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Measurement properties of a new wireless electrogoniometer for quantifying spasticity during the pendulum test in ARSACS patients

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ABSTRACT

Introduction: Autosomal recessive spastic ataxia of Charlevoix/Saguenay (ARSACS) is a neuromuscular disorder that induces spasticity in lower limbs. The Wartenberg pendulum test is a classical method of assessing lower limb spasticity based on the dynamics of the pendular leg motion. However, in its original form, this test only provides subjective results and do not allow accurate assessment of spasticity.
Methods: Thirteen ARSACS patients were assessed using a new wireless electrogoniometer to measure spasticity by quantifying oscillation amplitudes and relaxation indices during the Wartenburg pendulum test. The validity of the instrument was evaluated by comparing its measurements to a known precise goniometer whereas discriminant validity was evaluated by comparing healthy participants and ARSACS patients. Reliability was measured using intraclass correlation (ICC) between pendulum test scores obtained at different moments in time.
Results: Data from different tests show that the proposed device is accurate (standard error of measurement of 0.0005°), discriminates healthy and ARSACS patients (most variables have $p = 0.00$) and provides repeatable results (significant ICC usually higher than 0.64 and $p < 0.05$).
Discussion: The proposed tool allows the clinician to analyze pendulum oscillation amplitudes and ratios and thus, provide an index of spasticity for the patients affected by ARSACS. This is important as the original procedure is only evaluated visually and the progression cannot be detected until the condition changes drastically. Thus, the system proposed meets the requirements of being useful, precise and user-friendly in the evaluation of patients in a research as well as a clinical environment.

1. Introduction

Autosomal recessive spastic ataxia of Charlevoix/Saguenay (ARSACS) is a neuromuscular disorder that induces spasticity in lower limbs [1], progressive ataxia and peripheral neuropathy with variable intensity of these three components [2]. Spasticity is defined as a motor disorder characterized by a velocity-dependent increase in tonic stretch reflex (muscle tone) associated with exaggerated tendon reflexes secondary to hyperexcitability of the stretch reflex [3]. These symptoms appear as early as during the gait learning process, which may be delayed to the age of 18 months [4]. The respective evolution of ataxia and spasticity is highly variable among patients. Some individuals present severe spasticity in their early twenties while others are much less affected even beyond the age of 40. However, the assessment of spasticity is a real challenge in this population. Over the years, certain tests [5–7] have been used to assess the severity of spasticity but none are entirely appropriate in regards to their metrological properties including validity and reliability [8]. This is particularly true for ARSACS since no data from the literature have been presented.

In an effort to resolve this issue, several researchers have proposed the use of the Wartenberg pendulum test [9–17]. This test consists of stabilizing the thigh of the patient while allowing the lower leg to oscillate freely like a pendulum. By examining the movement described by the lower leg, it is possible to qualitatively detect the presence of spasticity. In addition, by extracting the angle measurements at the knee and by processing the data, it is also possible to provide quantitative results that can be interpreted by health professionals. In the past, it has been shown that joint-angle measurement can be achieved using a number of approaches including video capture [9,13] and more recently, inertial measurement units (IMUs) which include measurements of linear acceleration (accelerometer) and angular velocity (gyroscope) [18–25]. Video capture is an accurate approach that typically consists of placing reflective markers at different areas around the joint and making angle measurements from the captured video. While these tests produce good results, they are expensive and time consuming

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because of the preparation process and the required video analysis that must be performed afterwards. In contrast, IMUs are low cost, require very little setup and produce results that are easily analyzed. For these reasons, the focus of this work is on the use of IMUs to evaluate spasticity in ARSACS. IMUs, which typically include accelerometers and gyroscopes, have previously been proposed for joint-angle measurements. However, in the case of the pendulum test in a clinical setting, the system requirements are different: they often need to be portable, cost-friendly and short administration time. In addition, since clinical settings generally have limited available technical support, the use of the device should be simple, straightforward and quickly deployable.

The purpose of this paper is threefold: 1) to describe a simple tool for the Wartenberg pendulum test and to evaluate its discriminant validity by comparing measurements of ARSACS and healthy individuals 2) to describe key measurement properties in order to better evaluate ARSACS patients 3) to assess test-retest reliability of the measurements made with the wireless electrogoniometer.

2. Methods

2.1. Design of the proposed system

The architecture of the proposed system is presented in Fig. 1a. On the left of the figure is described the portion of the system to be attached to the lower leg of the patient. The proposed system uses an accelerometer (ADXL345, Analog Devices) and a gyroscope (L3G4200D, ST Microelectronics) to calculate the joint-angle with a frequency of 100 Hz.

The system was implemented on a custom designed printed circuit board (PCB) as shown in Fig. 1b and is powered by two AA batteries.

To calibrate the device, a digital goniometer (Model 01130, Lafayette Instrument Company, IN, USA), was used. It consists of two rods that are connected together on one end and that are free to rotate around that point of contact. The point of contact contains a precise potentiometer which displays the angle of the rotation on the LCD screen. The proposed system is attached to the digital goniometer in a way that both systems measure the same angle. To calibrate the system, several angle measurements were taken by both systems in order to adjust parameters in the program running on the microcontroller.

Numerous pendulum tests were performed at the Neuromuscular Clinic at the Jonquière hospital and it was found that a timespan of about 15 s is necessary to complete the measurements. Additional tests were also performed to determine the ideal position to attach the device. It was found that the position of the device with respect to the point of rotation did not have a measurable impact on the observed angles. It was therefore decided, for convenience, to attach the device to an ankle strap adjacent to the Achilles tendon (Fig. 1c).

2.2. Participants

Forty-five individuals (24 males and 21 females) participated in this research (mean age 25.6 ± 7.3 years). Of these participants, thirteen were diagnosed with ARSACS (6 males and 7 females mean age 29.3 ± 9.03 years). Neurological assessment of these patients using the modified Ashworth scale (MAS) [5] revealed that 4 participants showed mild spasticity, 8 were moderate and 1 was considered severe.

Included in the healthy group, were individuals who are exempt of lower leg injuries. Excluded from the healthy group were participants who suffered from any injuries or neuromuscular conditions that could alter the motion of a swinging lower limb. The inclusion criterion for the ARSACS group was having received a diagnosis of ARSACS confirmed by genetic analysis. All subjects gave their informed consent to the procedures, which were approved by the university ethics committee.

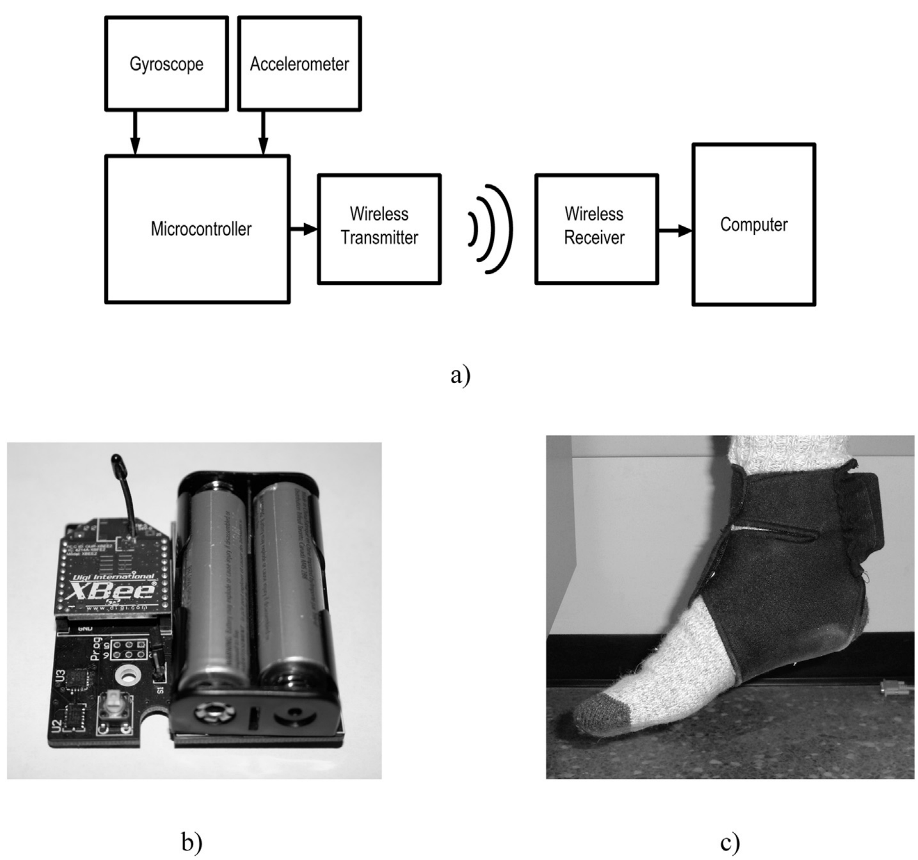

Fig. 1. a) Block diagram of the proposed design b) Photograph of the system c) Photograph of the ankle strap.