Implementation of a smartphone as a wireless gyroscope application for the quantification of reflex response

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***Abstract*— The patellar tendon reflex constitutes a fundamental aspect of the conventional neurological evaluation. Dysfunctional characteristics of the reflex response can augment the diagnostic acuity of a clinician for subsequent referral to more advanced medical resources. The capacity to quantify the reflex response while alleviating the growing strain on specialized medical resources is a topic of interest. The quantification of the tendon reflex response has been successfully demonstrated with considerable accuracy and consistency through using a potential energy impact pendulum attached to a reflex hammer for evoking the tendon reflex with a smartphone, such as an iPhone, application representing a wireless accelerometer platform to quantify reflex response. Another sensor integrated into the smartphone, such as an iPhone, is the gyroscope, which measures rate of angular rotation. A smartphone application enables wireless transmission through Internet connectivity of the gyroscope signal recording of the reflex response as an email attachment. The smartphone wireless gyroscope application demonstrates considerable accuracy and consistency for the quantification of the tendon reflex response.**

Index terms—iPhone, smartphone, iPhone application, gyroscope, wireless gyroscope, reflex, reflex quantification, patellar tendon reflex

I. INTRODUCTION

The patellar tendon reflex is an integral aspect of the standard neurological assessment. The neural circuitry of the tendon reflex is derived from structures of the central and peripheral nervous systems. Features of the reflex response provide useful insight regarding health status of a subject. Dysfunction to the tendon reflex response can enable a clinician with a diagnostic acuity for referral to specialized medical resources. A tendon reflex quantification strategy can be applied to establish that the reflex response is within normal or abnormal bounds [1,2,3,4].

Traditional approaches for quantifying tendon reflex response incorporate an ordinal scale, such as the National Institute of Neurological Disorders and Stroke (NINDS) Myotatic Reflex Scale and Mayo Clinic scale. The ordinal approach is applied with a clinician applying expert, however subjective, interpretation of the reflex response based on manual elicitation of the tendon reflex. However, the ordinal scale method's ability to quantify reflex response had been a subject of controversy [2,3,4,5,6].

LeMoyne developed a novel alternative for quantifying reflex response. A potential energy impact pendulum with an attached reflex hammer evokes the patellar tendon reflex. The impact pendulum imparts a discrete potential energy setting to a predetermined target of the patellar tendon. The patellar tendon reflex response is quantified by a wireless accelerometer mounted proximal to the lateral malleolus [3,4,7,8,9,10].

Further endeavors by LeMoyne successfully evaluated the feasibility of a smartphone (iPhone) and portable media device (iPod). Both devices feature a software application that can record the acceleration waveform of the reflex response and subsequently transmit the data as a file through email based on wireless Internet connectivity. The implications of the devices are the capacity to measure a subject's reflex response at a convenient location and wirelessly convey by Internet connection the data package anywhere else in the world to post-processing resources also with wireless Internet capability for expert diagnostic interpretation and post-processing [11,12].

Although the accelerometer signal provides an inherently useful strategy for quantifying the reflex response, other sensor signals may enable more intuitively perceptive measurements for the patellar tendon reflex response. Optoelectronic motion capture and the electro-goniometer can provide useful clinical data, such as the angular rotation rate about a joint [3,4,13]. The standard inertial measurement unit can consist of both the accelerometer and gyroscope. For example the smartphone, such as the iPhone, is also equipped with a gyroscope that can measure angular rotation rates [14].

The objective of the research is to apply the gyroscope sensor of the iPhone, a standard smartphone, to quantify the patellar tendon reflex response from the engineering proof of concept perspective. The gyroscope recording is conveyed wireless through Internet connectivity for post-processing. The post-processing is automated through a Matlab program.

II. BACKGROUND

A. Neurological organization of the tendon reflex

The tendon reflex neural circuitry globally encompasses the peripheral and central nervous systems. The brisk tap of the patellar tendon excites the muscle spindles transmitting a neural signal through the 1a afferent neurons for integration at the spinal cord. Supraspinal modulation induces a descending influence on the character of the reflex signal.

Manuscript received April 5, 2014.
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Efferent neurons convey the reflex signal back to the pertinent muscle inducing a contraction. Deviation from the ordinary reflex response can infer a disturbance to the health of the nervous system [1,3,4,15].

B. *Ordinal scale approach for tendon reflex quantification*

Two predominant ordinal scales for tendon reflex quantification are the NINDS Myotatic Reflex Scale (five-components) and Mayo Clinic scale (nine-components) [3,4,5,6]. Litvan evaluated the NINDS Myotatic Reflex from an intra-observer and inter-observer perspective, and the findings supported substantial to near perfect reliability and moderate to substantial reliability, respectively [5]. Conflicting research findings by Manschot make the reliability of the ordinal scale strategy a topic of controversy. For both the NINDS Myotatic Reflex Scale and Mayo Clinic scale the interobserver perspective never exceeded the threshold of fair agreement [6].

C. *Sensor system strategy for quantifying tendon reflexes*

Techniques have been developed for the quantification of tendon reflexes through the implementation of sensors. Motorized applications to coherently elicit the tendon reflex have been applied with electromyogram (EMG) recordings to quantify the reflex response [3,4,16,17,18]. Quantification devices have applied actuator inspired devices for evoking the tendon reflex with a means for measuring the reflex response through electro-mechanical sensors, such as a strain gauge [3,4,19,20,21]. Through manually applied instrumented reflex hammers, the reflex response of the patellar tendon has been quantified by the force and torque features of the reflex response [3,4,22,23]. The reflex response has also been quantified through wired triaxial accelerometers and optical electronic systems [3,4,24,25,26,27]. Wireless accelerometer systems for quantifying reflex response possess clear advantages over these described sensor applications, such as simplified mounting and application, minimal mass encumbrance, and robust signal transmission without line of sight or tethering requirements [3,4,7,28].

D. *Wireless quantified reflex system*

The wireless quantified reflex device developed by LeMoyne offers multiple advantages over other system for quantifying the patellar tendon reflex. The device established by LeMoyne applies a potential energy impact pendulum attached to a reflex hammer that can be precisely targeted to an aspect of the patellar tendon. The reflex response was measured through a wireless accelerometer, with no line of sight constraint requirement, such as for an optical electronic system, and no encumbrances, such as tethering by wire. The wireless accelerometer node was mounted proximal to the lateral malleolus of the ankle joint constituting an easily identifiable anatomical mounting position. The acceleration waveforms acquired by the wireless accelerometers were conveyed by wireless connection to a local PC [3,4,7,8,9,10]. With a tandem and synchronized accelerometer placed on the potential energy impact pendulum, reflex latency was obtained. The wireless quantified reflex device tested and evaluated by LeMoyne demonstrated the capacity to accurately, reliably, and reproducibly quantify reflex response and latency [3,4,9].

E. *Evolution to a smartphone (iPhone) and portable media device (iPod) for quantifying reflex response*

For further evolution of the wireless quantified reflex strategy devices with more affordable, easier to operate, and broader wireless coverage were tested and evaluated. The wireless quantified reflex strategy for the smartphone, such as an iPhone, and portable media device, such as an iPod, retained the use of the potential energy impact pendulum attached to a reflex hammer capable of imparting discrete and precise levels of stimulation to a specific and targeted aspect of the patellar tendon reflex. The patellar tendon reflex response was quantified first by a portable media device, such as the iPod, and second by a smartphone, such as the iPhone, with a potential energy impact pendulum [11,12].

A software application available to both the iPod and iPhone enables the recording of an acceleration waveform sample, which can then be transmitted wireless through Internet connectivity as an email attachment file. The implications are the experiment and post-processing site can be remotely located any where in the world with a wireless Internet connection. Preliminary evaluation of the iPod for wireless quantified reflex strategy of the patellar tendon demonstrated a high level of accuracy and consistency for obtaining the reflex response maximum acceleration [11].

With the software application portable to the iPhone, a ubiquitous smartphone, testing and evaluation of the iPhone through the wireless quantified reflex strategy was successfully conducted. The iPhone is equipped with a broader coverage range on the scale of cellphone coverage. Therefore, the application was tested and evaluated in a rural mountainous area. During post-processing in an urban location, a Matlab software automation program was applied to substantially reduce feature extraction of the acceleration waveform, such as the maximum of the reflex response. Based on the preliminary data from an engineering proof of concept level, the iPhone applied to the wireless quantified reflex strategy exhibited a high level of accuracy and consistency for obtaining the maximum of the reflex response acceleration waveform [12].

F. *Smartphone (iPhone) as a wireless gyroscope platform for quantifying reflex response*

The current sensor platform for the iPhone, a standard smartphone, consists of both an accelerometer and gyroscope. The acceleration waveform provides useful quantified data, such as the maximum acceleration of the reflex response; however, other sensor data may be more clinically intuitive. The gyroscope signal of the reflex response can provide the maximum angular rate of rotation about the knee joint, which is similar to the angular rate of rotation that can be acquired from optoelectronic motion capture and the electro-goniometer devices [12,13,14].

A software application enabled the gyroscope signal to be easily recorded by a smartphone, such as the iPhone. The software application incorporated a temporal delay, which facilitated the elicitation of the potential energy impact pendulum attached to a reflex hammer that evokes the patellar tendon reflex with a precise amount of stimulation. The broad wireless footprint of the smartphone enabled the recording of a series of patellar tendon reflex trials to occur at a location of the subject's convenience. The waveform of the gyroscope signal was transmitted wireless as an email attachment file through Internet connectivity. A Matlab program automated post-processing of the gyroscope data.

III. EXPERIMENTATION

The smartphone (iPhone) is capable of functioning as a wireless gyroscope platform for quantifying the angular rotational rate of the patellar tendon reflex response. The impact pendulum connected to a reflex hammer evokes the patellar tendon reflex response with a consistent amount of potential energy. Engineering proof of concept was achieved by evaluating a subject with healthy patellar tendon reflex for the selected leg. The wireless gyroscope application was set to a sample rate 100Hz. 40 trials were acquired through the following experimental protocol:

1. Place the smartphone functioning as a wireless gyroscope platform proximal to the lateral malleolus about the ankle joint though the elastic band of a sock. Orient the smartphone parallel to the tibia with the top of the smartphone in a superior position.
2. Target the reflex hammer attached to the potential energy impact pendulum level to the tibial tubercle.
3. Initiate the smartphone wireless gyroscope application.
4. Release the potential energy impact pendulum from a relative displacement of 30 degrees from gravity vector.
5. Wirelessly transmit the gyroscope signal recording as an email attachment through Internet connectivity.
6. Apply a minimal 15 second delay before conducting the next trial.

IV. RESULTS AND DISCUSSION

The principle design emphasis for patellar tendon reflex quantification system using a potential energy impact pendulum attached to a reflex hammer and smartphone wireless gyroscope application is to minimize requirements for specialized resources as illustrated in Figure 1. The impact pendulum enables precise targeting of the reflex hammer at discrete settings of potential energy. The smartphone wireless gyroscope application facilitates recording the angular rotation rate of the reflex response in a readily accessible manner. The acquisition of angular rotation rate may provide more clinically identifiable information of the reflex response in contrast to other sensor modalities, such as the acceleration signal. Also the smartphone and associated software application are essentially simple to operate and more commercially ready compared to other angular rotation rate measurement sensors, such as electro-goniometers and optical motion capture devices.

A Matlab software program that automated the feature extraction of the reflex response gyroscope signal facilitated the post-processing of the trial data. The program acquired the maximum angular rotation rate of the reflex response. The automation program greatly reduced and simplified the task of post-processing, by contrast to manual methodologies. Relevant descriptive statistics were calculated, and data was summarized graphically. Figure 2 presents a sample of the patellar tendon reflex from the perspective of the gyroscope signal. Table 1 represents a summary of the pertinent descriptive statistics of the maximum angular rotation rate, such as mean, standard deviation, and coefficient of variation, underscoring the data's considerable consistency.

Figure 1. The experimental apparatus for quantifying the patellar tendon reflex response through a wireless gyroscope application from a smartphone. The smartphone was mounted proximal to the lateral malleolus. The potential energy impact pendulum features an attached reflex hammer.

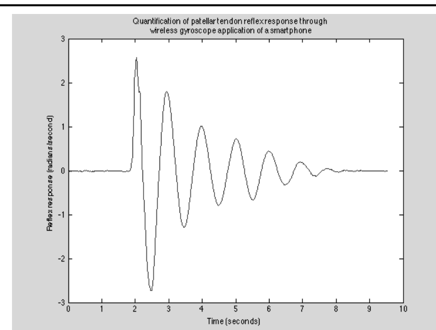

Figure 2. Representative sample trial of the gyroscope signal for the patellar tendon reflex response.

TABLE I. QUANTIFICATION OF PATELLAR TENDON REFLEX THROUGH SMARTPHONE WIRELESS GYROSCOPE APPLICATION (40 TRIALS)

Parameter	Mean (radians/ second)	Standard Deviation (radians/seconds)	Coefficient of Variation
Maximum angular rotation rate	2.53	0.27	0.11

The 40 trials of the maximum angular rotation rate of the reflex response demonstrate a considerable degree of accuracy and consistency. The mean of the maximum rate of angular rotation rate was 2.53 radians/second associated with a standard deviation of 0.27 radians/second. The coefficient of variation was calculated to be 0.11. Based on the sample size, the maximum angular rotation rate of the patellar tendon reflex response was bound with a 96% confidence level according to a 4% margin of error about the mean. The findings further emphasize the significance of the smartphone as a biomedical diagnostic tool. In essence a subject can be evaluated remotely, literally anywhere in the world, relative to the associated post-processing resources.

V. Conclusion

The smartphone has potential to substantially impact the biomedical industry as a diagnostic tool. The research findings emphasize the capacity to utilize the gyroscope sensor of the smartphone to quantify the reflex response characteristics of the patellar tendon. With a potential energy impact pendulum attached to a reflex hammer, the patellar tendon reflex was accurately evoked with high consistency. Each recording of the reflex response gyroscope signal was wirelessly conveyed as an email attachment through Internet connectivity. Post-processing was facilitated through a software program for automated feature extraction. The maximum angular rotation rate of the patellar tendon reflex response was bound with a 96% confidence level according to a 4% margin of error about the mean for a sample size of 40 trials. Future extrapolations of the smartphone as a wireless gyroscope application for the quantification of reflex response anticipate further emphasis regarding the Internet and automated feature extraction. The findings warrant greater testing and evaluation on a clinical scale.

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