Global Telehealth 2012
A.C. Smith et al. (Eds.)

doi:10.3233/978-1-61499-152-6-36

Can a Novel Smartphone Application Detect Periodic Limb Movements?

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Abstract. Background: Periodic limb movements (PLMs) are repetitive, stereotypical and unconscious movements, typically of the legs, that occur in sleep and are associated with several sleep disorders. The gold standard for detecting PLMs is overnight electromyography which, although highly sensitive and specific, is time and labour consuming. The current generation of smart phones is equipped with tri-axial accelerometers that record movement. Aim: To develop a smart phone application that can detect PLMs remotely. Method: A leg movement sensing application (LMSA) was programmed in iOS 5x and incorporated into an iPhone 4S (Apple INC.). A healthy adult male subject underwent simultaneous EMG and LMSA measurements of voluntary stereotypical leg movements. The mean number of leg movements recorded by EMG and by the LMSA was compared. Results: A total of 403 leg movements were scored by EMG of which the LMSA recorded 392 (97%). There was no statistical difference in mean number of leg movements recorded between the two modalities (p= 0.3). Conclusion: These preliminary results indicate that a smart phone application is able to accurately detect leg movements outside of the hospital environment and may be a useful tool for screening and follow up of patients with PLMs.

Keywords: Periodic leg movements, smart phone, accelerometer

Introduction

Periodic limb movements are repetitive, stereotypical and unconscious movements primarily of the lower extremities that occur in sleep [1]. PLMs in patients with otherwise unexplained hypersomnia or insomnia is known as periodic limb movement disorder (PLMD) [1-4]. The etiology of PLMs is mostly unknown, but consequences include arousals or awakenings from sleep that if frequent may cause symptoms such as unrefreshing sleep and excessive daytime sleepiness or an inability to initiate or maintain sleep. Several treatment options are available for patients with PLMD. Dopaminergic agents such as levidopa/carbidopa or ropinirole are considered first line treatment and second line medical therapy includes benzodiazepines such as clonazepam, anticonvulsant agents including sinamet and GABA agonists of which baclofen is most widely used [4,5]. Although PLMs are central to the pathophysiology of PLMD, they are mostly seen as part of other sleep disorders such as restless leg syndrome (RLS) or obstructive sleep apnoea (OSA) [1,3,6]. RLS is characterized by

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tingling sensations in the lower extremities that are most intense in the evenings and are relieved by movement of the extremities. Although only a minority of patients with PLMs has RLS, about 80% of patients with RLS do exhibit PLMs. These leg movements are mostly considered an incidental finding with uncertain clinical implications. However, in a subset of RLS patients, PLMs may cause similar symptoms to those seen in PLMD; daytime sleepiness of insomnia type symptoms. In these patients, the therapeutical options are similar to those in PLMD [1,3,7]. Obstructive sleep apnoea (OSA) is a prevalent sleep disorder in which the patency of the upper airway is repetitively compromised. Complete or partial airway closures occur mostly due to central obesity that compresses the airway, soft tissue or the tongue blocking airflow and/or inadequate ability of airway dilating muscles to maintain patency. When the upper airway is compromised in sleep, an arousal or awakening occurs as a rescue response to prevent prolonged oxygen desaturation and secondary to increasing respiratory effort. As part of such arousals, jerky limb movements are often seen [8]. Although they are secondary to airway obstruction and not considered to contribute to the negative health consequences or symptoms of OSA, they nonetheless are commonly encountered either clinically as a complaint or as a finding during the workup. PLMs of any etiology affect 4-11% of the adult population and are mostly an incidental finding that in the absence of symptoms indicating poor quality sleep are considered of limited significance [3, 7].

PLMs by definition last between 0.5 to 5 seconds and are characterized by dorsiflexion of the ankles and toes with flexion of the knee and hip. They are typically unilateral but may occur bilateral [1,3,7]. Although common and associated with a wide range of negative health implications, there is currently no practical way to screen for PLMs or follow the treatment efficacy of therapy aimed at reducing PLMs. The diagnostic gold standard for detecting PLMs is a polysomnographic evaluation which includes bilateral anterior tibial electromyography (BATEMG), a surrogate marker for movement [3,9,10,11]. Although the sensitivity and specificity of this approach is excellent, polysomnography is a cost and labour intensive study that most patients undergo a limited number of times. Also, despite the reliability and technical accuracy of this approach, another limitation to its usefulness may be intra-individual night-to-night variability in the frequency of PLMs in patients with movement sleep disorder—a single study might not be enough to establish this diagnosis [12]. Actigraphy is an alternative method that has been validated several times for the diagnosis of PLMs. It is less resource-consuming than a PSG, however, this approach still requires a device to be delivered to and retrieved from a patient as well as interpretation of the acquired data [13,14,15].

A growing percentage of the population owns a smart mobile phone equipped with an accelerometric sensor that detects movement [16,17,18]. The accelerometer detects movement in three axes and is used for multiple purposes including proper orientation of the screen when the mobile phone is turned. The aim of this study was to develop an LMSA that accurately detects leg movements remotely by exploiting the built-in accelerometer of a smart phone. Such an application could allow for inexpensive screening and follow-up for patients from their home environment. Primarily, the intent with such an application would be to screen for PLMD and to follow response to medical therapy aimed at reducing limb movements in patients with this condition as well as patients with RLS. A secondary possible use would be to screen remotely for

OSA if a specific pattern of leg movements could be identified as a signature for this condition.

1. Methods

1.1. Programming

A preliminary LMSA was created for iOS 5.x in Xcode incorporated into an iPhone 4S (Apple INC). All code was written in Objective-C. The built-in triaxial accelerometer was programmed to detect movement in a continuous fashion. A numerical entity that represented acceleratory force in any or several of the three axes was created. This measure of movement was set to a threshold level of 0.2 after preliminary comparison to BATEMG. A leg movement was defined as any movement generating a value of 0.2 or more with duration of 0.5 to 10 seconds (in analogy with American Academy of Sleep Medicine scoring criteria). The LMSA was programmed to store leg movements as well as the time of occurrence and not to store movement that did not meet above criteria (Figure 1 and 2).

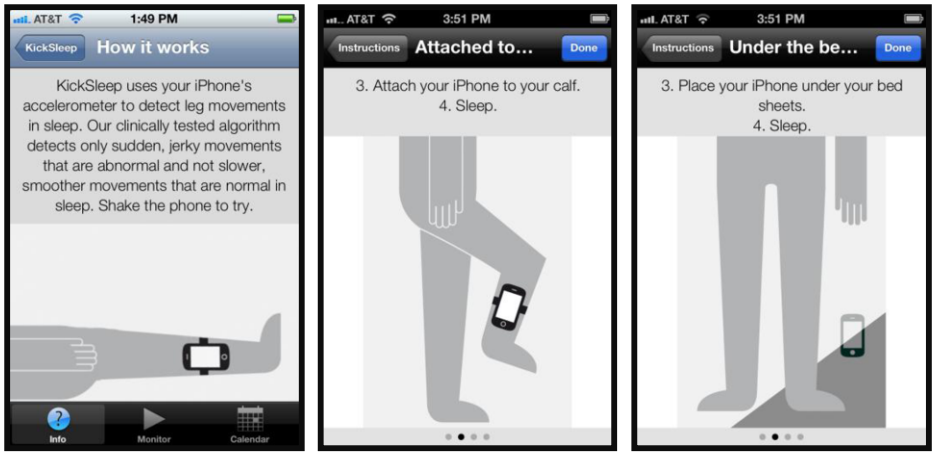

Figure 1. Screenshots demonstrating user instructions

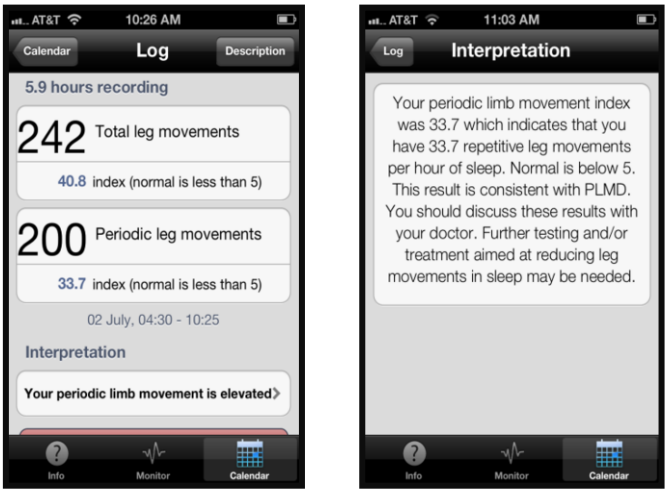

Figure 2. Screenshots – showing summary of data collected

1.2. Data acquisition

A healthy 32 year old male subject was admitted to the sleep laboratory and underwent simultaneous left lower extremity EMG and LMSA measurements of voluntary stereotypical leg movements. Leg movements were measured with an iPhone 4S attached to the lateral left mid-calf with an armband as well as below the bed sheet within ten inches of the left foot. Leg movements were scored as per the American Academy of Sleep Medicine Manual by the investigators prior to assessing the results of the LMSA. The subject was instructed to produce a total of 400 leg movements; 50 leg movements in the supine, prone, left recumbent and right recumbent position respectively with the iPhone either attached to the calf or placed under the bedding.

2. Results

403 leg movements were scored by EMG of which the LMSA recorded 392 (97%) as shown in Table 1. There was no difference in the mean number of recorded leg movements (50.4 +/- 0.51 vs. 49.0 +/- 3.7 p=0.3). There was no difference between the mean number of leg movements recorded with the iPhone attached to the calf (50.3 +/- 0.5 vs. 49.0 +/- 4.1 p=0.15) or under the bed sheet (50.5 +/- 0.58 vs. 49.0 +/- 5.4 p=0.6). With the iPhone attached to the calf, 196/201 leg movements were recorded as follows; 49/50 supine, 50/50 prone, 47/51 left decubitus and 50/50 right decubitus position. With the iPhone positioned under the bedding, 196/202 leg movements were recorded as follows; 41/51 supine, 51/50 prone, 53/50 left decubitus and 51/51 right decubitus position.

Table 1. Leg movements scored by LMSA and EMG.

Leg movements in the following position	iPhone attached to calf LMSA / EMG (196/201)	iPhone under bed sheet LMSA / EMG (196/202)
Supine	49/50	41/51
Prone	50/50	51/50
Left decubitus	47/51	53/50
Right decubitus	50/50	51/51

3. Discussion

Smart phone applications are becoming increasingly used in clinical practice. A few examples include heart rate monitoring, activity monitoring and fundoscopic eye examinations [19,20,21]. To the authors' knowledge, however, this is the first such application developed to detect repetitive leg movements in sleep which occur in a significant portion of the adult population and are associated with several sleep disorders. As per the American Academy of Sleep Medicine guidelines, a limb movement is to be scored if it meets certain criteria; An 8 mV increase in EMG voltage above resting EMG and duration of 0.5 to 5 seconds. PLMs can be scored if 4 or more such movements are seen separated by 5 to 90 seconds. Currently, a PSG or actigraphy are the only established modalities used to detect pathological limb movements. Both have limitations described above. This proof of concept study demonstrated that a smart phone application was able to accurately record leg movements and may be useful as a screening tool for PLMs as well as to follow the impact of treatment aimed directly or indirectly at decreasing PLMs. This will allow for remotely diagnosing patients in their home environment and replacing costly and resource consuming hospital-based testing. This approach would be particularly useful in a setting where patient consultations and medicine prescriptions are also done remotely, thereby eliminating further barriers to proper management of patients suffering from PLMs.

The most obvious use for this LMSA would be in the diagnosis and follow up of patients with PLMD, the only sleep disorder thought to result solely from abnormal limb movements in sleep. Diagnostic criteria for PLMD include symptoms such as unexplained sleepiness or insomnia with a periodic limb movement index above 5 (5 or more PLMs recorded per hour of sleep). In addition to detecting limb movements, the LMSA also has the capacity to calculate the periodic limb movement index which simplifies interpretation of results for the user as well as the health care provider.

Other potential uses include sleep disorders in patients with RLS. Most patients with RLS also have PLMs which causes some to suffer from sleepiness and unrefreshing sleep. Although limb movements can be accurately identified by PSG, there is currently no feasible way to follow treatment efficacy of medications intended to decrease PLMs in patients with RLS. Long term and interval examination of response to medications in RLS constitutes another clinical use of the LMSA. Finally, OSA is also associated with limb movements that occur as part of an arousal response to airway obstructions [22,23]. The pattern of limb movements in OSA patients has not been well studied but may offer a novel way of screening for this common disorder. Specifically, OSA is worsened in REM sleep which typically constitutes about 20% of sleep in an adult and more in children [24]. REM sleep is characterized by a high frequency of dreaming. Skeletal muscles with the exception of the diaphragm and extraocular muscles are paralysed in this sleep stage. This paralysis is considered a safety mechanism to ensure that dream enactment does not occur. A negative side effect of the disabling of skeletal muscles is a more collapsible airway secondary to paralysis of upper airway dilating muscles. REM sleep occurs in cycles that are usually about 40 minutes in duration and occur with increasing frequency towards the early morning. Limb movements that occur as part of a rescue response to airway obstructions would thus be expected to occur with increasing frequency in REM sleep. This may offer a feasible way to exploit the pattern of PLMs to identify OSA remotely. With a global population that continues to become more and more obese and more at risk of OSA, this approach may be particularly valuable.

Although the preliminary results of this study need to be validated, they nonetheless indicate that this novel diagnostic approach may overcome current barriers to optimal care for a significant subset of patients with sleep disorders.

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