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Implementation of an iPhone wireless accelerometer application for the quantification of reflex response

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Abstract— **The patellar tendon reflex represents an inherent aspect of the standard neurological evaluation. The features of the reflex response provide initial perspective regarding the status of the nervous system. An iPhone wireless accelerometer application integrated with a potential energy impact pendulum attached to a reflex hammer has been successfully developed, tested, and evaluated for quantifying the patellar tendon reflex. The iPhone functions as a wireless accelerometer platform. The wide coverage range of the iPhone enables the quantification of reflex response samples in rural and remote settings. The iPhone has the capacity to transmit the reflex response acceleration waveform by wireless transmission through email. Automated post-processing of the acceleration waveform provides feature extraction of the maximum acceleration of the reflex response ascertained after evoking the patellar tendon reflex. The iPhone wireless accelerometer application demonstrated the utility of the smartphone as a biomedical device, while providing accurate and consistent quantification of the reflex response.**

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

I. Introduction

The tendon reflex enables fundamental perspective regarding the standard neurological evaluation. The essential utility of the tendon reflex is derived from the multiple and diverse neurological structures that influence the tendon reflex characteristics. Peripheral nervous system structures, such as afferent and efferent neurons, convey the stimulus and response of the reflex loop. Central nervous system aspects, such as supraspinal influence and spinal cord integration, affect the characteristic attributes of the tendon reflex. Dysfunction relative to the anticipated nominal features of the tendon reflex may assist the clinician regarding the diagnosis of trauma to the central and peripheral nervous systems and further referral to a specialist. Two standard tendon reflexes can be elicited by tapping the patellar tendon or the Achilles tendon [1,2,3,4].

The clinician is tasked with briskly striking the selected tendon with a reflex hammer to stimulate the reflex loop. Based on the clinician's specialized skill and expertise, the clinician interprets the features of the reflex response and classifies the observed reflex response according to an ordinal scale system. Multiple ordinal scale systems exist. The NINDS Myotatic Reflex Scale consists of a five-point ordinal scale, and the Mayo Clinic ordinal scale is comprised of nine ordinal parameters for categorizing the reflex response [2,3,4,5,6]. However, the efficacy of the ordinal scale strategy for classifying reflex response has been a topic of controversy [3,4,5,6].

A successfully demonstrated alternative strategy involves the incorporation of wireless accelerometers for recording the acceleration waveform of the reflex response. The patellar tendon reflex is precisely evoked using a predetermined potential energy setting through an impact pendulum attached to a reflex hammer. Feature extraction of the acceleration waveform for the wireless accelerometer quantifies the patellar tendon reflex response [3,4,7,8,9,10].

Further extrapolation of the quantified wireless accelerometer reflex device has been successfully demonstrated through an iPod application that enables the iPod to function as a wireless accelerometer platform. The iPod application for quantifying reflex response requires local wireless Internet connectivity [11]. The iPhone provides expanded utility, since the iPhone can convey wireless data through broader cell phone coverage [12].

The iPhone enables a unique capability for quantifying the patellar tendon reflex response attributes by serving as wireless accelerometer platform, especially for patients in more rural settings who lack wireless Internet connectivity but have available cell phone coverage. A specific software application equips the iPhone with recording the acceleration waveform of the patellar tendon reflex response and wirelessly transmits the acceleration waveform data in an email attachment. The acceleration waveform is encapsulated in a Microsoft Excel Comma-Separated-Value file. A Matlab program performs automated feature extraction for the acceleration waveform of the maximum magnitude of reflex response. The objective of the research is to demonstrate the ability of the iPhone functioning as a wireless accelerometer application and augmented with a Matlab program that automates acceleration waveform feature extraction for quantification of the patellar tendon reflex from the engineering proof of concept level.

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II. BACKGROUND

A. Tendon reflex neurological foundation

The neural circuitry that derives the organization for the tendon reflex provides useful preliminary insight regarding the health status of the nervous system. Both the central nervous system and peripheral nervous system affect the functional characteristics of the tendon reflex. Influence from the central nervous system derives from supraspinal modulation and spinal cord integration. The afferent and efferent neurons of the peripheral nervous system transmit the neural signals of the reflex loop. Abnormal deviations from the standard healthy reflex response of the patellar tendon may implicate dysfunction to aspects of the central nervous system and peripheral nervous system [1,2,13]. Quantification of a dysfunctional reflex response acceleration waveform may provide a useful support regarding the referral of a patient to a specialist for more detailed diagnosis.

A clinician can evoke the patellar tendon reflex with a brisk tap from a reflex hammer [2]. The accompanying muscle spindles are excited from the tap of the reflex hammer, which transmit a signal through 1a afferent neurons to the spinal cord. At the spinal cord the central nervous system influences the tendon reflex through supraspinal modulation and integration at the interneuron of the spinal cord. The 1a afferent neurons synapse with the correlated alpha motor neurons. The efferent signal causes contraction of the pertinent muscle [1,13]. Deviation from customary healthy reflex response can implicate trauma to the nervous system [1,2,13]. Strategies have been applied for quantifying the features of the tendon reflex.

B. Ordinal scale strategy for quantifying reflex response

A standard strategy for quantifying reflex response is the ordinal scale, such as the five-component NINDS Myotatic Reflex Scale and nine-component Mayo Clinic scale. A highly skilled clinician evokes the tendon reflex. Based on observation, the clinician selects the ordinal scale that best characterizes the reflex response [2,5,6].

Litvan evaluated the efficacy of the NINDS Myotatic Reflex Scale, regarding the reliability from an intraobserver and interobserver viewpoint. Substantial to near perfect reliability was attained for the intraobserver perspective. The interobserver perspective accomplished moderate to substantial reliability. Litvan advocates the NINDS Myotatic Reflex Scale for a universal reflex scale [5].

Manschot obtained contrary results, based on a study involving the NINDS Myotatic Reflex Scale and Mayo Clinic scale. Regarding both scales, interobserver agreement never surpassed the fair agreement threshold [6]. Stam ascertained considerable interobserver disagreement regarding the Mayo Clinic scale. Stam found that for 28% of the examinations neurologists disagreed by at least two ordinal scale parameters. Neurologists also disputed asymmetry presence for 45% of the reflex pairs [14].

C. Sensor derived reflex quantification strategies

As an alternative to the expert yet subjective interpretation of a clinician, devices have been implemented to quantify both the eliciting reflex strike and resulting reflex response. In an effort to further improve the consistency of the response, mechanized devices have been incorporated to elicit the tendon reflex [3]. Van de Crommert and Faist measured tendon reflexes evoked by a motorized device with a mass of one kilogram through EMG recordings [15,16]. Cozens elicited the biceps brachii tendon reflex with a servo-positioned reflex hammer measuring response by EMG [17].

Another alternative to quantifying reflex response involves sensor systems other than EMG to record the characteristics of the reflex response [3]. Pagliaro measured the attributes of the reflex response through a load cell through a cable mounted to the ankle [18]. Koceja and Kamen demonstrated the capacity to evoke the tendon reflex through an electromagnetic solenoid. The reflex response was ascertained through a strain gauge device. [19,20]. Using a similar approach, Liebdowska quantified reflex response through a strain gauge apparatus by applying a sweep-triggering hammer to actuate the tendon reflex [21]. Zhang measured the attributes of the reflex response based on isometric conditions with a torque sensor by securing a predetermined knee flexion angle. The tendon reflex was initiated through an instrumented reflex hammer [22]. Mamizuka also quantified reflex input through an instrumented reflex hammer synchronized to a wired triaxial accelerometer for acquiring reflex response [23].

D. Wireless accelerometer reflex quantification system

LeMoyne successfully tested and evaluated a system for the accurate, reliable, and reproducible quantification of reflex response and latency [3,4]. The application consisted of a potential energy device for reflex input capable of selecting a wide range of discretely quantified settings. The reflex response is quantified through the acquisition of an acceleration waveform obtained by a wireless accelerometer mounted in proximity to the lateral malleolus near the ankle. Latency can be ascertained by synchronizing the ankle mounted wireless accelerometer to another wireless accelerometer attached to the potential energy reflex input device [3,4,7,8,9,10].

E. iPod wireless accelerometer application for reflex quantification

A further evolution of the wireless accelerometer reflex quantification strategy involves the incorporating the iPod as a functionally wireless accelerometer platform. The iPod application enables the iPod accelerometer to record the acceleration waveform of the patellar tendon reflex response. The iPod application subsequently emails the acceleration waveform as a Microsoft Excel Comma-Separated-Value file by wireless transmission. For precisely evoking the patellar tendon reflex, an impact pendulum attached to a reflex hammer delivered a specific predetermined potential energy setting. The iPod wireless accelerometer application for quantifying the patellar tendon reflex demonstrated a high level of accuracy and consistency. Notable limitations of the iPod application for quantifying the patellar tendon reflex are the requirement for wireless Internet connectivity and the tedious nature of feature extracting the data from the reflex response acceleration waveform regarding each trial [11].

Figure 1. iPhone wireless accelerometer reflex quantification system. *(mounted above and adjacent to the lateral malleolus)*

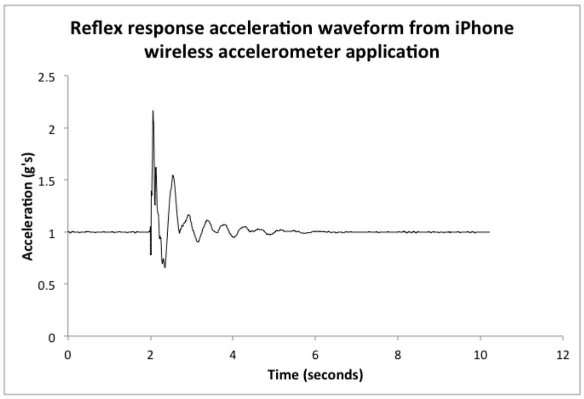

Figure 2. iPhone wireless accelerometer application reflex response acceleration waveform.

TABLE I. IPHONE WIRELESS ACCELEROMETER APPLICATION QUANTIFIED REFLEX RESPONSE (30 TRIALS)

Parameter	Mean	Standard Deviation	Coefficient of Variation
Maximum acceleration reflex response	1.89g's	0.16g's	0.08

F. iPhone wireless accelerometer application for reflex quantification

The iPhone consists of attributes that transcend the limitations of the iPod. Although the iPhone has a greater mass of 137 grams compared to the iPod with mass of 101 grams, the iPhone is equipped with a broader coverage range on the scale of cell phone coverage rather than a localized wireless Internet zone [11,12]. The expanded the capacity to wirelessly transmit emails consisting of acceleration waveform data based on cell phone coverage rather than wireless Internet zones expands the operational capacity of the iPhone wireless accelerometer, such as a rural setting that lacks a wireless Internet capability. A Matlab program provides automated feature extraction of the acceleration waveform, quickly post-processing the maximum acceleration magnitude of the patellar tendon reflex response.

The wireless reflex quantification system consists of an iPhone that functions as a wireless accelerometer application and a potential energy impact pendulum attached to a reflex hammer. The potential energy impact pendulum can select discrete potential energy settings for eliciting the patellar tendon reflex. The attached reflex hammer can be precisely aimed to strike a specific target of the patellar tendon. The iPhone is equipped with an application for acquiring the acceleration waveform and conveying the data wireless by email. The iPhone application includes a temporal delay for ease of use. Two audio tones inform the operator that the recording of the acceleration waveform has begun and ended.

In order to demonstrate the capacity for the iPhone wireless accelerometer application to quantify the patellar tendon reflex response in a remote location without wireless Internet connectivity, the experiment was conducted in Running Springs, California, which is a town in the San Bernardino Mountains. The data post-processing facilitated with a Matlab program for automating feature extraction was performed in Irvine, California, which is a city located in Orange County of California.

III. EXPERIMENT

A software application enabled an iPhone to function as a wireless accelerometer platform for quantifying the response of the patellar tendon reflex. A potential energy derived impact pendulum secured to a reflex hammer consistently elicited the patellar tendon reflex. Engineering proof of concept was demonstrated by evaluating a subject with healthy patellar tendon reflex of the respective leg. The acceleration waveform was sampled at 100Hz. The following experimental protocol was applied to obtain 30 trials.

1. Secure the iPhone functioning as a wireless accelerometer application through an elastic band, such as a sock, above and adjacent to the lateral malleolus. Position the iPhone so that the top is oriented superior, and align the iPhone from top to bottom parallel to the tibia.
2. Aim the reflex hammer of the potential energy impact pendulum level to the tibial tubercle.
3. Activate the iPhone wireless accelerometer application for recording the acceleration waveform of the patellar tendon reflex response.
4. Retract the reflex hammer attached to the potential energy impact pendulum 30 degrees relative to gravity vector.
5. Release the reflex hammer attached to the potential energy impact pendulum.
6. Convey the acquired acceleration waveform wirelessly through email.
7. Incorporate a 15-second delay before the next trial.

IV. RESULTS AND DISCUSSION

The iPhone wireless accelerometer application for quantifying the patellar tendon reflex response is presented in Figure 1. The impact pendulum attached to a reflex hammer enables discrete potential energy settings, such as 30 degrees relative to gravity, with precise and consistent targeting of the patellar tendon. Figure 1 demonstrates the simplicity of the anatomical mounting scheme of the iPhone above and adjacent to the lateral malleolus. The primary theme for the implementation of the iPhone wireless accelerometer application for the quantification of reflex response is to minimize requirement for specialized resources.

The mountainous remote location for the experiment and the city environment for data post-processing demonstrate the capability of the application to be operated in rural settings. With cell phone coverage the reflex response data is conveyed by wireless transmission through email using a Microsoft Excel Comma-Separated-Value file. A Matlab program automates feature extraction of the reflex response maximum acceleration. The automation software greatly reduces and simplifies post-processing tasks. Figure 2 illustrates a sample patellar tendon reflex acceleration waveform based on the magnitude of the orthogonal acceleration vectors. The maximum acceleration reflex response parameter is summarized in Table 1.

The experiment consists of 30 reflex response trials, which demonstrated considerable accuracy and consistency. The mean of the maximum acceleration reflex response was 1.89g's with a standard deviation of 0.16g's resulting in a coefficient of variation of 0.08. The maximum acceleration of the reflex response was bound with a 96% confidence level with a 4% margin of error about the mean. The quantified reflex strategy using an iPhone as a wireless accelerometer application shows considerable potential for diagnostics of the tendon reflex as a preliminary neurological evaluation further advancing smartphones in biomedical technology.

V. Conclusion

Smartphones, such as the iPhone, hold considerable opportunity for the evaluation of patient status. An iPhone equipped with an application to function as a wireless accelerometer application has demonstrated the ability to characterize the acceleration waveform of the patellar tendon reflex response with a considerable degree of accuracy and consistency. The reflex response acceleration waveform data was transmitted wirelessly through email, and an automation program feature extracted data. The quantified reflex application incorporates a potential energy impact pendulum attached to a reflex hammer for delivering precise input and targeting to elicit the patellar tendon reflex. The maximum acceleration of the patellar tendon reflex response was bound with a 96% confidence level with a 4% margin of error about the mean based on a sample size of 30 trials. The quantified reflex strategy can be evaluated remote to the resources for post-processing diagnostics. The successful initial proof of concept from an engineering perspective warrants greater testing and evaluation for the iPhone wireless accelerometer application with potential energy input for reflex quantification.

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