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Gait Asymmetry Assessment using Muscle Activity Signal: A Review of Current Methods

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Abstract. Gait asymmetry is a type of gait characteristics when there is difference in gait parameters statistically, measured bilaterally between left and right limbs. Gait asymmetry assessment is used to observe changes or deviation in gait due to pathological condition, effect of rehabilitation program or to give insight on effect of gait on stability and fall-risk. The assessments of gait asymmetry could be measured by using spatiotemporal, kinetics, kinematics parameters or by analysis of muscle activity signals obtained from surface electromyography (EMG). However, EMG-based assessment for gait asymmetry is not well explored compared to assessment using other gait parameters. This review aims to compare research designs, methods and procedure of previous studies that utilized EMG for gait asymmetry analysis. Therefore, any research in the future that involved gait asymmetry measurement could take note on and produce more reliable findings.

1. Introduction

Gait is defined as patterns or manner of locomotion from a point to a point such as walking, running, hopping, and skipping as the result of limb movement across the body [1]. It encompasses high interaction of central nervous system and musculoskeletal system to ensure the body stay upright in stable manner during movement [2].

The purpose of quantitative gait analysis is to study the biomechanics of walking and consequently assist in treatment or rehabilitation of patients with abnormal gait [3]. There are various kinds of data that are able to describe gait pattern such as spatiotemporal, kinetics, kinematics and also muscle

activity [4]. Application of gait analysis is primarily for medical purpose however; it is extensively applied for other purpose such as sport science [5].

Gait asymmetry characteristics is one of the assessments that can be analysed to measure deviation in gait between right and left limbs. Gait asymmetry assessment could give insight on effect of pathological condition such as stroke, cerebral palsy, Parkinson's disease, osteoarthritis and other medical condition concerning on gait such as injury or orthoses usage [6]. It also gives information on stability or risk of fall of able-bodied gait. Electromyography (EMG); the recording of muscle electrical activity also had been used in gait asymmetry measurement although it is not extensively used compared to other gait parameters [7]. By using EMG, extended information on walking pattern could be provided as it describes muscle activation, the process that initiate gait cycle.

2. Methodology

In this review, method for data acquisition and processing of surface EMG for gait analysis will be overview from previous studies. Aspect of study design such as subjects, selected assessed muscles, gait procedure, and asymmetry measures methods will also be discussed thoroughly. The search will be performed through electronic databases (ScienceDirect, IEEE Xplore and Web of Science) to find research conducted from 1995 to 2018 with the keyword gait, symmetry, asymmetry combined with electromyography (EMG).

There are total of 18 journal articles and conference proceedings [8-25] selected from the literature search of research done from year 1995 to 2018. All literatures were collected from databases of ScienceDirect, IEEE Xplore and Web of Science. The details of journal selection procedure are presented in figure 1.
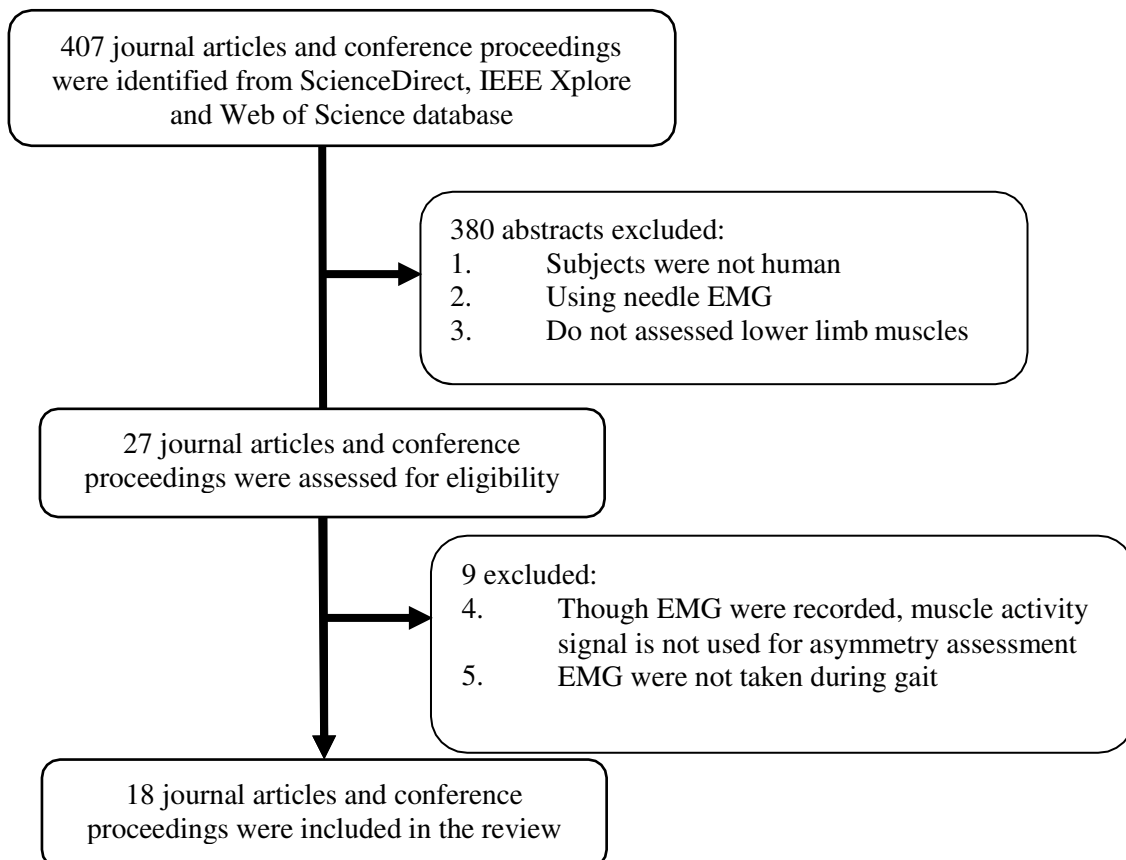
Figure 1. Flowchart of selecting journal articles and conference proceedings.

3. Results and Discussion

The studies included mostly had observational designs to observe gait asymmetry because of certain condition while other studies were experimental studies to evaluate the impact of gait training program or rehabilitation [8, 14], assistive device during gait [11, 16, 25] and after-effect of surgery [12, 19]. The studies reviewed here involved subjects in various kind of condition that causes asymmetric gait for example neuromusculoskeletal diseases such as stroke [10, 13, 20, 22, 24, 25], osteoarthritis [21], multiple sclerosis [18], cerebral palsy [18], cerebral hypoxia [18], and Parkinson's disease [8], hemiparesis [11, 18], patients with abnormal gait because of surgery [12], traumatic brain injury [18], amputees [9, 16], spinal cord injury [14], ligament injury [19], and genetic pathology [18]. Normal subjects were involved in majority of the studies for comparison purpose but there are three studies that involved only normal subjects to analyse dominant vs non-dominant limb effect on gait [15], balance in normal people [23] and another study that modulated limping gait on healthy people using split-belt treadmill [17].

3.1. Study Protocol and Muscles Assessed

Most studies record data of walking gait at preferred speed of the subjects except [16, 17, 23, 25] but all with different length of walkway ranging from 3 to 15 m. Some studies used treadmill [11-13, 17, 23, 25] and allow or purposely used assistive device for experimental purposes such as orthosis [14, 18, 25], prostheses [16] and other walking aid [18, 25].

Only one study stated the reason of choosing muscles assessed which is [18] that referred to physical medicine doctors and rehabilitation physicians to give recommendation on which muscles that best represent gait. The two muscles that were assessed in majority of the studies are tibialis anterior (TA) [13, 14, 18, 20, 21, 23, 25] and gastrocnemius muscles [13, 14, 18, 19, 21, 22, 25]. Both muscles are the prime mover of actions at the ankle joint. Tibialis anterior is the muscle that responsible for dorsiflexion and gastrocnemius playing the role in plantar flexion movement [26].

Other muscles that were assessed are also prime mover that are responsible for other two joints of lower limbs; hip and knee, for example vastus lateralis, biceps femoris and rectus femoris [26]. Study by Burnett et al. [15] also assessed the muscles at the trunk and abdomen because the study protocol is not only involved walking but also involve sit-to-stand, and stand-to-sit tasks.

3.2. EMG Signal Processing Technique

The EMG data were sampled at frequency ranging from 500-2160Hz but the majority of the studies recorded with sampling rate of 1000Hz [9]. The Nyquist rate state that sampling rate must be at least double the highest frequency components of the signal to ensure the signals are not distorted [27]. For surface EMG, the frequency components are between 400-500Hz so the studies reviewed here follows the recommended sampling rate which is in the range of 800-1000Hz [27]. For the signal conditioning of EMG, all studies vary on the type and cut-off frequency of the filters based on the needs of the raw signals. Based on all studies included, only four studies [15, 17, 22, 23] did not mention rectification of the signals. A study [25] done the signal processing of EMG based on SENIAM recommendation where firstly, the data should be high-pass filtered using 4th order Butterworth with a cut-off frequency of 10 Hz in order to remove motion artefacts. Then, the data should be full-wave rectified and low-pass filtered, also with 10Hz cut-off frequency of 4th order Butterworth.

3.3. EMG Asymmetry Assessment Approaches

Although EMG is often used in gait analysis, it rarely used for gait asymmetry quantification compared to other gait data; spatiotemporal, kinetics or kinematics data [7]. Several studies quantify asymmetry of gait using EMG signals in order to especially analyse muscle activation pattern in pathologic gait [8, 10-14, 18, 20, 21], however on the remaining studies EMG asymmetry were compared with other gait parameters. According to S. Viteckova et al. [7], gait asymmetry assessment approaches can be classified into four types; discrete, complete gait cycle, statistically-based and non-

linear methods. Every approach has pros and cons depending on the type of gait data used for the assessment, the need or purpose of the study.

Majority of the studies assessed asymmetry characteristics of EMG signals using statistical approaches such as cross-correlation [8], auto-correlation [14], t-tests [9, 19], ANOVA [12, 16, 25], or mean and standard deviation comparison [11, 15, 22]. In the other hand, other studies measure asymmetry using discrete approaches [15, 17, 20, 21, 23] with different kind of formulas to quantify asymmetry index of selected EMG data. The remaining studies observe qualitatively the asymmetry of the EMG profile based on its shape and timing. The details of the asymmetry assessment of EMG are as shown in table 1 and table 2 below.

Table 1. EMG asymmetry using statistical approaches

Method		EMG feature
Statistical	Cross-correlation	Latency corrected ensemble average (LCEA) of each muscle over the strides in a trial [8]
	Auto-correlation	EMG profile [14]
	t-tests	-Mean of integrated EMG and mean of ratios during first and second half of stance time and swing time [9] -Mean and SD of knee contact force estimated using EMG-driven musculoskeletal model of the knee
	ANOVA	-Peak activity of the gastrocnemius muscle [12], integrated EMG [16] -Ensemble averaged EMG profiles [25]
	Mean and SD	-EMG linear envelope [11] -Root mean square error [22] -Muscle synergies based on EMG envelope [24]

Table 2. EMG asymmetry assessment using discrete calculation

Method	Reference	EMG feature	Formula
Discrete measurement	[15]	RMS during stance phase	Symmetry Index $$SI = \frac{RMS_{ND,stance}}{RMS_{D,stance}}$$ ND: non-dominant limb D: dominant limb
	[17]	Fast and slow leg muscle contributions C_m during tied-belt and split-belt walking on a treadmill [17]	$$SI(\%) = \frac{C_{m,fast} - C_{m,slow}}{(\frac{1}{2})(C_{m,fast} + C_{m,slow})} \times 100$$
	[20]	Maximum root mean square (RMS) during stance phase	$$Symmetry\ ratio = \frac{paretic\ side\ parameter}{non-paretic\ side\ parameter}$$

	[21]	Mean muscle activity (mV) during the complete gait cycle	Asymmetry Index (ASI) $$ASI(\%) = \left\| \frac{2 \times (MA_L - MA_R)}{MA_L + MA_R} \times 100\% \right.$$ MA_L and MA_R representing individual mean muscle activities of the left and right limb, respectively
	[23]	Mean EMG integral	Symmetry index $$SI = \frac{(X_R - X_L) \times 2}{(X_R - X_L)} \times 100$$ Where X_R is signal from right leg and X_L is signal from left leg

4. Conclusion

This paper intended to review methodologies used for gait asymmetry assessment using muscle activity signal measured by surface EMG. Compared to other gait features, muscle activity signals using EMG is least used to measure gait pattern especially for asymmetric characteristics. It was not possible to recommend the best methods considering various factors such as subjects involved, joint of interest, and the purpose of study. However, this review highlighted the previous studies methodologies to observe the trend so that future research could refer and acquire more reliable findings. Future research will be able to compare and find the relationship of gait asymmetry measures from EMG with other method or technology in gait studies.

Acknowledgements

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