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Quantified reflex strategy using an iPod as a wireless accelerometer application

Robert LeMoyne, *Senior Member*, *IEEE*, Timothy Mastroianni, and Warren Grundfest, *Member*, *IEEE*

Abstract— **A primary aspect of a neurological evaluation is the deep tendon reflex, frequently observed through the patellar tendon reflex. The reflex response provides preliminary insight as to the status of the nervous system. A quantified reflex strategy has been developed, tested, and evaluated though the use of an iPod as a wireless accelerometer application integrated with a potential energy device to evoke the patellar tendon reflex. The iPod functions as a wireless accelerometer equipped with robust software, data storage, and the capacity to transmit the recorded accelerometer waveform of the reflex response wirelessly through email for post-processing. The primary feature of the reflex response acceleration waveform is the maximum acceleration achieved subsequent to evoking the patellar tendon reflex. The quantified reflex strategy using an iPod as a wireless accelerometer application yields accurate and consistent quantification of the reflex response.**

***Index Terms*—iPod application, iPod, wireless accelerometer, reflex, reflex loop, reflex response, reflex quantification**

I. Introduction

The characteristics of the deep tendon reflex represent fundamental insight for the standard neurological evaluation. Two types of tendon reflex can be effectively elicited through tapping either the Achilles tendon or the patellar tendon. The objective of the clinician is to briskly strike the reflex hammer against the tendon to initiate the reflex loop. Diverse neurological structures regulate characteristics of the reflex response. The clinician may deduce trauma to the peripheral and central nervous systems by observing a dysfunctional evaluation of the deep tendon reflex [1,2].

The clinician classifies the reflex response characteristics according to an ordinal scale system. For instance, the clinician may utilize the NINDS five-point ordinal scale or the Mayo Clinic nine-point ordinal scale to categorize reflex response. However, the reliability of these ordinal scale strategies has been a subject of controversy [2,3,4,5].

An alternative to interpreting reflex response and applying the result to an ordinal scale value is deriving an acceleration waveform from a wireless accelerometer and extracting a pertinent feature of the acceleration waveform, such as the maximum acceleration after eliciting the reflex response. The quantification of the reflex response has been successfully demonstrated through the integration of a potential energy impact pendulum device to evoke the patellar tendon reflex and a wireless accelerometer to record the acceleration waveform of the reflex response [5,6,7,8,9].

As an alternative to expensive wireless accelerometer systems for measuring the reflex response, the ubiquitous and relatively inexpensive iPod equipped with an accelerometer is demonstrated for quantifying the acceleration waveform of the reflex response. The attributes of the iPod enable the capacity to function as a wireless accelerometer system, by transmitting the acceleration waveform as a Microsoft Excel Comma-Separated-Value file through email. The patellar tendon reflex is evoked using a potential energy impact pendulum attached to a reflex hammer.

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R. LeMoyne, Dr., is Independent, Running Springs, CA 92382 USA (e-mail: rlemoyne07@gmail.com).
T. Mastroianni is Independent, Pittsburgh, PA 15243 USA (e-mail: cognitionengineering@gmail.com).
W. Grundfest, Dr., is a Professor of the Biomedical Engineering IDP, UCLA, Los Angeles, CA 90095-1600 USA (e-mail: warrenbe@seas.ucla.edu).

II. Background

A. Neurological foundation for the tendon reflex

The tendon reflex neural circuitry is influenced by the peripheral and central nervous systems. Therefore, the nature of the tendon reflex can provide preliminary insight as to the status of the nervous systems. Abnormal tendon reflex characteristics can imply dysfunction to either or both the central and peripheral nervous systems [1,2,10].

The patellar tendon reflex is evoked with a brisk reflex hammer tap from the clinician [2]. The reflex hammer tap excites the associated muscle spindles, for which the signal is conveyed through 1a afferent neurons to the spinal cord. At the spinal cord the 1a afferents synapse with the associated alpha motor neurons. The central nervous system serves two functions: integration at the interneuron of the spinal cord and supraspinal modulation descending from the brain. The efferent signal causes the pertinent muscle to contract [1,10]. Alteration of the deep tendon reflex response can occur because of trauma to the central nervous system [1,2,10]. The objective of quantifying tendon reflex response has been previously attempted.

B. Reflex response quantification through ordinal scale strategy

The ordinal scale strategy for quantifying reflex response requires the expert assessment of a highly trained and skilled clinician. Upon evoking the tendon reflex, such as the patellar tendon reflex, the expert observation of the clinician is used to determine the suitable ordinal scale parameter that best pertains to the observed reflex response.

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Multiple ordinal scales exist, such as the NINDS Myotatic Reflex Scale and the Mayo Clinic scale [2,3,4].

Litvan advocates the reliability of the NINDS Myotatic Reflex Scale, based on a research study. The NINDS Myotatic Reflex Scale consists of five ordinal components. The research results discovered reliability from both an intraobserver and interobserver perspective. From the viewpoint of the intraobserver substantial to near perfect reliability was achieved. Respective of the interobserver, moderate to substantial reliability was obtained. Based on the findings of the research, Litvan supports the NINDS Myotatic Reflex Scale for recognition as the universal reflex measurement scale [3].

Manschot, in consideration of both the five point ordinal NINDS Myotatic Reflex Scale and the nine ordinal component Mayo Clinic scale, conducted a contrarian study. In terms of both reflex scales, the interobserver agreement did not exceed a threshold beyond fair agreement. The NINDS scale notably only consists of five ordinal parameters [4].

Stam further demonstrates a considerable degree of interobserver disagreement, respective of the nine point ordinal Mayo Clinic scale. The study by Stam ascertained that neurologists were in disagreement by at least two ordinal scale parameters for 28% of the examinations. For 45% of the reflex pairs neurologist were in dispute as to the presence of asymmetry [11].

The ordinal scale strategies addressed notably lack the capacity to characterize temporal features of the reflex loop. There exist multiple disparate scales for reflex quantification. The multiple scales may impair communication among professionals in the healthcare industry. For which, misunderstandings could impact the quality of patient management [4].

C. Previous reflex quantification strategies

Multiple prior attempts have been conducted to quantify reflexes. Pagliaro and Zamparo developed a method of evoking the tendon reflex through an instrumented hammer, while quantifying the reflex response through a load cell connected by cable to the ankle [12]. Other advances in reflex quantification involved the implementation of quantified input, such as through a motorized component to elicit the tendon reflex [13,14,15,16,17]. Van de Crommert and Faist implemented a system that involved a one kilogram motorized device to elicit the tendon reflex, while quantifying response through EMG [13,14]. Cozens developed a reflex quantification system, for which a servo-positioned reflex hammer provided quantified input for the tendon reflex of the biceps brachii, while using EMG to quantify the response [15]. Koceja and Kamen developed a quantified input to the tendon reflex through an electromagnetic solenoid [16,17].

Further advances involved emphasis on measuring the mechanical attributes of the reflex response [16,17,18,19,20]. Koceja and Kamen ascertained reflex response through a stain gauge device [16,17]. Liebdowska quantified input and output through a manual operated sweep-triggering hammer for evoking the tendon reflex and a strain gauge apparatus for measuring the response [18]. Zhang implemented a method that consisted of an instrumented reflex hammer with isometric reflex response measured through a torque sensor locked in a specific knee flexion angle [19]. Mamizuka quantified reflex response through the use of a wired triaxial accelerometer synchronized to an instrumented hammer [20].

D. Wireless accelerometer reflex quantification system

LeMoyne developed an accurate, reliable, and reproducible strategy for quantifying reflex response and latency [5]. The strategy involved a potential energy system for evoking the patellar tendon reflex, enabling both discrete input and variability. The reflex response is quantified through a wireless accelerometer, which can be readily mounted to the lateral malleolus of the leg near the ankle. The 46-gram wireless accelerometer node from Microstrain provides minimal mass intrusion on the reflex response [5, 6]. With a synchronized and tandem-activated wireless accelerometer on the potential energy reflex input component, the reflex latency can be measured [5,7,8,9].

E. iPod wireless accelerometer reflex quantification system

The next proposed evolution in the wireless reflex quantification system incorporates the use of an iPod application for acquiring the acceleration waveform of the reflex response. The iPod constitutes a unique wireless accelerometer, since the acquired accelerometer waveform can be captured in a Microsoft Excel Comma-Separated-Value file and conveyed wirelessly by email. The concept of implementing an iPod application as a wireless accelerometer application for obtaining the acceleration waveform of gait has been successfully demonstrated [21].

Although the 101-gram iPod has a greater mass of than the previously demonstrated 46-gram wireless accelerometer node from Microstrain, the iPod has many more beneficial features. The iPod has superior storage capacity, such as 32GB, in contrast to the previous wireless accelerometer application limited to 2MB of storage. The iPod has the capacity to transmit the accelerometer waveform data wirelessly through the internet by email, as opposed to a specific computer equipped with the capacity to acquire the wireless data. The iPod is equipped with robust software capability, which exceeds the capabilities of the previous wireless accelerometer node [6,22].

The integrated reflex quantification system consists of an impact pendulum potential energy swing arm and iPod functioning as a wireless accelerometer application. The potential energy swing arm is capable of producing discrete settings of potential energy to evoke the patellar tendon reflex. Also, the reflex hammer attached to the swing arm can be precisely aimed to strike a specific aspect of the patellar tendon. The iPod application for acquiring the acceleration waveform can utilize a temporal delay for ease of operation. After an audio tone informs the operator that the iPod application has commenced the recording of the acceleration waveform, the operator of the wireless reflex quantification system may release the swing arm that

Fig. 1. iPod wireless accelerometer reflex quantification system with iPod wireless accelerometer mounted above and adjacent to the lateral malleolus.

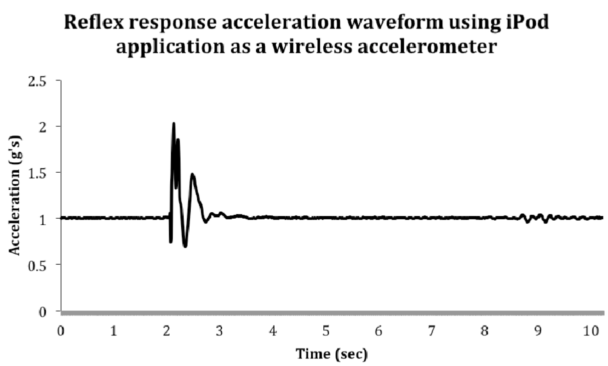

Fig. 2. iPod wireless accelerometer application reflex response acceleration waveform.

Table 1
iPod wireless accelerometer application quantified reflex response of 30 trials

Parameter	Mean	Standard Deviation	Coefficient of Variation
Maximum reflex response	2.04g's	0.18g's	0.09

connects to the reflex hammer at a precise potential energy setting. A subsequent audio tone informs the operator that the recording of the acceleration waveform has ended. The operator of the wireless reflex quantification system can then email the acceleration waveform as a Microsoft Excel Comma-Separated-Value file through wireless internet connectivity to an email source at the discretion of the operator.

III. Experimentation

An application enabled the iPod to function as a wireless accelerometer reflex quantification device. The iPod was used in conjunction with an impact pendulum potential energy reflex hammer swing arm for consistently evoking the patellar tendon reflex. For engineering proof of concept, a subject with healthy patellar tendon reflex of the respective leg was evaluated. The acceleration waveform of the reflex response was sampled at a rate of 100Hz. The subsequent experimental protocol was applied for the acquisition of 30 trials:

1. Mount the iPod functioning as a wireless accelerometer application using the elastic band of a sock above and adjacent to the lateral malleolus. Orient the iPod with the top in a superior position, such that the iPod from top to bottom is parallel with the tibia.
2. With the potential energy reflex hammer device, precisely aim the reflex hammer level to the tibial tubercle.
3. Activate the iPod wireless accelerometer system for the acquisition of the reflex response acceleration waveform.
4. Retract the swing arm of the potential energy reflex hammer device 30 degrees from gravity vector.
5. Release the swing arm.
6. Convey the recorded acceleration waveform wirelessly through email.
7. Continue the protocol to acquire 30 trials, with a minimal 15 second delay from evoking the next patellar tendon reflex sample.

IV. Results and Discussion

The quantified reflex strategy using an iPod as a wireless accelerometer application is illustrated in Figure 1. The potential energy reflex input system enables precise and consistent targeting of the patellar tendon. Discrete levels of potential energy, such as 30 degrees swing arm orientation relative to the gravity vector, can be consistently selected. Figure 1 illustrates the anatomical mounting strategy for the orientation of the iPod above and adjacent to the lateral malleolus. The overall development theme of the quantified reflex strategy using an iPod as a wireless accelerometer application is to minimize the need for highly specialized resources to elicit the patellar tendon reflex and acquire the acceleration waveform of the reflex response.

Upon acquisition of the patellar tendon reflex response acceleration waveform into a Microsoft Excel Comma-Separated-Value file, the reflex response data was transmitted wirelessly through email for further post-processing. The acceleration waveform illustrated in Figure 2 was derived from the three orthogonal acceleration vectors. In previous wireless quantified reflex studies the major parameter used to characterize and quantify the reflex response was the maximum reflex response in g's of acceleration relative to gravity [7,8,9]. The maximum reflex response parameter is summarized in Table 1. The 30 reflex response trials demonstrated considerable accuracy and consistency. The mean for maximum reflex response was determined to be 2.04g's with a standard deviation of 0.18g's corresponding with a coefficient of variation of 0.09. The quantified maximum reflex response parameter was bound with a 96% confidence level with a 4% margin of error about the mean. A similar application for gait analysis has demonstrated the capacity for the evaluation site and post-processing site to be at remote locations [21]. Similarly, the quantified wireless accelerometer application using the iPod is capable of acquiring the reflex response acceleration waveform and emailing the acceleration waveform by wireless transmission for post-processing at a remote location. The quantified reflex strategy using an iPod as a wireless accelerometer application demonstrates considerable potential for diagnostics of the tendon reflex as a preliminary neurological evaluation.

V. CONCLUSION

A quantified reflex strategy using an iPod as a wireless accelerometer application has demonstrated the capacity to quantify the acceleration waveform of the reflex response with a high level of accuracy and consistency. The quantified reflex system also utilizes a potential energy swing arm for imparting precise input and targeting to evoke the patellar tendon reflex. The maximum acceleration of the reflex response was bound with a 96% confidence level with a 4% margin of error about the mean using a sample size of 30 trials. The featured quantified reflex strategy can be readily applied remote to the resources for providing post-processing diagnostics. The successful initial proof of concept from an engineering perspective warrants greater testing and evaluation for the iPod wireless accelerometer application with potential energy input for reflex quantification.

Duration of operation, data storage, mass properties, and software of the iPod are envisioned to progressively evolve, advancing the ability to quantify reflex response attributes. Software advances are of considerable interest. The iPod is also equipped with a gyroscope sensor [22]. The gyroscope sensor may provide further insight as to the quality of the reflex response.

The current strategy for deriving latency is to use two tandem activated wireless accelerometers [5,6,7,8,9]. The tendon reflex consists of not only excitatory neural influence, but also inhibitory neural influence [1,10]. A new challenge would be to derive a functional latency based on a single acceleration waveform of reflex response derived from feature extraction and machine learning algorithms.

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