REVIEW

Accelerometers in rehabilitation medicine for older adults

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Abstract

Recent technological developments have led to the production of inexpensive, miniature accelerometer sensors with potential for use in a clinical setting. These sensors can provide reliable information on mobility and objective measurement of gait. They are currently used mainly in a research setting; however, with recent advances, incorporation into clinical practice is possible. For illustrative purposes this paper describes some current applications of accelerometers in gait and balance evaluation, falls risk assessment and mobility monitoring. Accelerometers provide quantitative measures of gait, they are capable of identifying specific gait changes in older adults and in fallers and can be used to objectively quantify ambulatory activity levels. Accelerometers have many potential uses in monitoring of patients in rehabilitation. They provide an added objective and quantitative dimension to gait analysis when combined with clinical assessment. They have the potential in the future to stratify falls risk facilitating early initiation of appropriate therapeutic intervention, thus reducing further falls. The challenge facing clinicians and biomedical engineers is to further harness this technology making it part of everyday clinical practice.

Keywords: accelerometer, rehabilitation, gait, mobility, falls, elderly

Introduction

Using accelerometers to assess human body movement was first proposed in the 1950s [1, 2]. However, these devices were expensive, bulky and unreliable, therefore, unsuitable for ambulatory monitoring techniques. However, in the past decade a revolution has taken place in the fabrication of accelerometers, primarily driven by the automotive industry for use in air-bag release systems. This new generation of accelerometers was designed to satisfy the extremely stringent quality and reliability requirements of that industry, as well as meeting the demand for high-volume, low-cost manufacturing. As a consequence accelerometers are now available as miniature, inexpensive ($5.80), low-power devices [3] providing the capability for quantitative, portable measurement of balance and gait changes in the elderly when combined with modern ambulatory recorders (Figure 1).

Accelerometers measure both static (e.g. gravity) and dynamic (e.g. vibration) acceleration. They consist of a moveable bar suspended on micro-machined springs that provides resistance against acceleration. Deflection of this bar is then converted into an acceleration reading. Three accelerometers can be incorporated into a single device providing information on three-dimensional movement (tri-axial accelerometer).

To illustrate the potential of these devices, this paper reviews some current applications of accelerometers in gait and balance evaluation, fall risk assessment and mobility monitoring. It discusses some of the deficiencies in existing research and highlights the potential for incorporation of accelerometer based instrumentation into a rehabilitation setting.

Gait analysis and balance evaluation using accelerometers

Falls are a major source of morbidity and mortality in the elderly; the consequences include significant injury, fractures, hospital admission and even death [4]. Fear of recurrence can result in a loss of confidence, restricting domestic and social activities, leading to isolation and loneliness [5].

The cause of falling is multifactorial, however, impairments in gait and balance are often fundamental [6]. Identification of these gait abnormalities is essential to early initiation of appropriate therapeutic intervention as part of a falls prevention strategy. Accelerometers can be used to measure these gait changes [7–9].

Comprehensive and accurate gait evaluation involves a skilled clinical assessment including medical history and
examination. However, impairments in gait and balance are sometimes quite subtle and subject to individual interpretation. Studies have shown that clinical observation of gait can be subjective, qualitative and sometimes inconsistent particularly when the observers are not very experienced [10, 11, 12–14]. Therefore, simple, quantitative methods for gait and balance evaluation in older adults are desirable to provide additional objective information.

**Gait analysis**

Accelerometers are an ideal choice for evaluating variability of movement and balance providing a non-invasive, portable method of measurement. They can also accurately measure simple parameters of gait such as stride time, stride symmetry and speed [7, 15, 16]. The accelerations experienced by the trunk during walking reflect the cyclical movement of the trunk as it slows down and speeds up, rises and falls, and moves from side to side. The repeated patterns obtained with measures of acceleration contain information on the smoothness or variability of the walking pattern (index of smoothness).

The effects of ageing on the gait of normal subjects (age 20–98 years) has been assessed using trunk accelerometers [7]. In normal older subjects walking speed was slower compared with younger subjects, with a decrease in stride length and a resultant reduction in trunk movement. This would indicate a more cautious gait which may be an adaptation to reduce the risk of falling.

Head and trunk accelerometers have been used to assess accelerations during the gait cycle and a lower magnitude of acceleration was found at push-off in older adults [8].

These devices have also been used to examine the effects of ageing on head and trunk movements while walking on level and irregular surfaces [9]. It was found that older subjects exhibit a more conservative gait pattern when compared with younger subjects, which was most noticeable when walking on an irregular surface. It was characterised by reduced speed and shorter step length.

These modifications of the gait pattern indicate how ageing affects postural responses to challenging conditions and may be an adjustment to improve stability of the head and trunk.

**Balance evaluation**

Balance evaluation using accelerometers has been compared with comprehensive clinical balance assessments in healthy older subjects and idiopathic fallers [17]. For comparison a variety of clinical balance tests (variants of Romberg’s tests, heel-toe straight line walking and a functional reach test) and quantitative motor co-ordination tests (rapid stepping tests and heel-toe transitions) were performed. Acceleration amplitude data was obtained while standing on the floor or compliant foam with eyes open and eyes closed. A significant difference was found between the faller and non-faller groups for the acceleration values. However, the only clinical balance test score to distinguish between the two groups was Romberg’s test using the right leg alone with eyes open. The motor co-ordination tests showed a significant difference between the groups for rapid stepping but not for heel-toe transition. Therefore, clinical evaluation methods alone show deficiencies in identifying patients at high risk of falling.

In a separate study, the gait of older adults with and without stability problems and young subjects was compared using trunk accelerometers [18]. Subjects were classified as having stability problems if they had a history of falling or reported that they felt unsteady when standing or moving. An index of smoothness was calculated in this study and peak acceleration amplitude was measured. The older individuals with stability problems were shown to be significantly different from the younger controls and the older individuals without stability problems (i.e. less smooth trunk movement and lower peak acceleration amplitude).

These studies suggest that accelerometers are useful for assessing balance and that they detect definite abnormalities in the gait of fallers. However, as of yet they have not been prospectively investigated to determine their effectiveness in predicting future falls risk.

**Measurement of sit to stand movements using accelerometers**

The ability to stand up and sit down easily and securely is a fundamental activity of daily living. Without this, older adults are confined to their chairs, dependent on the care of others. When evaluating mobility, clinicians routinely conduct an observational assessment of the sit-stand-sit transition.

Using accelerometers it is possible to conduct an analysis of this movement cycle [19, 20]. Using accelerometer data a framework was proposed to standardise and define the events of the sit-stand-sit movement cycle in normal subjects aged 20–78 years. It was divided into two discrete phases: a rising phase and a descending phase and seven events were identified for each phase. Normal expected values were established for these events [19, 21].

Future analysis of the sit-stand-sit movement cycle should benefit from this definition of the phases and events within the cycle. An increased understanding of the cycle can be used to provide further insight into the causes behind difficulty rising, to design more suitable chairs and to devise more effective therapeutic intervention programmes.
Abnormalities of this movement cycle were shown to be capable of distinguishing between older adults with a high and low risk of falling (as determined by fall history and Tinetti balance and gait disorder scores), therefore, analysis of this movement cycle may also have an application in the evaluation of fall risk in older adults [22].

**Activity monitoring using accelerometers**

Mobility is often the primary goal of a rehabilitation programme. Physical illness in older age is regularly associated with a reduction in mobility leading to dependence in daily living. Regular physical activity is strongly associated with both physical and mental health and is a primary determinant of quality of life [23]. Increased mobility improves stamina and muscle strength.

Ambulatory activity monitoring using accelerometers is a reliable technique, providing continuous, unsupervised, objective, monitoring of mobility [24, 25].

Two accelerometers, one on the trunk and another on the leg are sufficient to distinguish between sitting, standing, lying and movement [25, 26]. Accuracy of this accelerometer-based activity monitoring during extended measurements on older adults in a rehabilitation setting showed an average activity detection accuracy of 95% [25]. An activity monitor using four accelerometers (two on the trunk and one on each thigh) can distinguish up to 20 everyday postures with high sensitivity and specificity [27]. These include various forms of sitting, standing and lying, as well as general movement, walking, ascending and descending stairs, cycling and running. This monitor has been validated on normal subjects, amputees, failed back surgery patients, congestive heart failure patients and in psychophysiological studies [28–30]. Validation studies have also been performed in a home setting [30].

A recent study has shown that a single device on the trunk comprising an accelerometer and a gyroscope is capable of accurately detecting posture change and walking in older adults [31]. Limiting the sensors to a single body site results in an even neater monitoring system.

These ambulatory measures have many potential uses including objective assessment of mobility in a clinical or home-environment over a prolonged period (‘24 hour ambulatory mobility monitor’). This can be used as an initial assessment tool or as an adjunct to monitoring progress during and after rehabilitation.

Research is currently in progress evaluating accelerometers as a fall-detection system. Falls have been distinguished from activities of daily living with 100% accuracy using a single triaxial accelerometer device on the trunk (unpublished data). This system uses mobile phone short message service (SMS) technology for alarm transmission to a carer. These features can be incorporated into an ambulatory monitoring system providing the additional security of an alarm system in the event of a fall.

**Why accelerometers?**

Many techniques are used to assess gait and mobility in a clinical setting [32]. Some of these include observation, physical science techniques (footswitches, gait mats, force plates, optical motion analysis), diaries and questionnaires.

Observational techniques are an integral part of gait and balance analysis and as discussed accelerometers can provide a useful objective adjunct. Many of the other techniques have significant disadvantages for continuous analysis. The physical science techniques are laboratory based. Footswitches (pressure sensitive devices placed in the shoe) record temporal gait parameters (e.g. stride time, speed) but are extremely unreliable. Optical motion analysis involves videotaping subjects wearing light reflective sensors. This is an expensive, impractical and time-consuming procedure. It is reasoned that accelerometers have significant advantages when compared with many of these techniques and can provide similar information in many instances.

Miniature accelerometers can be applied directly to the skin and are attached by cable to a portable recorder. Continuous recordings are stored on a memory card in the recorder and are then downloaded to a PC for analysis.

**Conclusion**

Recent technological developments have led to the production of inexpensive, miniature accelerometer sensors with potential for use in a clinical setting. These sensors can provide reliable information on mobility and objective measurement of gait and balance. Accelerometers have significant advantages when compared with other quantitative methods currently used for gait analysis which are often impractical, unreliable and costly. Accelerometers are currently used mainly in a research setting, however, with recent advances incorporation into clinical practice is possible.

This paper describes some current applications of accelerometers in gait analysis, balance evaluation, falls risk assessment and mobility monitoring. Accelerometers provide quantitative measures of gait, they are capable of identifying specific gait changes in older adults and in fallers and can be used objectively to quantify 24 hour ambulatory activity levels.

A detailed clinical examination is fundamental to gait analysis to which the accelerometer provides an ideal objective adjunct. They have been researched extensively in balance evaluation and have been validated in comparison to comprehensive clinical balance testing. However, a quantitative balance score reflecting the extent of balance impairment has not yet been developed.

Accelerometers can detect significant differences in gait between fallers and non-fallers, yet prospective studies have not been performed to assess the ability of accelerometers to predict future fall risk. Many of these studies are currently in progress with a view to developing automated systems for use in a clinical setting.

Twenty-four hour ambulatory mobility monitoring provides reliable and objective information, which can be used as an initial assessment tool or an adjunct to evaluating progress during and after rehabilitation. This is ready for incorporation into clinical practice and is already in use in the Netherlands [27].

It is envisaged that the number and type of applications for this technology will increase as its potential is recognised.
For instance, it is under investigation in patients with Parkinson’s disease as an objective assessment of mobility and tremor [33, 34] to detect changes with modifications in drug treatment. Accelerometers have also been implanted in hip prosthesis and have been shown to detect loosening [35].

The miniature nature of accelerometers has made their incorporation into clothing possible by integrating the sensors into fabric [36] which would facilitate compliance in long-term mobility monitoring.

As outlined in this paper, accelerometers are currently used primarily in a research setting, however, the processing algorithms and monitoring techniques have been extensively validated. The next phase in the development of accelerometer-based instrumentation is incorporation of this research expertise into a commercial device. Creating a product that is easy to use and acceptable to clinicians would be a major design goal. Other issues include making the device waterproof and developing sensors that are easy to apply and re-apply. The challenge facing clinicians and the medical devices industry is to harness this technology making it practical and acceptable for incorporation into everyday rehabilitation practice.

Key points

- Recent technological developments have led to the production of inexpensive, non-invasive, miniature accelerometer sensors ideal for use in many clinical monitoring situations.
- For illustrative purposes this paper describes some current applications of accelerometers in gait and balance evaluation, falls risk assessment and mobility monitoring.
- Accelerometers provide an added objective and quantitative dimension to gait analysis when combined with clinical assessment.

References

References listed below are cited in bold in the text. A full list of references can be found on the journal website at www.ageing.oxfordjournals.org


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