whitney test used had obviously revealed that there are significant features of the tested muscles between ASD and TD children. The significant features were identified for the p-value that is less than 0.05. The results showed that, out of 42 data, there were 5 significant features between ASD and TD children, there are TA muscle during 30% of gait cycle, GAS muscle during 50% and 60% of gait cycle, and BB muscle during 10% and 80% of gait cycle as shown in Table 2. During 10% and 80% of gait cycle, the p value for BB muscle was seen equal to 0.021 and 0.018, respectively, while at 30% of gait cycle, the p value for TA muscle was observed equal to 0.017. Meanwhile, for GAS muscle during 30% of gait cycle, the p value showed 0.049.

Table 2 Mann-whitney Test of the Tested Muscles

Gait cycle	LR 10%	MST 30%	TST 50%	PSW 60%	ISW 80%	MSW 90%	TSW 100%
BF	0.687	0.495	0.496	0.442	0.416	0.322	0.540
RF	0.926	0.804	0.751	1.000	0.652	0.636	0.234
TA	0.975	***0.017**	0.274	0.535	0.478	0.853	0.690
GAS	0.137	0.163	***0.049**	***0.034**	0.308	0.183	0.520
BB	***0.021**	0.402	0.174	0.865	***0.003**	0.830	0.492
TB	0.476	0.278	0.965	0.859	0.574	0.684	0.287

*Significant difference (p value<0.05)

This study sought to determine whether there are differences in muscle activity of lower limb and arm muscles between ASD and TD children during walking. It was inferred that there are significant differences of lower limb and arm muscles between ASD and TD children during mid-stance phase. Meanwhile throughout mid-swing phase, the arm muscle showed a significant difference. This is in line with the function of BB muscles as the prime movers during the concentric phase as investigated by Dickie *et al*. (2017). Interestingly, the muscle of TA indicated significant occurrence activation between ASD and TD children [26]. The result in this paper is consistent with that of previous findings where the muscle activity of TA muscle was significantly enhanced when the body movement was accompanied by an arm swing movement [27]. Generally, all the muscle activation patterns are affected by the individual's walking style. Therefore, the body muscles are salient in contributing to body support approximately 50% to 95% of the vertical ground reaction force [28].

The findings also revealed that the arm swing throughout walking in ASD children was differed from TD children, it should thus influence the gait pattern of ASD children. It was shown from the disparities of BB muscle contraction between ASD and TD children during mid-stance and mid-swing phases. During this period, the foot began to leave the ground and continued as the body weight travels along the length of the foot until it was aligned over the forefoot, causing the body to be supported by only one leg [29]. The walking gait of ASD children might affect their walking cadence and arm swing pattern, just like hemiplegia children who use theirs arms less during fast walking compared to TD children [30]. The previous report sustained that normal arm swing will contribute to gait stability [31] and performing arm movements during walking, which may influence stride characteristics and patterns of lower limb muscle activation [8]. The muscle activation of BB and TB also showed obvious fluidity in EMG signals reading in mid-stance and mid-swing phases. Besides, the observation from the video taken in this study exposed that most of the ASD children were fidgeting during walking and their movement were perceived as clumsy and uncoordinated. A vigilant gait was apparently shown during the experiment. A few of the ASD children also had over-focused attention to the instruction given. The over-focused pattern of attention in ASD children occurred due to the difficulty in shifting attention [32].

The results obtained in this study were inclined to the number of subjects involved and the average of demographic data including body mass and height. These factors may influence the variability in stride length as reported by Rinehart *et al*., and the difficulty of ASD children in walking will reduce the stride regularity [33]. This study also did not address the specific EMG signals reading as indicators to distinguish both groups, as its goal is to investigate if there are significant differences on the lower limbs and arm muscles between ASD and TD children during walking. This study is not without limitations. Studies focusing only on EMG signals in identifying parameters that affect gait in ASD children are insufficient. In addition, other gait parameters such as temporal spatial, joint kinematics, joint kinetics and 3D GRF gait patterns would also provide valuable information of gait impairment in ASD children. Recommendations for future studies should increase the size of subjects to gain higher validity.

4.0 CONCLUSION

The distinction of lower limbs and arm muscles between ASD and TD children based on the EMG signals have been observed in this study. Out of 6 muscles tested, 3 muscles have showed significant difference between ASD and TD children, which are the TA muscle, GAS muscle and BB muscle. It can be concluded that EMG signals during walking can be used as one of the techniques to distinguish between ASD and TD children. This prove that the ASD children can be pre-diagnosed through a muscle activation test throughout the walking process. Five significant features of EMG signals were verified to be different between ASD and TD children, there are TA muscle at 30% of gait cycle, Gas muscle at 50% and 60% of gait cycle, and BB muscle at 10% and 80% with significant values of 0.017, 0.049, 0.034, 0.021 and 0.003, respectively.

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