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Research Article

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Low-Cost 2-Channel Electromyography Telemeter using a Personal Computer Microphone Port

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Abstract

Objective: For the convenient use of electromyography devices in physical rehabilitation during locomotion, we developed a simple, low-cost 2-channel electromyography telemeter (LC-EMGT) that can be connected wirelessly with a personal computer (PC) microphone port.

The aim of this study was to verify whether the performance of our LC-EMGT fulfills the need for monitoring EMG during locomotion of patients in rehabilitation. For this purpose, we compared the performance of our LC-EMGT with an existing EMG device (NeuropackΣ).

Methods: Muscle activity of the left and right vastus medialis were recorded when the participant repeated a standing-up movement for 10 seconds at 55-bpm speed. The EMG signal was simultaneously recorded by the LC-EMGT and NeuropackΣ. We compared the waveform of these EMG signals and their root mean squared signals in appearance and by cross-correlation analysis. Also, we monitored the orthopedic patients' EMG waveforms during standing-up and ascending stairs.

Results: The cross-correlation analysis demonstrated an approximately 170-ms delay in EMG measurement by LC-EMGT due to the wireless signal transformation. Meanwhile, the amplitudes of the waveforms in the LC-EMGT were almost equal to those of the NeuropackΣ. In addition, with the LC-EMGT, we could visually monitor EMG waveforms of the patients during standing-up and stair climbing on-line using a PC.

Conclusion: Consequently, the LC-EMGT was as reliable as the existing EMG device at monitoring EMG signals and is available as an EMG monitor in real-time. The LC-EMGT is cost-effective, convenient, and may be generally used in various clinical and sports situations.

Keywords: Electromyography; EMG monitor; Telemeter; EMG-biofeedback; Gait; Motor learning; Rehabilitation

Introduction

Physical therapists (PT) monitor muscle tension and muscle movement visually or via palpations when providing patients with locomotor instruction. However, when muscle movement must be accurately measured for research or medical examination, electromyography (EMG) is used. Therefore, EMG could also be a useful tool for PTs to accurately monitor locomotion. De Luca et al. reported the following three applications of EMG: measuring muscle activation timing, examining the force and EMG signal relationship, and using the EMG signal as a fatigue index [1].

EMG has also been used to determine the effectiveness of physical therapy in those with motor disorders such as assessment of back pain [2-4], monitoring movement and effectiveness of physical therapy around the hip joint [5], and clarification of patellofemoral pain syndrome-related weight-bearing rehabilitation outcomes [6]. In stroke patients with spasticity or motor paralysis, it is possible to follow functional changes by using EMG to clarify characteristics of standing and standing-up in hemiplegic stroke patients [7-10]. It is also possible to observe characteristics of posture in those with Parkinson's disease via EMG [11].

Additionally, EMG has been widely used in healthy patients, such as monitoring EMG waveform changes during different modes of locomotion (e.g., normal walking, stepping over obstacles, and descending stairs)[12], examining disparities in effectiveness due to different muscle activity patterns during balance training [13], assessing effects on walking in elderly patients due to differences in exercise training [14], and the use of sports-related EMG analyses [15].

Thus, EMG is used to quantify qualitative improvements in exercise, and is useful not only for determining the existence or non-existence of illness, but also for the PT and the patient to accurately assess changes in exercise [16].

Reports on the effectiveness of EMG-BF therapies in hemiplegic stroke patients are especially numerous. Of those that focus on walking, there are two confirming the effectiveness of muscle re-education and motor training when EMG-BF devices were used

[17,18], and one confirming significant improvements in walking speed and stride length owing to the use of an EMG-BF device in combination with treadmill walking training [19]. Sajiki et al. found in their study on stroke patients, a correlation between increased 10-m maximum walking speed and improved functionality in activities of daily living (ADL) [20], thus showing that walking is a primary factor that greatly impacts ADL improvement. Therefore, BF therapy using an EMG monitoring device for walking training of hemiplegic stroke patients may to lead to improved walking ability and functionality in ADL.

However, the high cost of commercial EMG monitors (from one hundred to several ten thousand dollars) poses a major obstacle to their general purchase and application. Moreover, there are many instances where daily use of commercial EMG monitors is difficult.

To address the cost issue of commercial EMG monitoring, Muraoka et al. developed a simple, two-channel EMG-BF device that can be inexpensively produced and display the EMG via connection to an everyday personal computer (PC) [21]. However, because this device relies on a wired connection, the space in which the device can be used is limited by wire length. Particularly for rehabilitation involving movement (e.g., walking training), eliminating obstacles to allow for safe movement of patients and caregivers, and making the device connection wireless, are necessary improvements that will permit EMG-BF's use in larger spaces. A prior representative report on the use of wearable sensors in human gait analysis [22] further indicated the need to make EMG monitor connections wireless during movement and exercise.

Additionally, when the PC connected to the Muraoka et al. device was driven by AC power, AC electrical switching noise would infiltrate the EMG signal through the USB power supply. Therefore, it is desirable that such noise not infiltrate the display or the EMG recording when the PC is AC-powered.

To address the above two issues of safety and noise infiltration, we improved upon the Muraoka et al. device, developing a wireless, low-cost 2-channel electromyography telemeter (LC-EMGT) that uses audio-based Bluetooth transceiving, and then compared the basic performance of this LC-EMGT to a commercial EMG. We furthermore report on a trial of the LC-EMGT in a clinical setting during the movements of a patient with a motor disorder.

Methods

Device overview

Details on the present proposed device including the electrodes, the electrode wires, the uniquely designed EMG amplifier, the Bluetooth transmitter/receiver (BTT005N, Zhongshan K-mate General Electronics Co. Ltd, China), and the PC are shown in Figure 1. Production cost for the LC-EMG device (approximately 45 dollars) and equipment for wireless transceiving (35 dollars) was approximately 80 dollars.

The transmitter currently functions up to a distance of approximately 10 meters from the receiver, with the myoelectric potential detected by the electrode amplified with the EMG amplifier and then transmitted via the Bluetooth transmitter.

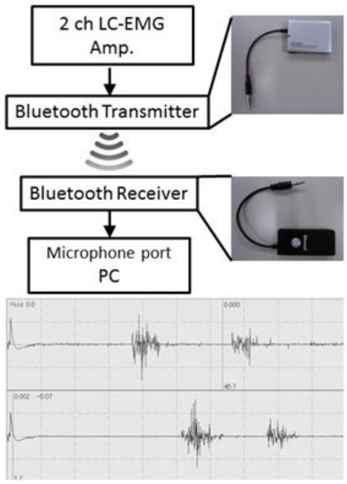


Figure 1: The present device used a low cost 2ch EMG amplifier, sending the myoelectric signal through a bluetooth transmitter/receiver to a PC where the waveform was displayed using audio based software.

The voltage values wirelessly transmitted via the Bluetooth transmitter are received by a Bluetooth receiver plugged into the stereo microphone input terminal on an ordinary PC. Display of the waveform is done using ordinary audio waveform display software (Handy Oscillo-scope version1.25, ©Karasudani Takashi, Japan).

A circuit map of the EMG amplifier is shown in Figure 2. The EMG amplifier has an additional AC coupling condenser in the output region of the circuit described in the paper by Muraoka et al., which changed the amplification factor to 495. The board used was designed and made at our laboratory. And in the amplifier output, AC coupling condensera passive CR low-pass filter (cutoff frequency: 1940.9 Hz) was installed in series.

Performance evaluation testing Simultaneous measurements with an existing commercial EMG

We compared waveforms recorded simultaneously using the proposed device and the commercially available, NeuropackΣ (NPΣMEB-5504, NIHON KOHDEN CORPORATION, Japan).

The muscle activity of one of the coauthors, a healthy adult female, was simultaneously measured with both devices, with Channel 1 (1ch.) at the left vastus medialis and Channel 2 (2ch.) at the right vastus medialis, and with the positive and negative electrodes of the proposed device placed at locations of four finger-widths distances along the line from the superior margin of the patella to the abdominals (Figure 3). Additionally, reference electrodes were placed at the right ankle. We used adhesive electrode (HV-3DPAD Omron co. Ltd., Japan), which is available at general consumer electronics retailers, as a low-frequency therapy device by dividing it into three pieces. With regards to the participant, she was positioned approximately three meters away from the PC and verbally cued to cyclically stand up from a sitting position (55 times/min) over a period of 10 seconds, with EMG recorded from the first cue until the completion of the movements. NPΣ was set at a frequency band of 20 – 500 Hz with sensitivity at 500 μV/div. Regarding the myoelectric signal measured from both devices, sampling frequency was set at 1 kHz and measurements were simultaneously recorded on the PC for 10 seconds, with the first two seconds from both signals removed and the remaining eight seconds used for analyses. The Root Mean Square (RMS) over 100-ms increments was calculated every 1 millisecond from the obtained myoelectric signal, thereby providing an index of the amount of muscle activity per unit time. To examine the similarities and synchrony of both waveforms derived via the two devices being compared, a cross-correlation function was estimated. R3.3.1 (Open-source software) and XLSTAT (XLSTAT 18.07.40458, Addinsoft, Japan) were used as statistical analysis software.

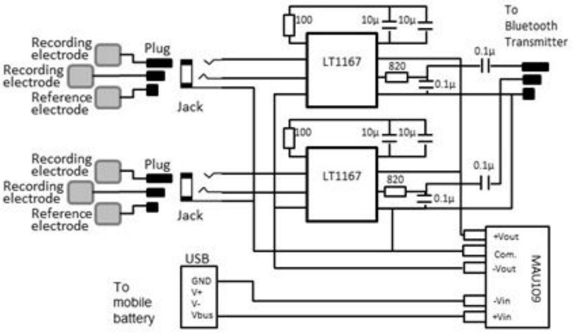


Figure 2: EMG amplifier circuit diagram of low-cost EMG telemeter (LC-EMGT). The EMG amplifier added an AC coupling condenser to the output of the circuit based on that of Muraoka et al. and installed a 100Ω gain regulation resistor on each amp, changing its amplification factor to approximately 495.

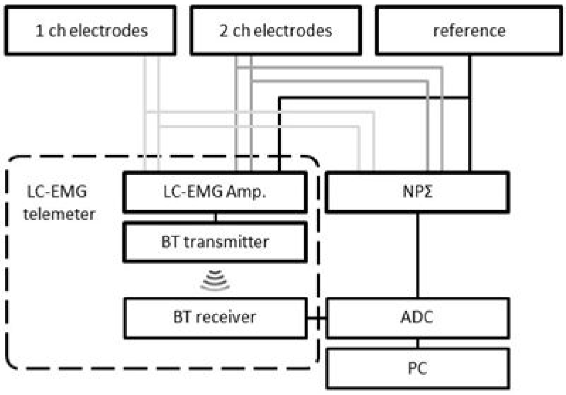


Figure 3: Wiring during the measurement experiment. The wires from each of the positive, negative, and reference electrodes were split and connected to the LC-EMGT and the commercial EMG (Nihon Koden Neuropack Σ:NPΣ). Signal from the two devices was respectively input wirelessly (via bluetooth) and directly into an AC power-driven PC and recorded.

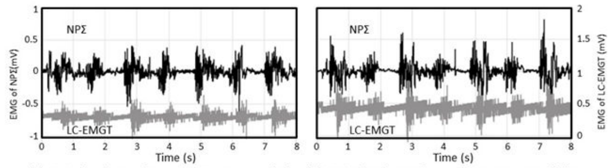
Collection and recording of waveforms for clinical purposes via generic free software

Informed consent was obtained from the subject, a 71-year-old female (body weight: 45.0 kg, height: 151.7 cm, Body Mass Index: 19.55 kg/m^2) outpatient with bilateral knee osteoarthritis who voluntarily participated. The day from onset was 158 days. At the time of consultation, she had pain in her left knee during movement. However, this was observed to have improved six months following the consultation. Her WOMAC score (short version) was 5 points. Her range of joint motion for both left and right was 145 degrees. With extension at 0 degrees, her manual muscle test (MMT) grades per the lead PT were 5 for both left and right. The patient could stand and ascend stairs independently.

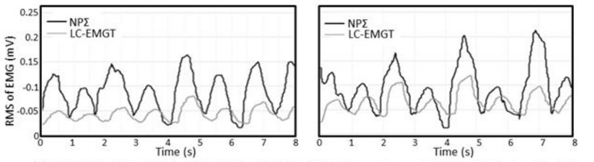
The positive and negative electrodes of the LC-EMGT were placed at the subject's left and right vastus medialis for 1ch. and 2ch. respectively, and reference electrodes were placed bilaterally on the patella. The subject performed repeated standing movements from a seated position prompted by a metronome sound at a rate of 55 bpm. The seat height used for the standing movements was 38 cm. Stair climbing was performed at a normal speed in conjunction with a start cue. The staircase had eight stairs with a landing halfway. The EMGs for both movements were collected for 25 seconds beginning simultaneously from the start of movement, with the LC-EMGT transmitted signals recorded via the microphone input on an AC-powered PC (CF-SX1, Panasonic, Windows 7) (Figure 4).

Recordings and waveform display were done using the free Windows software, Handy Oscilloscope (for Windows 8/7/me/XP). Analyses were done using Excel 2013 (Microsoft), with the first and last two seconds of the recording excluded. Additionally, the recorded waveform was converted considering the amplification factor.

Finally, the present study was conducted under the approval of the ethics committee of this institution (approval number: 280095).



(a) EMG signal waveforms of Lt Vastus Medialis (b) EMG signal waveforms of Rt Vastus Medialis



(c) RMS envelopes of EMG of Lt Vastus Medialis (d) RMS envelopes of EMG of Rt Vastus Medialis

Figure 4: EMG signal waveforms and their RMS envelopes recorded by LC-EMGT and NPΣ. Almost the same periodic curve was seen between each device.

Results

Simultaneous measurements with an existing commercial EMG

Figures 4a and 4b show the left (1ch) and right (2ch) vastus medialis respectively. Figures 4c and 4d show the RMS envelopes (with RMS values calculated at 100-ms intervals) of waveforms recorded via both devices during standing movements at the left and right vastus medialis, respectively.

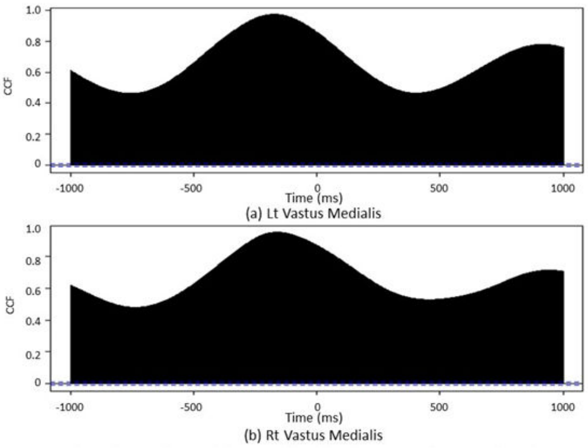


Figure 5: The envelopes of the EMG signals in LC-EMGT and Neuropack Σ of Lt Vastus Medialis and Rt Vastus Medialis. The cross-correlation function for both showed a peak lag of about 170ms.

The upper and lower waveforms in each graph (referenced on the left and right axes, respectively) represent data from the NPΣ and the LC-EMGT, respectively. Figures 5a and 5b show the cross-correlation function of EMG waveforms derived from both devices at the left and right vastus medialis, respectively. The cross-correlation function of the left vastus medialis indicated a peak value of 0.976 in - 173 ms. Meanwhile the cross-correlation function of the right vastus medialis indicated a peak value of 0.955 in - 159 ms.

A delay of approximately 170 ms was observed in the LC-EMGT derived waveforms at both the left and right vastus medialis. However, there was a cyclical emergence and decay in waveforms from both locations, and, bearing the delay in mind, the muscle activity at both locations had approximately the same periodicity between both devices. Furthermore, almost no artifacts were observed. Therefore, despite there being a delay of about 170 ms, both waveforms were synchronous and similar (Figure 5).

Figure 6 illustrates the relationship between the NeuropackΣ and the LC-EMGT using Bland–Altman analysis. The mean difference between the NeuropackΣ and the LC-EMGT was -0.045 mV (SD, 0.026) of the left vastus medialis, -0.052 mV(SD, 0.037) of the right vastus medialis.

Collection and recording of waveforms for clinical purposes via generic free software

Figures 7a and 7b show recorded waveforms from the knee osteoarthritis patient during standing-up and stair climbing, respectively. Again, 1ch and 2ch were at the left and right vastus medialis, respectively. Additionally, Figures 7c and 7d show the RMS envelope during standing-up and stair climbing, respectively.

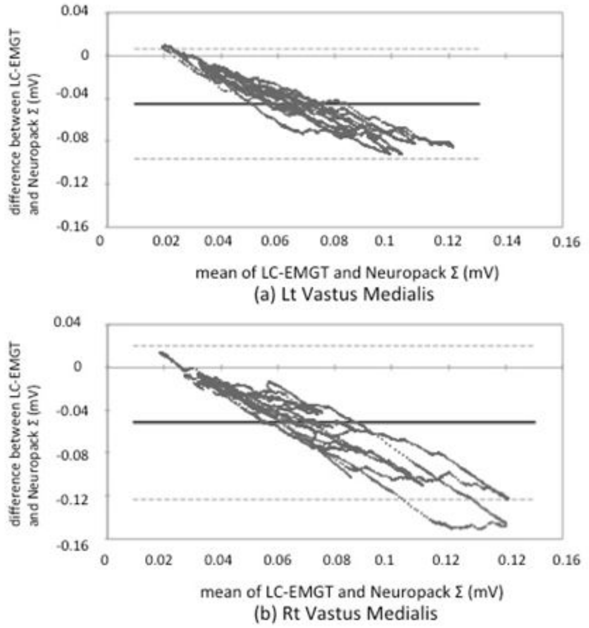


Figure 6: The Bland-Altman plot of the EMG signals in LC-EMGT and Neuropack Σ of Lt Vastus Medialis and Rt Vastus Medialis.

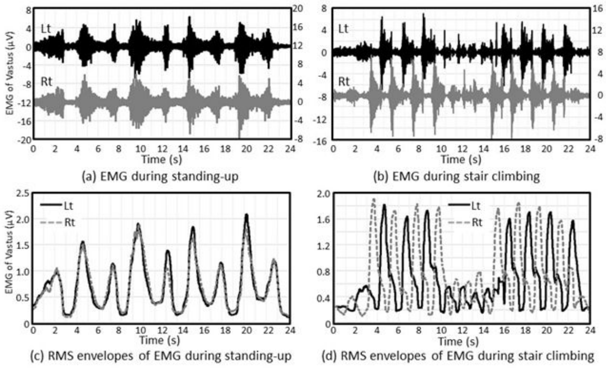


Figure 7: EMG signal waveforms and their RMS envelopes recorded by LC-EMG during standing-up and stair climbing.

There was no hindrance due to wires during movement or task performance. Moreover, there was no prominent noise in the myoelectric signal, which was observable in association with movement. Although the subject had come in for consultation regarding left knee pain initially, the pain had improved at the time of data collection. Based on the EMG waveforms during her standing-up, no major differences between the left and right vastus medialis were observed. Furthermore, based on the EMGs, there was almost no difference between the muscle activities on both sides. However, with stair climbing, muscle activity in the clinically relevant left vastus medialis appeared to be slightly reduced.

Discussion

We improved upon the basic EMG-BF device with stereo inputs proposed by Muraoka et al., making the EMG monitor wireless using an audio-based Bluetooth transmitter/receiver. The device was also producible at a low-cost with about 20 easy to obtain parts, including the instrumentation amplifier, DCDC converter, resistors, and condensers. We hoped our device would also be easy for healthcare professionals with little engineering knowledge to make. The additional procurement of the implemented audio-based Bluetooth transmitter/receiver was a simple matter and, thus, the proposed device is predicted to be easily producible as well. Additionally, although the commercially available EMG telemeter used in the present study featured numerous channels, it is expensive, costing several ten thousand dollars. Therefore, despite the proposed device only featuring two channels, its ability to assess the timing or amount of muscle activity between two muscles (e.g., an agonist and antagonist), the low cost of parts (under 100 dollars), and the ease with which it can be turned into a wireless myoelectric monitor are thought to make it more than sufficient to meet the needs of those involved in clinical practice or sports.

Results from the performance evaluation testing confirmed through simultaneous measurement with the existing high-performance commercial EMG telemeter that the two channel LC-EMGT is able to accurately detect the muscle activity of the subject.

Although there was a delay of approximately 170 ms in the Bluetooth signal, for purposes of performing feedback or analyses following the completion of exercise, or for slow patient movements (i.e., not running), this degree of latency is thought to not pose any substantial problems. Moreover, despite the myoelectric waveform being recorded on an AC-powered PC, there was no electrical noise intermixed in the signal. Thus, we confirmed that it is possible to perform low-noise myoelectric measurements independent from the surrounding environment and the PC type.

The monitor results with the LC-EMGT for clinical purposes confirmed that the muscle activity in the subject's left and right vastus medialis were nearly identical during standing-up movements. However, during stair climbing, activity at the clinically-relevant left vastus medialis was slightly reduced. Compared to the bilateral leg movements of standing, multiple stair climbing movements that require the support of a single leg revealed a tendency for different amounts of force to be exerted between left and right muscles, thus clarifying the continued need for this approach. These results suggest then that monitoring with EMG during each movement and assessing the waveforms is one possible means of obtaining quantitative information when determining therapy guidelines in the planning of rehabilitation programs for the physical exercise of patients.

In this experiment, while the LC-EMGT was implemented for clinical purposes, it was possible to execute movements safely, and with no hindrance to observation and support during stair climbing. Making the EMG monitor's PC connection wireless reduced hindrance to movement and the risk of stumbling and falling on the device wires, and permitted expansion into a more spacious measuring environment. The Bluetooth transmitter used functions at a range of approximately 10 m and is, therefore, thought usable in walking training (e.g., 10-m walking evaluations). The present device allows motion analyses involving movement applicable to walking (e.g., walking and stair climbing), and EMG-BF therapy to be performed easily at low cost. Therefore, LC-EMG-BF is expected to offer increased opportunities for EMG device applications in sports, exercise training, and rehabilitation across a wide range of disorders.

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