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Wireless accelerometer reflex quantification system characterizing response and latency

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Abstract— **The evaluation of the deep tendon reflex is a standard aspect of a neurological evaluation, which is frequently evoked through the patellar tendon reflex. Important features of the reflex are response and latency, providing insight to status for peripheral neuropathy and upper motor neuron syndrome. A wireless accelerometer reflex quantification system has been developed, tested, and evaluated. The reflex input is derived from a potential energy setting. Wireless accelerometers characterize the reflex hammer strike and reflex response acceleration waveforms, enabling the quantification of reflex response and latency. Spectral analysis of the reflex response acceleration waveform elucidates the frequency domain, opening the potential for new reflex classification metrics. The wireless accelerometer reflex quantification system yields accurate and consistent quantification of reflex response and latency.**

Index Terms—**reflex, reflex loop, reflex response, reflex latency, wireless accelerometers, reflex quantification**

I. Introduction

A routine component to the standard neurological evaluation consists of observing the characteristics of the deep tendon reflex [1, 2]. The tendon reflex can be readily evoked through the lower limb with the patellar tendon at the knee and the Achilles tendon at the ankle. The clinician is tasked with the objective of striking the tendon with a brisk reflex hammer strike to evoke the reflex. The clinician qualitatively evaluates the amplitude of the reflex response and temporal characteristics of the reflex, such as latency. Given the diverse neurological aspects that influence the reflex arc, a clinician may interpret both central and peripheral nervous system trauma from a dysfunctional tendon reflex evaluation. The resultant characteristics of the qualitative tendon reflex are generally quantified using a five-point ordinal scale [2].

Given the qualitative features of the standard neurological examination, current technological advancements enable biomedical systems that can advance the acuity of the tendon reflex evaluation while alleviating the rampant strain on medical resources. The synthesis of wireless 3D accelerometers incorporating MEMS technology enables an alternative concept for the quantification of the deep tendon reflex. The system consists of two wireless accelerometers and a potential energy derived pendulum swing arm with a mounted reflex hammer.

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II. Background

A. Tendon reflex anatomy

The inherent neural circuitry of the tendon reflex loop integrates aspects of both the central and peripheral nervous system. With the diverse neurology foundational to the reflex arc, dysfunctional characteristics observed through evoking the tendon reflex can be indicative of neurological dysfunction [1, 2, 3].

The patellar tendon reflex is elicited with a clinician briskly striking the tendon with a reflex hammer [2]. The resultant tendon strike stimulates the associated muscle spindles and coupled 1a afferent neurons. The signal is transmitted to the spinal cord. At the spinal cord the 1a afferent neurons synapse with the respective alpha motor neurons. There are two central nervous system features that modulate the reflex: descending supraspinal input from the brain and spinal cord interneuronal integration. The efferent signal evokes a contraction of the relevant muscle [1, 3].

Trauma to the central nervous system can result in the alteration of deep tendon reflex response [1, 2, 3]. The clinical evaluation of the tendon reflex can facilitate the localization of dysfunction impacting the central nervous system [1, 2]. Another characteristic of the tendon reflex loop is latency, which is indicative of the status of the peripheral nervous system and related to nerve conduction [4, 5]. Previous attempts have been conducted to quantify both the response and latency of the tendon reflex.

B. Issues with ordinal scale reflex response evaluation

Litvan conducted an assessment of the reliability of the NINDS Myotatic Reflex Scale, which consists of five ordinal components. Results demonstrated substantial to near perfect reliability from an intraobserver perspective and moderate to substantial reliability for interobserver evaluation. Litvan advocates that the reliability of the NINDS Myotatic Reflex Scale warrants the acceptance as a universal scale for measuring reflexes [6].

However Manschot ascertained results that contradict the findings of Litvan, addressing the NINDS scale and the Mayo Clinic scale, which consists of 9 ordinal components. With respect to both scales, interobserver agreement did not exceed fair. A notable attribute of the NINDS scale is that the scale only consists of five ordinal components [7].

Stam demonstrates the extensive interobserver disagreement through consideration of the nine ordinal component Mayo Clinic scale. The study found that neurologist disagreed by at least two ordinal scale units or greater for 28% of the examinations. The neurologists disagreed on the presence of asymmetry for 45% of the reflex pairs [8]. Another notable deficiency of the ordinal reflex scale is the capacity to characterize any temporal aspects of the reflex.

C. Issues with electrodiagnostics and reflex latency

A traditional means for evaluating peripheral nerve conduction is through electrodiagnostic testing. Specialized training is an inherent aspect of electrodiagnostic evaluation, implicating its medical resource intensive nature [9]. Multiple studies have addressed the efficacy of electrodiagnostic testing.

Cocito conducted a study evaluating the appropriateness of electrodiagnostic testing; finding 28% of the examinations were unwarranted [10]. A study by Mondelli claimed that only 77.2% of the electrodiagnostic evaluations were considered useful by the neurophysiologist substantiating the clinical diagnosis [11]. Podnar found that only 45% of the examinees referred for electrodiagnostic testing were confirmed with dysfunction in the peripheral nervous system [12].

An alternative and less resources intensive method for characterizing nerve conduction is by evaluating the latency of the tendon reflex [4]. Types of neuropathy to the peripheral nervous system can be ascertained through eliciting the patellar tendon reflex. Protracted reflex latency is associated with types of peripheral neuropathy [13, 14]. The inherent significance of the tendon reflex latency is the reflex loop consists of both afferent and efferent nerve fibers [1, 3, 13, 14].

D. Previous reflex quantification systems

Devices have been developed for attempting to quantify tendon reflexes. Pagliaro and Zamparo produced a system that incorporated an instrumented reflex hammer with a load cell tethered by cable to the ankle [15]. Van de Crommert and Faist investigated reflex response during gait through EMG with a one kilogram motorized reflex input system [16, 17]. Cozens developed a system appropriate for bedside evaluation of acute brain injured subjects with a servo-positioned tendon hammer quantified input for the biceps brachii reflex and EMG for quantified response [18]. Lebiedowska integrated a manual operated sweep-triggering hammer with a strain gauge device for quantifiying input and output of reflex [19]. These reflex quantification systems provide incremental advances with the subject of reflex quantification; however the proposed wireless 3D MEMS accelerometer reflex quantification system provides advanced utility in contrast to prior devices.

Other systems developed by Mamizuka, Zhang, Koceja, and Kamen are capable of synchronizing reflex input and response without the use of EMG. However the wireless accelerometer reflex quantification system provides greater utility. The device is portable and uses defined potential energy for input, with unrestricted range of motion. Mamizuka integrated a synchronized wired triaxial accelerometer with an instrumented hammer for measuring both response and latency, based on the temporal disparity between reflex input and response waveforms [20]. The system developed by Zhang incorporated an instrumented reflex hammer with a torque sensor locked at a particular knee flexion angle to evaluate the isometric contraction of the reflex response. Latency was defined as the temporal disparity between reflex input and torque from the response [21]. Koceja and Kamen produced a device incorporating electromagnetic solenoid evoked reflex input, which measured response through a strain gauge device. With synchronized input and response measurement, latency was obtained. However the size of the device is on order with the size of the subject, limiting portability [22, 23].

E. Wireless 3D MEMS accelerometer reflex quantification system

In comparison to the previous devices, the wireless accelerometer reflex quantification system is capable of synchronizing both quantified and accurate reflex input with highly reliable measurement of the response [24, 25]. In contrast to the device by Pagliaro and Zamparo, the wireless accelerometer reflex quantification system does not require any tethering to measure response and can acquire full temporal characterization of the response. The system by Van de Crommert and Faist modifies the reflex response with a one kilogram reflex input component mounted to the leg. The proposed wireless accelerometer reflex quantification system mounts a 46 gram wireless accelerometer node to the leg [26]. The system by Cozens is envisioned for acute subjects with brain injury; however the wireless accelerometer reflex quantification system is intended for subjects with chronic neurological pathologies. The input component for the device by Lebiedowska lacks the ability to provide variable input; contrary to the wireless accelerometer reflex quantification system that can provide consistent quantified input using predetermined and variable potential energy settings.

The proposed wireless reflex quantification system integrates two synchronized wireless 3D MEMS accelerometers sampling at 2048 Hz using a wireless activated and downloaded datalogger mode for user convenience. The proposed wireless reflex quantification system is an evolution beyond previous wireless reflex quantification systems that sampled at 100 Hz using a real-time wireless data stream [24, 25]. The selection of a well defined anatomical anchor has been established as essential for reliable quantification of limb movement [27]. The selected anatomical anchor for wireless reflex quantification is the lateral malleolus.

Fig. 1. Wireless reflex quantification system.

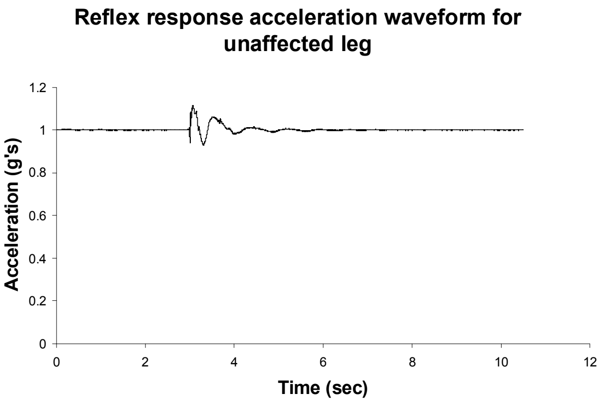

Fig. 2. Reflex response acceleration waveform.

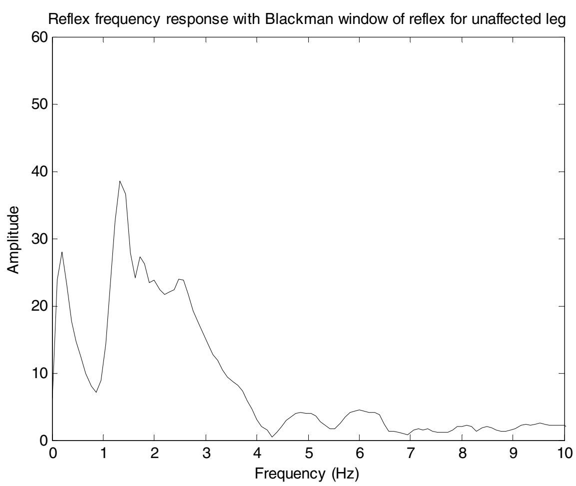

Fig 3. Frequency response of reflex with Blackman window.

Table 1
Reflex response and latency parameters

Parameter	Mean	Standard Deviation
Maximum (g's)	1.130	0.016
Local Minimum (g's)	0.945	0.007
Latency derived from Maximum (ms)	73.41	6.17
Latency derived from Local Minimum (ms)	9.28	1.29

The potential energy derived swing arm enables precise quantities of potential energy to be selected for eliciting the tendon reflex. The reflex hammer mounted to the swing arm can be aimed before the tendon strike for consistency. Two wireless accelerometers were mounted to the swing arm and adjacent to the lateral malleous of the subject, as illustrated in Figure 1. The wireless accelerometer mounted adjacent to the ankle enables the quantification of the reflex response with respect to amplitude and temporal characteristics, without impairing range of motion. The other wireless accelerometer mounted to the swing arm defines the temporal characteristics of the reflex hammer strike evoking the tendon reflex. The tandem wireless accelerometers are synchronized to a common trigger, providing the capacity to measure latency as the disparity between reflex hammer strike and reflex response acceleration waveforms. Rather than using an ordinal scale as a means of assessment, the full temporal nature of the reflex response and latency can be elucidated. Post-processing algorithms may be subsequently incorporated for ascertaining response amplitudes.

III. Experimentation

The initial test and evaluation of the system involved the unaffected leg of a chronic hemiparetic (subject 1). Each trial was conducted based on the following protocol:

1. Mount the wireless 3D accelerometer adjacent to the lateral malleolus.
2. Aim the reflex hammer level to the tibial tubercle.
3. Activate in tandem both wireless 3D MEMS accelerometers with datalogging mode.
4. Pull the swing arm 30 degrees from gravity vector.
5. Release the swing arm.

Repeat the protocol for 15 trials with a minimum 15 second pause between evoking the patellar tendon reflex. Both wireless accelerometers sampled at a rate of 2048 Hz.

IV. Results and Discussion

The wireless reflex quantification system demonstrated consistent results. Figure 2 illustrates a representative acceleration waveform for the reflex response. Two essential aspects of the waveform are the initial local minimum and maximum values. Latency is defined as the temporal disparity between swing arm strike relative to local minimum and maximum values. The maximum and local minimum of the reflex response waveform including their respective latencies are represented in Table 1. The maximum and local minimum were bound with a 96% confidence level based on a 4% margin of error about the mean. The latency derived from the maximum aspect of the reflex response waveform was bound with a 95% confidence level using a 5% margin of error about the mean. Latency based on the local minimum was bound by a 90% confidence level with a 10% margin of error about the mean.

Further spectral analysis of a sample reflex response waveform was conducted. The spectral analysis incorporates a Blackman window. Figure 3 characterizes the frequency domain of the reflex response. Spectral analysis of the reflex response acceleration waveform may permit novel classification techniques for reflex evaluation.

V. Conclusion

The deep tendon reflex evaluation is a fundamental aspect of the standard neurological examination. A wireless accelerometer reflex quantification system has been demonstrated to measure both reflex response and latency with considerable consistency. The wireless reflex quantification system incorporates a potential energy derived input with wireless accelerometers characterizing both reflex input and reflex response acceleration waveforms. The maximum and local minimum aspects of the reflex response waveform were bounded by a 96% confidence level based on a 4% margin of error about the mean. The latency defined by the reflex response waveform maximum was bounded by a 95% confidence level based on a 5% margin of error about the mean. The shorter latency derived from the reflex response local minimum was bounded by a 90% confidence level based on a 10% margin of error about the mean. The results are an evolution from previous wireless accelerometer reflex quantification systems, as the datalogger method enables improved sampling acuity and user convenience [24, 25]. The findings warrant clinical trials with the wireless reflex quantification device.

The frequency domain has been elucidated for the reflex response using spectral analysis, enabling new metrics for the classification of neurological status. The wireless 3D reflex quantification system could be capable of evaluating the inherently disparate reflex attributes for chronic hemiparetic subjects, with a contrast between affected and unaffected limb. The wireless reflex quantification system may advance therapy and drug efficacy evaluation methods.

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