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Role of Body-Worn Movement Monitor Technology for Balance and Gait Rehabilitation

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This perspective article will discuss the potential role of body-worn movement monitors for balance and gait assessment and treatment in rehabilitation. Recent advances in inexpensive, wireless sensor technology and smart devices are resulting in an explosion of miniature, portable sensors that can quickly and accurately quantify body motion. Practical and useful movement monitoring systems are now becoming available. It is critical that therapists understand the potential advantages and limitations of such emerging technology. One important advantage of obtaining objective measures of balance and gait from body-worn sensors is impairment-level metrics characterizing how and why functional performance of balance and gait activities are impaired. Therapy can then be focused on the specific physiological reasons for difficulty in walking or balancing during specific tasks. A second advantage of using technology to measure balance and gait behavior is the increased sensitivity of the balance and gait measures to document mild disability and change with rehabilitation. A third advantage of measuring movement, such as postural sway and gait characteristics, with body-worn sensors is the opportunity for immediate biofeedback provided to patients that can focus attention and enhance performance. In the future, body-worn sensors may allow therapists to perform telerehabilitation to monitor compliance with home exercise programs and the quality of their natural mobility in the community. Therapists need technological systems that are quick to use and provide actionable information and useful reports for their patients and referring physicians. Therapists should look for systems that provide measures that have been validated with respect to gold standard accuracy and to clinically relevant outcomes such as fall risk and severity of disability.

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The use of technology to quantify mobility in physical therapy has lagged behind other rehabilitation specialties, such as cardiac and musculoskeletal specialties. This lag in use of technology is due to the inherently complex nature of mobility and to the lack of simple technology available to therapists to measure and quantify mobility. Measurement of mobility is complex because it includes many different neural control systems associated with balance and gait, as well as adaptive mechanisms for maintaining mobility under altered conditions.[1] Balance and gait need to be evaluated in every patient at risk for a fall, and training of balance and gait is recommended by all national and international expert panels for fall prevention.[2,3] However, characterization of balance and gait abnormalities that lead to fall risk is currently highly dependent on examiners' expertise because subjective rating scales are typically used in the clinic.[4–6] Although there are many performance-based, clinical tests of balance and gait, many tests suffer from ceiling effects in individuals who are highly functioning and cannot be adopted because of lack of expertise to use and interpret them accurately.[7]

Although sophisticated laboratories have been characterizing balance and gait disorders for many decades, it has not been practical for physical therapy practitioners to take advantage of this knowledge. Many laboratory measures quantifying balance and gait have been shown to differ between people likely to fall and people without fall risk and between people with subtle neurological or musculoskeletal impairments and healthy individuals (for review, see Hobert et al[8] and Mortaza et al[9]). These laboratory measures of balance and gait are now becoming available to physical therapists via new technologies involving small body-worn movement monitors.

This article will focus on 3 important advantages to using body-worn movement monitors for assessment and treatment of balance and gait disorders: (1) accurate impairment-level metrics that characterize how and why performance of balance and gait activities are impaired, (2) increased sensitivity of the measures to document mild disability and change with rehabilitation compared to clinical tests of functional performance, and (3) opportunity for immediate biofeedback provided to patients that can focus attention and enhance treatment efficacy. We also will discuss some important distinctions between common system types and forecast the potential benefits of body-worn sensors that will allow therapists to participate in telerehabilitation to monitor gait and balance in the home, home exercise adherence, and the quality of natural mobility in the community.

Recent Advances in Body-Worn Sensors

It is important for physical therapists to understand the differences between 2 types of body-worn sensors: activity monitors and movement monitors. Although both activity monitors and movement monitors detect motion with inertial sensors, activity monitors cannot measure the quality of gait and balance impairment, a focus for physical therapy, so most of this paper will focus on movement monitors.

Activity monitors are designed to measure the *quantity* of movement, such as how long a person is walking or running or when he or she is sedentary versus active. Activity monitors, such as the StepWatch (Modus Health, Washington, DC), *activ*PAL (Glasgow, United Kingdom), and ActiGraph (Pensacola, Florida), use accelerometers (either uniaxial or triaxial) to detect the number and size of acceleration spikes associated with body motion, usually to count steps or calculate time spent in different postures.[10–12] Activity monitors are popular devices for lay consumers because they can count steps per day (such as pedometers), hours of sleep (from periods of nonmoving, horizontal posture), amount of time spent in different postures (walking, lying down, sitting), and sedentary time. These devices also are used to estimate calories burned and cadence (steps per minute). Typically, a single activity monitor is worn on the wrist or belt. Activity monitors also have the advantage of a long battery life, with up to 30 days of continuous recording, and they are increasingly inexpensive. However, therapists should be cautioned about using widely available consumer devices such as smartphone applications and exercise devices (eg, Jawbone [Jawbone, San Francisco, California], Basis Peak [Basis, San Francisco, California], and Nike-Fuel [Nike Inc, Beaverton, Oregon]) in their clinical practice because they have not undergone validity testing for accuracy or reliability, especially with patient populations. Activity monitors of any type provide limited information on gross activity patterns and cannot provide therapists information on quality of movement, joint kinematics, or motor impairments.

Unlike activity monitors, movement monitors record 3 axes of motion from 3 or more types of inertial sensors (eg, accelerometers that measure linear accelerations, gyroscopes that measure angular velocity, and magnetometers that measure heading with respect to the Earth's magnetic field). By combining all of these signals from multiple, synchronized sensors with models of human body motion, whole-body joint kinematics, spatial and temporal gait characteristics, and many aspects of balance control can be accurately measured.[13–15] Recent advances in movement monitors, such as small size and weight, synchronized data collection from multiple sensors, high-frequency data sampling, smart monitors with online data processing for high-speed analysis, and clinical user interfaces that provide useful information, are transforming this technology for clinical use. The small size and ease of application of body-worn sensors allow unobtrusive monitoring during clinical testing (Fig. 1A).

A recent technical advance in movement monitors for physical therapists is sophisticated software algorithms that calculate useful balance and gait measures by combining the information from the three-dimensional (3D) accelerometer, 3D gyroscope, and magnetometer signals. Body segment orientation and displacement in space can now be measured, replacing more expensive, time-consuming, and nonportable motion analysis systems in laboratories.[16–18] This advance means that joint range of motion can be measured accurately during dynamic movements such as gait, lunges, and stair climbing, not only in static conditions, as with goniometers. Thus, gait measures such as stride length, pitch angle of the foot at heel-strike, and foot clearance from the floor can now be calculated from movement monitors.[15,19,20]

Movement monitors are able to measure the quality of body motion by characterizing the kinematics and spatiotemporal aspects of mobility, both in the clinic and in real-life conditions. Limitations of movement monitors are their relatively short battery life (10 to 12 hours, so they must be charged each night) and their higher cost when compared with activity monitors.

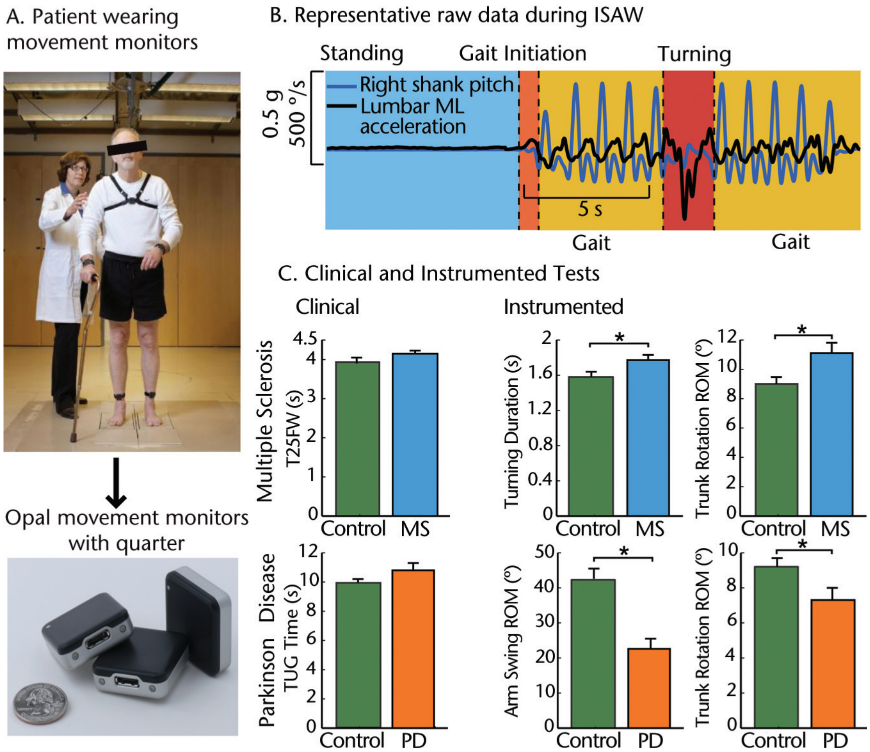

Figure 1.
(A) Photo of therapist (F.H.) with a patient wearing movement monitors on his sternum, belt, ankles, and wrists attached with elastic bands. A close-up of the APDM Opal monitors (APDM Inc, Portland, Oregon) is shown in inset below. (B) Representative raw data of angular velocity signals detected from the lower leg and the mediolateral (ML) acceleration signal from the trunk during the Instrumented Stand and Walk Test (ISAW), divided into 4 phases: quiet standing, step initiation, gait, and turning. (C) Group mean and standard errors of clinical and instrumented tests to distinguish mobility in healthy control participants from those with mild multiple sclerosis (MS) (n=31) or untreated Parkinson disease (PD) (n=12). The clinical 25-ft walk time (T25FW) and the Timed "Up & Go" Test (TUG) could not distinguish between MS or PD and age-matched control participants, respectively. However, significant differences (*$P<.05$) were found between groups for several objective, instrumented measures. Data adapted from published studies.[32,44] ROM=range of motion.

Each movement monitor system has limitations and benefits, depending on the desired mobility measures and how it will be used by therapists. Some commercial systems have only one movement monitor, placed on the lumbar segment, which allows therapists to measure postural sway and, sometimes, temporal characteristics of gait, such as cadence, trunk stability, and number of steps (eg, McRoberts [The Hague, the Netherlands], SwayStar [Balance International Innovations GmbH, Iseltwald, Switzerland], BTS [BTS Bioengineering Corp, Milan, Italy]). Other movement monitors include a sensor on each foot to more fully characterize the spatial and temporal characteristics of foot motion during gait and turning (Gait Up [Lausanne, Switzerland], APDM [APDM Inc, Portland, Oregon], and BioSensics [BioSensics LLC, Cambridge, Massachusetts]). Two systems (by APDM and BioSensics) allow additional synchronized sensors on the legs, trunk, and arms that allow full-body characterization of balance, gait, and postural translations. Multiple movement monitors also can be used to measure kinematic joint angle movements (Xsens

Table.
Examples of Balance and Gait Measures Related to Fall Risk Included in the Instrumented Stand and Walk (ISAW) Protocol[a]

System	Measure	Definition	Studies
Postural sway	Amplitude	Peak-to-peak sway or total sway area	Merlo et al,[43] Buatois et al[61]
	Velocity	Change in amplitude of sway	Bigelow and Berme[42]
Step initiation	Anticipatory postural adjustments (APA)	APA size and duration	Sparto et al,[62] Uemura et al[63]
Turning	Velocity	Amplitude of angular velocity	Galan-Mercant and Cuesta-Vargas,[64] Zalaria et al[65]
Gait, spatial	Width variability	Coefficient of variation step width=SD/mean (dimensionless)	Mortaza et al,[9] Brach et al[37]
Gait, temporal	Stride velocity	Walking speed=average of right and left shanks (m/s)	Mortaza et al,[9] Lee and Kerrigan,[39] Newstead et al[41]
	Double support	Percentage of a gait cycle both feet on the ground (% of cycle)	Mortaza et al,[9] Mbourou et al,[40] Newstead et al[41]
	Stride time variability	Coefficient of variation stride duration=SD/mean (dimensionless)	Mortaza et al,[9] Hausdorff et al[38]
Gait, upper body	Trunk stability	Harmonic ratio or multiscale entropy of trunk acceleration	Doi et al,[66] Riva et al[67]

[a] The balance and gait systems with their measures and definitions are accompanied by references providing evidence that they predict falls.

[Enschede, the Netherlands]), but clinically friendly systems are needed. Soon, systems will allow continuous monitoring of mobility for days or weeks in home communities. It is important for therapists to consider the quality and quantity of the validation and reliability studies of movement monitor systems as well as their ease of use, quality of reports, and supported clinical protocols, such as the Timed "Up & Go" Test (TUG) and Clinical Test of Sensory Integration for Balance (CTSIB).

Importance of Impairment-Level Balance and Gait Measures

Physical therapists commonly use standardized rating scales such as the Berg Balance Scale (BBS) or the Mini-BESTest to assess gait, balance, and functional activities; however, a precise impairment-level assessment of balance and gait is often difficult to obtain. Movement monitors worn on patients during functional balance and gait assessments now allow accurate assessment of balance and gait impairments to guide and track rehabilitation. For example, movement monitors have recently been used to quantify the quality of mobility during the TUG, the CTSIB, and a 2-minute walk.[21–32] The instrumented version of these common tests adds a multitude of gait and balance characteristics to the standard stopwatch times and clinical judgment. The added balance and gait measures can precisely measure *how* and *why* functional performance is impaired. For example, movement during performance of the TUG may be slow due to impaired turning, slowed steady-state gait, or impaired sit-to-stand transition. By applying several movement monitors on the patient prior to a clinical balance or gait test, therapists can instantly and automatically characterize many specific impairments to help determine where the problem is occurring.[33]

Impairment-level measures from movement monitors, such as those listed in the Table provided, can provide therapists with specific impairments in stance postural control, step initiation, turning, spatial and temporal gait characteristics, and upper body motion during gait. These objective impairments can then be used by physical therapists to precisely target their therapy and to sensitively track subtle changes over time.[34–36] The clinical TUG, for example, will indicate whether a patient needs therapy to improve mobility. The instrumented TUG (ITUG), for another example, can inform therapists about which specific aspects of mobility need to be improved (even when the total time to perform the task has not improved).

Measures of balance and gait quality from movement monitors may better predict fall risk than clinical balance and gait tests such as gait speed; however, more studies of the predictive value of movement monitors are needed.[6,22] The Table lists studies that provide evidence that many objective balance and gait measures can separate fallers from nonfallers. For example, double-support time and gait variability have been shown to better predict falls than gait speed.[9,37–41] In addition, postural sway metrics better predict fall risk than stopwatch measures of standing in particular postures.[42,43]

To evaluate fall risk with movement monitors quickly, we have developed a new, short protocol, the

Instrumented Stand and Walk Test (ISAW), that automatically results in more than 50 objective measures of balance and gait impairments from body-worn movement monitors.[33] Figure 1B shows how the ISAW compresses 4 different subcomponents of mobility into one protocol in less than a minute: (1) postural sway in standing balance, (2) anticipatory postural adjustments associated with step initiation, (3) spatial and temporal components of gait (upper and lower body), and (4) turning 180 degrees. Figure 1B also illustrates how sensor data from movement monitors can be used to divide the ISAW into different subcomponents of mobility that capture particular skills needed for activities of daily living. The gyroscope angular velocity on the belt can detect turning velocity, and the gyroscopes on the lower leg show each step cycle.

Specific balance and gait impairments identified by movement monitors are potentially modifiable when therapy is targeted to the impairments. For example, we tested 2 groups of patients with mild disability (one with multiple sclerosis [MS] and the other with untreated Parkinson disease [PD]) (Fig. 1C). Both groups had normal gait speed (measured with a stopwatch during the time to walk 25 ft [1 ft=0.3048 m] [T25FW] or the TUG [clinical tests in Fig. 1C]). Nevertheless, both groups showed abnormal balance and gait characteristics with instrumented tests. Specifically, the MS group showed a longer turning duration compared with healthy controls, and the untreated PD group showed a reduced arm swing compared with healthy controls. Interestingly, both groups also showed significant impairments in the rotation of their upper trunks while walking.[32,44] However, the patients with PD showed significantly *decreased* trunk rotation, and the MS patients showed significantly *increased* trunk rotation during gait compared with healthy controls. Therefore, therapy for the PD group may be focused on increasing trunk rotation (eg, by increasing arm swing and reducing axial rigidity), whereas therapy for the MS group may be focused on decreasing trunk instability during gait (eg, by increasing core strength and utilizing a cane). In contrast, when therapists are limited to measuring only the duration of the TUG, which was normal in both groups of patients, it may be more difficult to justify, focus, and measure effects of therapeutic intervention.

Studies have shown different mobility impairments may reflect problems with different, independent neural control systems. For example, postural sway in stance, anticipatory postural adjustments during step initiation, locomotor patterns of gait, and coordination of turning involve separate neural circuitry and, therefore, are differently represented in patients with balance problems. Thus, some patients with frequent falls may show abnormal postural sway but normal anticipatory postural adjustments and gait, whereas other patients show abnormal turning characteristics but normal straight-ahead walking.[1,32,44] Identification of specific types of balance problems allows for more specific rehabilitation to remediate the constraints on safe mobility.[45]

A person undergoing rehabilitation focused on improving mobility may benefit from having sensitive, quantitative measures of specific impairments underlying balance and gait disorders. Performance tests of mobility, such as the BBS or TUG, measure whether an individual *can* accomplish tasks, such as turn in a circle or walk a particular distance. Movement monitors, however, provide objective measures of impairments documenting *how* and *why* the individual's balance or gait, or both, is impaired. Physical therapists can then use objective measures to guide their exercise programs to specific impairments.

Importance of Sensitive Measures of Mild Balance and Gait Impairments

Reimbursement of physical therapist services requires evidence of the problem[46] and of gradual improvement with therapy, but current clinical balance scales and stopwatch measures are often insensitive to mild impairments in high-level performers.[47–49] Objective impairment measures during clinical balance and gait protocols such as the ITUG have been shown to be more sensitive to differences between healthy people and patients with very mild neurological disorders compared with traditional clinical measures such as time to perform a motor task.[26,29,32,44] For example, although patients with very mild untreated PD have normal 3-m TUG performance time compared with age-matched controls (10.8±0.5 seconds versus 9.9±0.3 seconds, respectively), they may show many impairments in quality of walking, turning, and sit-to-stand performance (Fig. 1C).[44] Evidence supports early rehabilitation intervention for neuroplasticity; therefore, early detection of balance and gait problems in patients with mild impairments is important.

Patients with mild traumatic brain injury (TBI) also may show normal gait speed with significant gait impairments only detectable with instrumentation. For example, Figure 2 compares step-by-step stride durations during a 2-minute walk in an 18-year-old football player who sustained a concussion without loss of consciousness 4 weeks prior to testing and in a teammate of the same age without a concussion. Although both athletes had the same average gait speed, the athlete with a

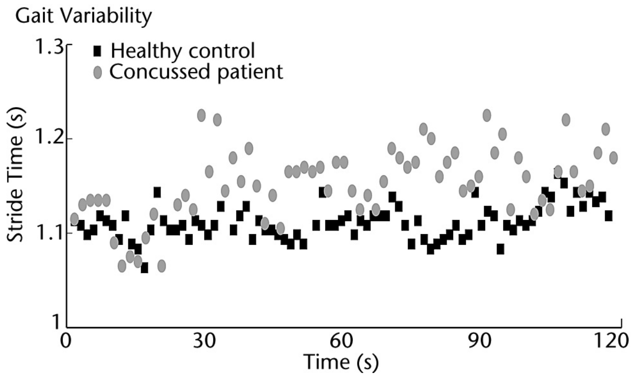

Figure 2.
Gait stride time from movement monitors on the ankles during a 2-minute walk at a comfortable speed is more variable in a young athlete after a sports concussion compared with an age-matched control athlete.

prior concussion showed an increase in variability of stride times, indicative of dynamic balance deficits during gait and increased fall risk.[50] These relatively high-level mobility impairments could easily be missed by physical therapists limited to traditional balance and gait testing.[49]

Movement Monitors Offer a Great Opportunity for Biofeedback Rehabilitation

An important role of the physical therapist is to provide patients with accurate feedback about their performance and movement errors. Movement monitors have great potential to augment feedback (biofeedback) using more immediate and more sensitive feedback than therapists can apply without technology. Biofeedback is the technique of using technology to provide biological information to patients in real-time that would otherwise be unknown.[51] Biofeedback provides clinicians with a useful tool for giving patients quick, precise instructions on how to modify movement patterns. Thus, biofeedback complements normal internal feedback and acts as an additional "sixth sense" or "sensory substitution" for patients who have lost sensory function.

Our laboratory has demonstrated the power of audio-biofeedback to immediately reduce postural sway during stance in patients with vestibular loss.[52,53] Patients wore a movement monitor on their belt that sensed body tilt with respect to gravity during quiet stance. Audio-biofeedback was applied as a tone that increased in volume with extent of postural sway (more in the right ear during right sway and in the left ear during left sway). Forward and backward sway were indicated by a high-pitch tone and low-pitch tone, respectively. Every patient with bilateral loss of vestibular function who could not stand on a compliant foam surface with eyes closed without biofeedback could maintain equilibrium with the audio-biofeedback that substituted for their lost vestibular information. Very little training was required, and the effectiveness of biofeedback was proportional to the amount of vestibular loss and to the difficulty of the task.[52,53]

Recently, we used the same audio-biofeedback approach in patients with mild TBI who had excessive postural sway in stance. Not only does the movement monitor on the belt sensitively measure increases in postural sway when people stand in more challenging sensory conditions, such as on compliant foam, but feeding back, the trunk tilt signal greatly reduced postural sway in every condition, even without practice (Fig. 3). Because it is not possible for therapists to manually provide quick, accurate feedback about postural sway, biofeedback can supplement balance training.

Biofeedback to improve balance can be used to improve training and motor learning, as well as an instrumented prosthetic. For example, patients with unilateral vestibular loss practiced walking tandem on a line with eyes closed both with and without audio-biofeedback for 20 trials in a crossover design.[54] Patients who practiced with the audio-biofeedback to minimize lateral trunk tilt performed significantly better than without biofeedback. Specific biofeedback about stride length, foot clearance, and gait asymmetry also has the potential for improving gait disorders. However, the long-term effects of using movement monitor biofeedback need to be further investigated.

Importance of Mobility Measures During Daily Community Living

A critical barrier to mobility assessment is the need for measuring mobility in natural, functional settings and across long periods of time to monitor risk for falls, fluctuations across the day, functional decline or response to interventions, and influence of changing environments. Single-event mobility measures in the clinic may not accurately reflect functional mobility during daily life because increased attention on the task during clinical testing enhances motor performance.[55] In addition, single, sparsely spaced measures cannot assess within-day, day-to-day, or other clinically relevant windows of change, such as medicationinduced motor fluctuations or fatigue. The assessment of mobility during activities of daily living could objectively quantify mobility function outside the clinic similar to how a Holter heart rate monitor evaluates cardiac function over days and weeks.

Recently, new studies have focused on home and community mobility using wearable, light-weight movement monitors for multiple days.[56,57] Novel measures of turning and gait characteristics, calculated from movement monitors on the trunk and legs, enable a detailed analysis of mobility over weeks of continuous monitoring. Previously, continuous monitoring was limited to use of activity monitors to measure the quantity of activity, but now movement monitors allow continuous monitoring of quality of activity.[56–58]

Figure 4 shows recent data from our laboratory in which we compared the predictive values of measures of turning during a prescribed task with continuous monitoring of turning during daily activities over a week in elderly fallers and nonfallers. Patients of a mean (±SD) age of 86±7 years, with (n=19) and without (n=16) a history of one or more falls during the previous year, wore movement monitors on their shoes and on their belt all day for 7 days and for prescribed tasks (including several 180° and 90° turns and the time to walk 9 ft). The mean (±SD) number of turns per hour of recording was 63±17, and the mean (±SD) turn angle was 95±2 degrees, with no difference between fallers and nonfallers. Although the fallers and nonfallers showed no difference in the time to walk 9 ft and in turning characteristics during the prescribed tasks, several turning characteristics significantly distinguished patients with a history of falls from those without falls during the 7 days of continuous monitoring (Fig. 4).

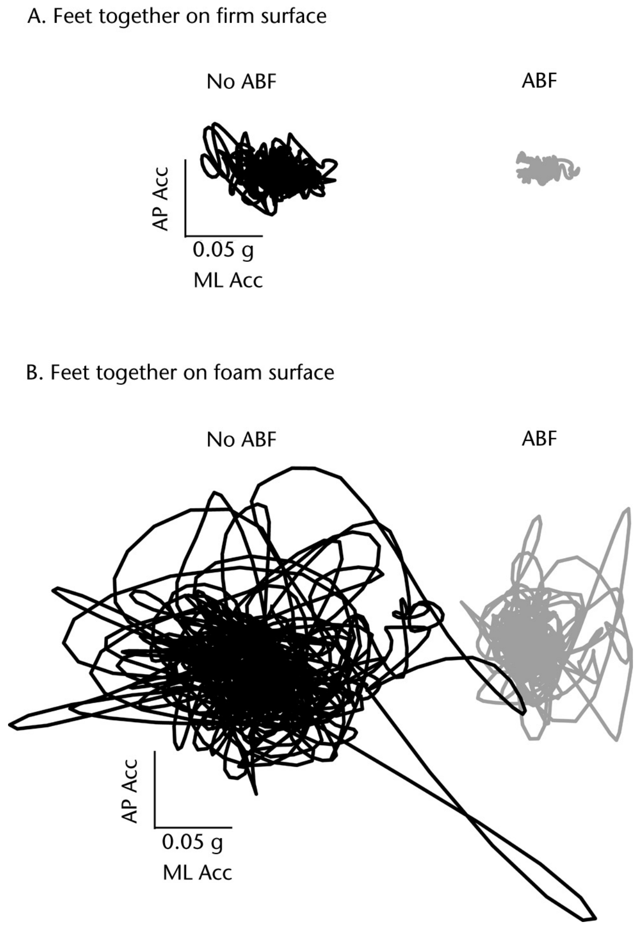

Figure 3.
Reduction of postural sway with audio-biofeedback (ABF) from a movement monitor on the belt during stance on (A) a firm surface and (B) a foam surface with eyes closed in a patient with a mild traumatic brain injury (TBI). AP Acc=anteroposterior acceleration, ML Acc=mediolateral acceleration.

These preliminary results are promising, but larger-scale studies are needed to determine whether continuous monitoring of mobility will better predict future falls than single performance tests.

Important Features to Consider in Movement Monitors for Balance and Gait Rehabilitation

Physical therapists have high stakes in emerging movement monitoring technology. Ideally, physical therapists should be involved with companies developing movement monitors in order to promote the development of systems that are valid, sensitive, responsive, and feasible for clinical practice. To be useful as a clinical device, movement monitors must demonstrate accuracy and reliability by high-quality validation with respect to laboratory gold standards and clinically relevant outcomes, such as fall risk and disability. Movement monitors should be able to sensitively measure impairments that therapists and patients care about, such as quality of balance and walking, so that even patients with high levels of performance can improve their function or prevent decline. Data obtained from

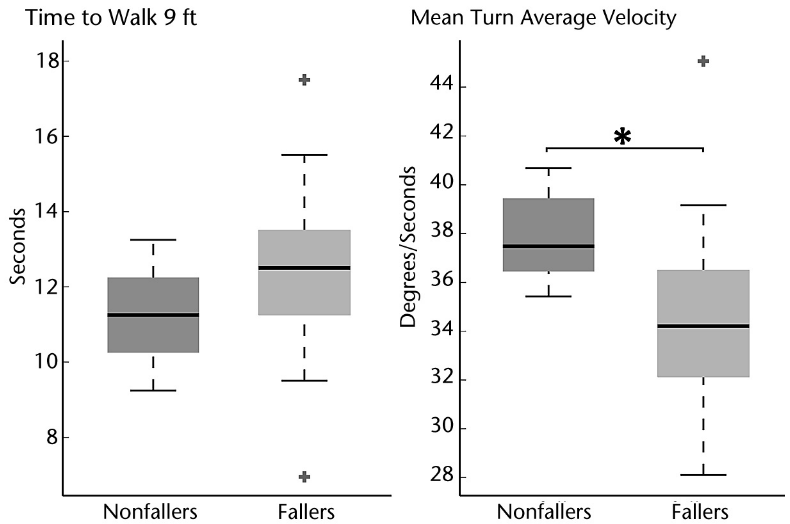

Figure 4.
Continuous measures of turning velocity over a week (mean turn average velocity) is more sensitive than clinical gait speed (time to walk 9 ft) in predicting fallers in a sample of 19 elderly fallers (≥1 fall in the last year) and 16 elderly nonfallers. On each box, the central mark is the median, the edges of the box are the 25th and 75th percentiles, and the outliers are plotted as +. *P<.05.

movement monitors should offer relevant information on the severity of specific impairments that can guide treatment and are responsive to change. Feasible systems should quickly and easily provide useful reports to therapists, physicians, and patients about their balance and gait impairments and progress.

Multiple opportunities are available for physical therapists to directly influence product development at technology companies. One accessible method of promoting the development of movement monitoring technology that supports physical therapist practice is to communicate with company representatives at national professional meetings about what types of products you would find useful. In addition, therapists can ask a company to provide a group demonstration of their new technology and then act as a "focus group" to advise the company about their products in development. The National Institutes of Health (NIH) also sponsors grant programs that facilitate communication between clinicians and technology companies. The National Center for Medical Rehabilitation Research at NIH supports a Center for Translation of Rehabilitation Engineering Advances and Technology (TREAT) as part of a larger network of rehabilitation research resource centers. For example, Dr King was awarded a pilot grant from TREAT to develop, with a local company, an instrumented version of the Balance Error Scoring System (BESS) focused on assessment of balance after concussion.[59,60] The pilot study demonstrated that simply adding one sensor to the pelvis during the clinical test significantly improved sensitivity and specificity in classifying people with concussion.[47] Clinicians and clinical researchers also can engage with technology companies by collaborating on submission of Small Business Innovation Research (SBIR) grants to the NIH. An SBIR is submitted to NIH by the company to develop novel technologies and includes contracts for research and feasibility testing by clinical partners.

By increasing the sensitivity of our balance and gait outcomes to identify mild balance and gait problems or subtle changes of mobility over time, physical therapists will capture a wider net of people with a range of balance deficits. Movement monitors can provide impairment-level metrics to characterize how and why functional performance is impaired to better focus treatment on the underlying causes. We predict that therapists will soon use movement monitors to evaluate balance and gait continuously, during daily activities for more ecological and realistic understanding of patients' mobility in the world. Physical therapists also can incorporate movement monitors to provide real-time biofeedback to improve motor learning and motor performance both during a regular training session and remotely. Telerehabilitation will become a reality when patients' adherence to home exercises can be monitored by uploading movement monitor data to their therapists. With technology becoming more and more accessible and pervasive, physical therapists need to critically evaluate the advantages and limitations of implementing emerging technologies, such as body-worn sensors, into their clinical practice.

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