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Review

Accelerometry: A technique for quantifying movement patterns during walking

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Abstract

The popularity of using accelerometer-based systems to quantify human movement patterns has increased in recent years for clinicians and researchers alike. The benefits of using accelerometers compared to more traditional gait analysis instruments include low cost; testing is not restricted to a laboratory environment; accelerometers are small, therefore walking is relatively unrestricted; and direct measurement of 3D accelerations eliminate errors associated with differentiating displacement and velocity data. However, accelerometry is not without its disadvantages, an issue which is scarcely reported in gait analysis literature. This paper reviews the use of accelerometer technology to investigate gait-related movement patterns, and addresses issues of acceleration measurement important for experimental design. An overview of accelerometer mechanics is provided before illustrating specific experimental conditions necessary to ensure the accuracy of gait-related acceleration measurement. A literature review is presented on how accelerometry has been used to examine basic temporospatial gait parameters, shock attenuation, and segmental accelerations of the body during walking. The output of accelerometers attached to the upper body has provided useful insights into the motor control of normal walking, age-related differences in dynamic postural control, and gait patterns in people with movement disorders.

Keywords: Acceleration; Locomotion; Posture; Stability

1. Introduction

An alternative approach to conventional gait analysis techniques, such as optoelectronic and force plate motion analysis, involves the use of accelerometers attached to the body for the purpose of examining segmental accelerations during walking. The present day benefits of using accelerometers to assess movement include: the low cost compared to more commonly used gait laboratory equipment; testing is not restricted to a laboratory environment; accelerometers are small which enables subjects to walk relatively unrestricted; a variety of accelerometer designs offer diversity of dynamic range and sensitivity; and direct measurement of 3D accelerations eliminates errors associated with differentiating displacement and velocity data. This paper reviews the use of accelerometers in quantifying movement patterns during walking, and examines the history of accelerometer applications in studying locomotion.

2. The accelerometer

There are several classes of commercial accelerometers such as fluid, reluctive, servo, and magnetic [1]. However, classes that are more common to the investigation of human motion are strain gauge, piezoresistive, capacitive, and piezoelectric. The basic mechanism underlying acceleration measurement is often described in terms of a mass–spring system, which operates under the principles of Hooke's law

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($F = kx$), and Newton's 2nd law of motion ($F = ma$). When a mass–spring system is submitted to a compression or stretching force due to movement, the spring will generate a restoring force proportional to the amount of compression or stretch. Given that mass, and the stiffness of the spring can be controlled, the resultant acceleration of the mass element can be determined from characteristics of its displacement:

$$F = kx = ma, \quad \text{thus} \quad a = \frac{kx}{m}$$

In practice, acceleration is quantified using a number of techniques depending on the accelerometer class. For example, in a capacitive accelerometer, a silicon mass element is surrounded by an array of paired capacitors on opposite sides of the accelerometer housing. As the mass element reacts to movement, an imbalance is created between opposing capacitors that produce an electrical output signal proportional to the magnitude of the applied acceleration. Regardless of accelerometer class, the relationship between the electrical output and a corresponding reference value of acceleration must be determined by calibration procedures performed under specific conditions.

2.1. Calibration

The two primary means of calibrating an accelerometer are via static or periodic calibration. Static calibration typically involves comparing the output of a stationary accelerometer to a known constant acceleration (e.g. gravity). The output of a stationary accelerometer's sensing axis aligned with the global vertical must correspond to -1 g (or -9.81 m s^{-2}), and 1 g when inverted. Once raw accelerometer output has been obtained for the static conditions of -1 and 1 g, a two-point linear calibration can be performed which transforms the raw output to units of acceleration. Calibration procedures similar to the two-point method include the zero-span and slope-intercept methods, both of which assume linearity between acceleration and the raw output. Periodic calibration is more time consuming than static calibration and requires specialised equipment such as a shaker. Periodic calibration involves harmonic forcing of the accelerometer to determine the relationship between the known acceleration harmonics and the raw output of the accelerometer [2,3]. The benefit of performing a periodic calibration is that the accuracy of acceleration measurement may be enhanced, particularly at a range of amplitudes and frequencies that could be expected under real-world conditions [3].

The use of commercially produced monitors that employ principles of accelerometry to quantify physical activity and energy expenditure has gained popularity in recent times. Monitors such as the Intelligent Device for Energy Expenditure, ActiGraph, and the TriTrac-R3D, calibrate raw output from accelerometers attached to the body (often referred to as accelerometer 'counts') to some meaningful indicator of physical activity or energy [4–6]. A limitation of some commercial monitors is that data is generated with proprietary software featuring algorithms and assumptions unknown to the user. As a consequence, it may be necessary to develop user-specific calibration procedures, or undertake validity and reliability studies to determine if, and how, a monitor will perform during specific movement tasks [7,8]. At present there are no standardised procedures for using accelerometer-based monitors to assess physical activity. However, international congresses dedicated to objective physical activity monitoring have made efforts to develop best practices for future research [9]. Although commercially available energy expenditure and physical activity monitors have been valuable in quantifying movement

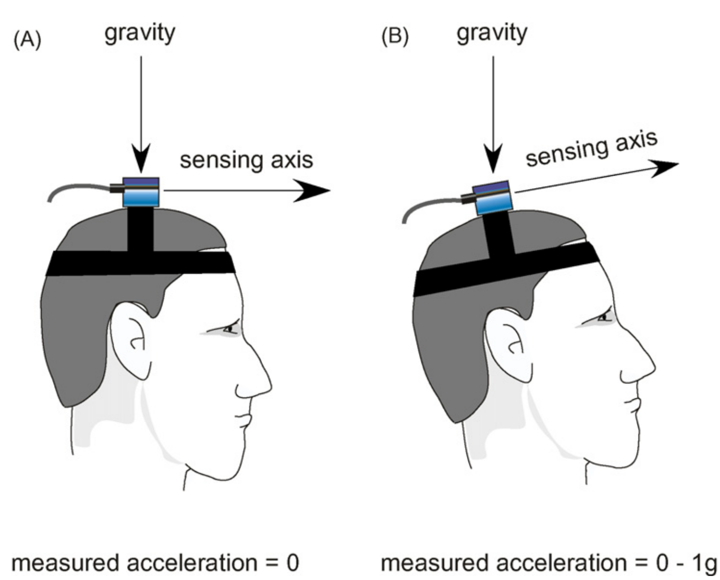

Fig. 1. If an accelerometer remains stationary in the global coordinate system, the output of a sensing axis aligned with the global horizontal will not have an inertial or gravitational component (A). Altering the orientation of the sensing axis so that it is no longer perpendicular to the gravitational vector will result in a measured static acceleration (B).