Journal of Neuroscience Methods 201 (2011) 27–34

Contents lists available at ScienceDirect

Journal of Neuroscience Methods

journal homepage: www.elsevier.com/locate/jneumeth

Muscular timing and inter-muscular coordination in healthy females while walking

Cora Huber[a,*], Corina Nüesch[b], Beat Göpfert[a], Philippe C. Cattin[c], Vinzenz von Tscharner[d]

[a] Laboratory of Biomechanics & Biocalorimetry, University of Basel, c/o Biozentrum/Pharmazentrum, Klingelbergstrasse 50-70, CH-4056 Basel, Switzerland
[b] Orthopaedic Department, University Hospital of Basel, Spitalstrasse 21, CH-4031 Basel, Switzerland
[c] Medical Image Analysis Center, University of Basel, c/o University Hospital Basel, Spitalstrasse 21, CH-4031 Basel, Switzerland
[d] Human Performance Laboratory, The University of Calgary, 2500 University Drive NW, Calgary, Alberta, Canada T2N 1N4

ARTICLE INFO

Article history:
Received 7 April 2011
Received in revised form 1 July 2011
Accepted 8 July 2011

Keywords:
Thigh muscles
Gait
EMG
Wavelet analysis
Rhythmicity

ABSTRACT

The dynamic interplay between muscles surrounding the knee joint, the central nervous system and external factors require a control strategy to generate and stabilise the preferred gait pattern. The electromyographic (EMG) signal is a common measure reflecting the neuromuscular control strategies during dynamic tasks. Neuromuscular control mechanisms, found in processed EMG signals, showed a precise pacing with a pacing rhythm and a tight control of muscle activity in running and maximally contracted muscles. The purpose of this study was to provide an insight how muscles get activated during walking. The EMG power, extracted by the wavelet transform (92–395 Hz), over a time period encompassing 250 ms before and 250 ms after heel strike was analysed. The study showed that the wavelet-based analysis of EMG signals was sufficiently sensitive to detect a synchronisation of the activation of thigh muscles while walking. The results within each single subject and within the group consisting of 10 healthy females showed that, although there was a lot of jitter in the locations of the intensity peaks, the muscle activation is controlled, on average, by a neuromuscular activity paced at about 40 ms, however with variable amplitudes. Albeit the jitter of the signal, the results resolved the temporal dependency of intensity peaks within muscles surrounding the knee and provided an insight into neural control of locomotion. The methodology to assess the stabilising muscle activation pattern may provide a way to discriminate subjects with normal gait pattern form those with a deteriorated neuromuscular control strategy.

1. Introduction

The knee is a complex joint with many muscles which have to be controlled by the neuromuscular control mechanism. The dynamic interplay between these muscles, the central nervous system (CNS), and external factors do require a control strategy to generate and stabilise the preferred gait pattern. Many studies have shown that small changes in external factors, for instance different shoes, do not change the preferred movement (Nigg, 2001). However, to stabilise a preferred movement the neuromuscular control system must be very flexible. The stabilising neuromuscular control strategy applied while walking can be observed by monitoring the muscle activity using electromyography (EMG) as an indicator.

The EMG signal is a common measure reflecting the neuromuscular control strategies during dynamic tasks (DeMont and Lephart, 2004; Farina et al., 2004; Guidetti et al., 1996; Rutherford et al., 2010; Wakeling, 2009; Wong, 2009; Zebis et al., 2008). Neuromuscular control mechanisms, found in processed EMG signals, showed a precise pacing with a pacing rhythm (Stirling et al., 2011; von Tscharner et al., 2011a, 2011b; Brown, 2000; Brown et al., 1998; Salenius et al., 1996, 1997; Vallbo and Wessberg, 1993). Works done in the late 1990s showed that these rhythms are correlated to the activity of the motor cortex and can therefore be considered as a result of the activity of the CNS (Brown et al., 1998). However, the studies revealing the corticomuscular interaction usually did not explicitly resolve the pacing in the EMG signal. In maximally activated muscles (von Tscharner et al., 2011a, 2011b) and muscle activities measured while running (Stirling et al., 2011) the rhythms were explicitly resolved and showed a tight control of muscle activity. Thus, the presence of rhythmicity within a longer

Abbreviations: BF, biceps femoris; EMG, electromyography; CNS, central nervous system; HAM, hamstring muscle group; QF, quadriceps femoris; RF, rectus femoris; ST, semitendinosus; VL, vastus lateralis; VM, vastus medialis.

* Corresponding author. Tel.: +41 0 61 265 94 64; fax: +41 0 61 265 95 74.
E-mail addresses: cora.huber@unibas.ch (C. Huber), cnueesch@uhbs.ch (C. Nüesch), beat.goepfert@unibas.ch (B. Göpfert), philippe.cattin@unibas.ch (Ph.C. Cattin), vincent@kin.ucalgary.ca (V. von Tscharner).

0165-0270/$ – see front matter © 2011 Elsevier B.V. All rights reserved.
doi:10.1016/j.jneumeth.2011.07.008

lasting muscular event indicates that there is a kind of programmed function controlled by a neuromuscular activity (Arsenault et al., 1986).

The musculoskeletal mechanics of gait depends on multi- and biarticular muscles that are activated in a specific sequence. Especially at heel strike where the human locomotor system is affected by irregular impact forces, controlled muscle activation strategies are essential for counteracting the destabilising forces. A coordinated activity of Mm. quadriceps femoris (QF) is essential to maintain dynamic stability of the patellofemoral joint (Mellor and Hodges, 2005a, 2005b). Such an active control of the patella by precise coordination between the Mm. vastus medialis (VM) and vastus lateralis (VL) is important the more extended the knee joint is (Mellor and Hodges, 2006), as occurring at heel strike. Consequently, as the foot touches the ground, the muscles have to be prepared to absorb the impact shock by a muscle tuning (Nigg and Wakeling, 2001) to control the stabilisation of the knee joint dynamically (Mellor and Hodges, 2006). A balanced VM and VL activity is required to control the translation of the patella to prevent their maltracking (Cowan et al., 2001; Mellor and Hodges, 2005a; Pal et al., 2011). Already a time delay of 5 ms in the onset of the VM relative to VL alters the patellofemoral joint mechanism (Neptune et al., 2000).

Therefore, our hypotheses were: (a) that the EMG signal combined with the wavelet based analysis of this signal is sufficiently sensitive to detect a synchronisation of the activation of thigh muscles while walking and (b) that the neuromuscular control uses a similar timing raster like timing for the synchronisation of muscle activity during gait. The study was designed to investigate how the muscles are controlled by the neuromuscular system before and after heel strike while walking.

The study should provide insight into muscle activation during a movement that does not need absolutely tight control. In decerebrated cats, the gait pattern is still present but not stable (Grillner and Wallen, 1985; Grillner and Zangger, 1984). We therefore have to consider that human muscles have at least two major functions, one is to provide the energy to sustain the movement, and the other is to keep the movement in line by stabilising the joints. It was previously shown that EMG intensity pattern can discriminate between healthy subjects and subjects suffering from osteoarthritis (von Tscharner and Valderrabano, 2010). However, pattern classification did not reveal explicitly the changes in the neuromuscular control strategy. Therefore the important next step is to understand the timing strategy of the neuromuscular control. A methodology to assess the stabilising muscle activation pattern may provide a way to discriminate subjects with a normal gait pattern from those with a deteriorated neuromuscular control strategy.

2. Materials and methods

2.1. Subjects

Ten healthy female volunteers (age: 48 ± 7 years, body mass: 61.1 ± 4.9 kg, height: 1.64 ± 0.05 m) with no history of previous knee or lower extremity surgery, osteoarthritis, neurological, or musculoskeletal disorders participated in this study. They were informed of the experimental risks and signed an informed consent form approved by the local Ethics Committee.

2.2. Experimental design

An instrumented three dimensional gait analysis with synchronous measurement of the lower extremity muscle activity during normal gait was performed. The lower body kinematics were recorded at 240 Hz with a six-camera motion capture system (Vicon MX13+, Oxford, UK) using the Helen Hayes model (Kadaba et al., 1990). The subjects walked barefoot at a comfortable, self-selected walking speed along a 10 m walkway within the laboratory. A minimum of 12 valid trials was collected. The time of heel strike was determined from the position of the heel marker. Two steps per trial were extracted. Due to technical problems, mainly movement artefacts, less than 12 trials were available from seven subjects. Nine trials, thus 18 steps per subject, were used for the calculations. In total 180 steps were analysed.

2.3. Data recording

Surface EMG was recorded from the QF and hamstring (HAM) muscle groups for the right thigh. The muscles of the QF group were: Mm. rectus femoris (RF), VM, and VL, and of the HAM group: Mm. semitendinosus (ST) and biceps femoris (BF). Bipolar Ag/AgCl surface electrodes (diameter: 10 mm, inter-electrode distance: 22 mm, Noraxon U.S.A. Inc., Scottsdale, AZ, USA) were used. After shaving and cleaning the skin with alcohol according to SENIAM-recommendations (Hermens et al., 2000), three electrode pairs were placed side by side on each muscle, in the direction of the muscle fibres, to get additional spatial and temporal information. The first electrode pair, referred to as original, was positioned according to the SENIAM-recommendations whereas the lateral and medial electrode pairs were laterally displaced by 28 mm from the original electrode pair (Fig. 1). The ground electrode was positioned on the tibial tuberosity. The surface EMG was collected with single differential amplifiers (band path of 10–700 Hz, Biovision, Wehrheim, Germany) at a sampling frequency of 2400 Hz without further processing. Cables and electrodes were kept in place by elastic net bandage (Elastofix, Type B-25 m stretched, BSN medical GmbH & Co. KG, Hamburg, Germany) which was pulled over the thigh.

2.4. Data processing

2.4.1. Wavelet transform

The signal analysis was performed using a wavelet transform with 13 non-linearly scaled wavelets characterised by their centre frequency: 7, 19, 38, 62, 92, 128, 170, 218, 272, 331, 395, 457, and 542 Hz (von Tscharner, 2000). Centre frequencies lower than 92 Hz were not considered further because time resolution has to be short enough to detect the rhythm. The theoretical time resolution of the wavelets defined by von Tscharner (2000) represents the time difference of two events that occur at the same frequency and within the same recording that is required for the events to be discriminated. For wavelets with centre frequencies above 92 Hz time resolution is between 25 and 10 ms. In signals of mixed frequency and when comparing peaks recorded in different trials time resolution is much shorter and mainly limited by the sampling frequency. Centre frequencies higher than 395 Hz were omitted because of high frequency noise. EMG power at each time point was calculated by summing the power extracted by the wavelets with centre frequencies of 92–395 Hz. The EMG power over a time period encompassing 250 ms before and 250 ms after heel strike was used for the analysis. The average EMG power of the triplicate electrodes was called a waveform. Thus, heel strike was at time 0 within the waveform. Waveforms were normalized by dividing them by the sum across the waveform. The waveforms indicate the fine structure across time of the step-specific strategy of muscle activation. Each individual waveform represented the average waveform of all steps for a given subject. The group waveform was computed by averaging the individual waveforms.