Balance and Gait Impairment

Sensor-based assessment for patients with peripheral neuropathy

Grace Campbell, PhD, MSW, RN, CRRN, and Marjorie A. Skubic, PhD

BACKGROUND: Individuals with peripheral neuropathy (PN) frequently experience balance and gait impairments that can lead to poor physical function, falls, and injury. Nurses are aware that patients with cancer experience balance and gait impairments but are unsure of optimal assessment and management strategies.

OBJECTIVES: This article reviews options for balance and gait assessment for patients diagnosed with cancer experiencing PN, describes advantages and limitations of the various options, and highlights innovative, clinically feasible technologies to improve clinical assessment and management.

METHODS: The literature was reviewed to identify and assess the gold standard quantitative measures for assessing balance and gait.

FINDINGS: Gold standard quantitative measures are burdensome for patients and not often used in clinical practice. Sensor-based technologies improve balance and gait assessment options by calculating precise impairment measures during performance of simple clinical tests at the point of care.

KEYWORDS
postural balance; gait; peripheral neuropathy; assessment; financial toxicity

INDIVIDUALS WITH PERIPHERAL NEUROPATHY (PN) frequently experience balance and gait impairments, leading to persistent mobility issues, falls, and injury (Campbell, Hagan, Gilbertson-White, Houze, & Donovan, 2016; Toft Hansen, Visovsky, & Berry, 2012). PN can result from various etiologies, including diabetes (Morrison, Colberg, Parson, & Vinik, 2014); malignancies, such as multiple myeloma (Leone et al., 2016) and colorectal cancer (Wang et al., 2016); and vitamin deficiencies, toxins, and medications (Staff & Windebank, 2014).

Patients with cancer often experience medication-related PN as a result of neurotoxic chemotherapies. Chemotherapy-induced PN occurs in 68%–80% (Park et al., 2011; Seretny et al., 2014) of individuals receiving platinum agents, taxanes, and bortezomib (Bhatnagar et al., 2014; Verstappen, Heimans, Hoekman, & Postma, 2003). Hallmark signs and symptoms of PN include numbness, tingling, burning pain, and decreased sensation (Smith et al., 2014), starting with the fingers and toes and progressing proximally. In some patients, PN symptoms decrease when treatment stops, but others experience continued worsening of symptoms, known as coasting (Miltenburg & Boogerd, 2014; Park et al., 2011). Reports estimate that chemotherapy-induced PN can persist for six or more months after treatment cessation in as many as 50%–80% of individuals (Bandos et al., 2018; Briani et al., 2014; Majithia et al., 2016). No established treatment exists for chemotherapy-induced PN, but current guidelines suggest that duloxetine may reduce painful symptoms (Hershman et al., 2014).

Balance and gait impairments are common among individuals with PN (Kneis et al., 2016; Miaskowski et al., 2017; Toft Hansen, Visovsky, et al., 2012; Visovsky & Daly, 2004; Visovsky, Meyer, Roller, & Poppas, 2008; Winters-Stone et al., 2011), creating an increased risk of falls (Gewandter et al., 2013; Marshall, Zipp, Battaglia, Moss, & Bryan, 2017; Toft Hansen, Overcash, & Kip, 2012). Individuals with PN who have balance and gait impairment are at risk for numerous negative outcomes, including falls and injuries (Chen et al., 2005; Ward, Wong, Moore, & Naeim, 2014), fear of falling, decreased physical activity, deconditioning, and disability (Fletcher, Guthrie, Berg, & Hirdes, 2010; Pautex, Herrmann, & Zulian, 2008). PN-related balance and gait impairments may persist for years after treatment stops (Winters-Stone et al., 2016). Early rehabilitation is key to minimizing long-term functional impairments (Teasell, Bitensky, Salter,
& Bayona, 2005). Therefore, identification of balance and gait impairments, combined with timely referrals to rehabilitation, is imperative to prevent negative PN-related outcomes.

A survey of Oncology Nursing Society (ONS) members found that nurses know that PN is prevalent, can affect patient mobility and safety, and may require referral to rehabilitation treatment (Smith et al., 2014). But the survey also found that nurses feel poorly prepared to identify and manage PN symptoms and consequences (Smith et al., 2014), suggesting that PN-related gait and balance issues may be underdiagnosed and undertreated. Often, nurses are the patient’s primary point of contact with the healthcare system (Smith et al., 2014) and, therefore, are ideally positioned to evaluate patient needs and recommend supportive and rehabilitative interventions.

The literature to guide practice in this area is limited. Gold standard balance and gait measures, such as computed dynamic posturography (CDP), could identify subtle impairments early in the survivorship trajectory. CDP was used in several seminal retrospective studies documenting persistent balance and gait impairments among cancer survivors with PN (Miaskowski et al., 2017; Wampler et al., 2007; Winters-Stone et al., 2011, 2016, 2017). However, such measures require costly laboratory equipment (Mancini et al., 2011) that is usually only available in research settings or in large tertiary care centers. Patients may be unable or unwilling to travel to tertiary care centers for evaluation, particularly if their impairments are subtle and they are eager to resume their postcancer life activities, making gold standard measures impractical for prospective evaluation of functional change during cancer treatment.

Low-burden clinical tests are sometimes used in oncology nursing practice; 41% of ONS survey respondents reported that they always assess gait and balance by using a Romberg test (asking the patient to close his or her eyes for 30 seconds) or by observing patients as they walk (Smith et al., 2014). These tools are practical for point-of-care testing, but they lack the necessary precision for identifying subtle, early-stage, PN-related balance and gait impairments. In addition, they cannot fully characterize each patient’s specific impairments to inform an individualized treatment plan. The purpose of this article is to provide clinicians with a summary of current options for balance and gait assessment and to describe innovative, commercially available, clinically feasible technologies that could improve point-of-care detection of treatable PN-related balance and gait impairment.

**Gold Standard Balance and Gait Assessment**

Objective, quantifiable assessments represent the gold standard balance and gait measures for research and clinical care; they are the most reliable and valid measures available. Gold standard measures comprise computerized objective calculation of parameters, such as centimeters of postural sway, step length, and step width, removing human error and provider subjectivity from the evaluation, yielding a quantitative measure with high intra- and inter-rater reliability. Widely used gait and balance assessment methods, including CDP, spatiotemporal gait mapping, and environmentally mounted motion capture systems (see Figure 1), are listed in Tables 1 and 2.

The advantages to using gold standard measures include robust psychometric properties and detailed quantitative measurement of a variety of balance and gait parameters. Despite these advantages, the clinical use of these methods is limited, particularly during active treatment. For example, the large size and high cost of equipment is prohibitive for many oncology care settings. Some gait mapping mats are theoretically portable when the mat is rolled; even so, the rolled mats are large, heavy, and cumbersome. Even in large tertiary medical centers where the equipment is available, it often is located off-site from the cancer center, requiring additional appointments, more time, and additional costs for patient parking. In addition, insurance coverage for such sophisticated balance assessment is not universal; even if covered, additional insurance co-payments could be burdensome. Because these tests are burdensome to patients, they are infrequently used in cancer care. They also may exhibit poor ecological validity (i.e., their ability to predict performance in real-world settings and situations, such as a crowded clinic or the patient’s home, is not established). One study found that CDP was correlated with patient self-retrospective recall of falls in the prior 12 months, but not with future falls collected prospectively for 6 months via monthly participant self-report (Winters-Stone et al., 2011). Whether these study results represent a lack of ecological validity, improvement from the natural recovery trajectory, or simply inaccurate fall recall among participants is unclear. Additional investigation is needed about relationships between gold standard balance and gait measures and real-world performance.

![FIGURE 1. BALANCE AND GAIT ASSESSMENT MEASURES](image-url)
Clinical Tests of Balance and Gait

Manual clinical tests can be used in care settings to detect balance and gait impairments. Commonly used balance and gait tests measure time to perform various standing or walking tasks, or assign a categorical or ordinal score, rated by examiner observation of the patient performing increasingly difficult mobility tasks.

Clinical balance and gait tests can be used in almost any care setting and require little special equipment, minimal training, and no specialty credentialing to administer (Guralnik et al., 1994; Viccaro, Perera, & Studenski, 2011). Clinical balance and gait tests can indicate increased fall risk and difficulty completing activities of daily living among community-dwelling older adults (Canbek, Fulk, Nof, & Echternach, 2013; Viccaro et al., 2011) and some adults with cancer (Hile et al., 2010; Visovsky & Daly, 2004). Clinical tests can be easily administered in oncology settings, but are most often used in rehabilitation clinics separate from the point of oncology care. Therefore, similar to gold standard tests, scheduling additional appointments and traveling to other locations contributes to patient burden, and additional co-payments may exacerbate the financial toxicity of cancer treatment.

Clinical tests may also lack sufficient sensitivity to detect balance and gait impairments among younger individuals or those with a higher precancer level of physical function, and may need to be modified by increasing stance times for performing balance tests (Hile et al., 2012). Even with modification, clinical tests may not detect balance and gait changes among adults aged 65 years or younger, particularly among active individuals with few comorbidities. In addition, whether clinical balance and gait tests demonstrate ecological validity is unclear. In a study of individuals with multiple sclerosis (Stellmann et al., 2015), clinical walking tests of 10 meters were poorly correlated with in-home gait speed measured by an accelerometer for seven days. This study suggests that the ecological validity of brief clinical tests in PN should be investigated.

Sensor-Based Functional Assessment

The limitations of existing balance and gait tests highlight an important gap in cancer survivorship care. Reliable, valid, sensitive, low-burden, clinically feasible quantitative tests are needed. Sensor-based balance and gait testing, such as body-worn sensors and gaming systems, may fill this gap (see Figure 2). Examples of sensor-based balance and gait assessment, with advantages and limitations, are provided in Table 3.

BODY-WORN SENSORS: Body-worn sensors, such as fitness trackers, are widely used. More specialized body-worn sensors incorporating accelerometers and gyroscopes can measure key balance and gait parameters. Sensors may be strapped to the patient’s chest, waist, ankle, or wrist, and a computer uploads the data and calculates parameters of interest (Alqahtani et al., 2017; de Bruin et al., 2012). One study used an app made for Android devices to collect and process measures collected by sensors worn on various locations of the body (Sejdić et al., 2015) during an overground walk. Another study tested a system using portable sensors strapped to the body to collect data during performance of standard clinical balance and gait tests. The sensors download data to a computer via a docking station. Customized software then calculates a variety of measurement parameters for each balance and gait test and furnishes reports that clinicians can use for treatment planning (Horak, King, & Mancini, 2015; Mancini et al., 2011).

Body-worn sensors could be implemented in clinics or in patients’ homes, overcoming the burden of gold standard tests; however, home use has not been widely tested. They also provide rich characterization of balance and gait impairments to identify etiology and potential interventions for specific impairments (Horak et al., 2015). One body-worn system can differentiate postural sway patterns and gait parameters between a variety of neurologic conditions to individualize each patient’s treatment plan (Horak et al., 2015; Mancini et al., 2011), negating the need to refer patients to a laboratory setting equipped with gold standard measures, such as CDP or motion capture for complex balance and gait analysis.

The use of gyroscopes and accelerometers is a promising development in the quest for quantitative assessments at the point of care. However, despite their advantages over gold standard and clinical tests, several shortcomings limit their translatable use. A primary limitation is patients’ perceptions that wearable devices are invasive or inconvenient (Chaudhuri, Oudejans, Thompson, & Demiris, 2015; Demiris et al., 2004). Therefore, body-worn sensors may not be feasible for extended in-home use, although they could be used in an outpatient clinic during formal functional testing situations, with data uploaded to a clinical record immediately. In addition, variations in sensor placement between wrist, waist, or lower leg can yield discrepant measurements, particularly when calculating variability of step rhythm, length, or width (Del Din et al., 2016). Finally, body-worn sensors may be costly and are usually not covered by insurance. Until these devices are mass produced and commercially available, widespread clinical application may be limited.

“The sensors provide the same quantitative measurements without the patient inconvenience.”
GAMING SYSTEMS: Sensors from commercially available gaming systems (e.g., Nintendo Wii®, Sony PlayStation®, or Microsoft Kinect®) may provide a reliable, valid, clinically feasible, low-cost way to characterize balance and gait. The spatial sensing technology used in these systems can precisely measure the same quantitative balance and gait parameters provided by gold standard measures, but are much more feasible for use in the oncology clinic or in patients’ homes. When used to record patient performance of the simple clinical tests of balance and gait, the sensors can provide the same quantitative measurements of specific balance and gait parameters provided by gold standard methods, but without the patient burden and inconvenience of most gold standard testing.

Sensor-equipped gaming systems have become increasingly popular for delivering rehabilitation interventions to older adults (Molina, Ricci, de Moraes, & Perracini, 2014; Studenski et al., 2010), stroke survivors (Sampaio, Subramanian, Arena, & Bhatt, 2016), and cancer survivors (da Silva Alves et al., 2017). Despite the integration of gaming into rehabilitation treatment, gaming sensors have only recently been incorporated into functional assessment. Like gold standard measures, gaming sensors can detect and quantify specific, subtle dimensions of balance and gait impairments that cannot be obtained using clinical tests. Gaming sensors are small, easily portable, and inexpensive. The sensor is inexpensive (about $100), connects to a standard laptop computer, and is small, which makes storage in the oncology clinic easy. Like clinical tests, but unlike gold standard measures, gaming sensors can be used with minimal staff training and minimal patient burden in a variety of settings. Unlike wearable accelerometer and gyroscope sensors, they do not require attachment to the body or charging of batteries. Gaming sensors’ versatility allows them to be used in post-assessment applications, such as real-time fall detection (Rantz et al., 2014), or as a platform for delivering telerehabilitation interventions remotely (Mishra, Skubic, & Abbott, 2015).

Gaming sensors use interactive video capture of depth images with sensor-emitted infrared light to identify joint positions of skeletal elements of gait, centimeters of postural sway in anteroposterior and mediolateral planes, and joint range of motion. They provide a low-cost, portable, quick screening method that is easy to use. This method can be used remotely (Mishra, Skubic, & Abbott, 2015). Despite the small cost and ease of use, gaming sensors cannot be used as the gold standard because they do not provide domain-specific scores to guide treatment of visual, vestibular, and sensorineural impairment contributing to balance deficits. The measure also provides a composite balance score that is correlated with history of falls. Repeated use may have inherent therapeutic benefit by training visual, vestibular, and sensorineural systems to anticipate and adjust to balance challenges.

TABLE 1.
GOLD STANDARD MEASURES OF BALANCE AND GAIT ASSESSMENT

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<th>MEASURE</th>
<th>DESCRIPTION</th>
<th>ADVANTAGES</th>
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<td>Computed dynamic posturography</td>
<td>To measure dynamic balance, the patient stands on force plates while facing a visual display and wearing a safety harness to prevent falls. Force plates are visual displays that move in response to and as a result of the patient’s own movements (known as “sway-referenced”). This method can isolate visual, vestibular, and sensorineural domains of balance function through 6 test conditions (combinations of force plate and display movement).</td>
<td>The measure is psychometrically reliable and valid and provides domain-specific scores to guide treatment of visual, vestibular, and sensorineural impairment contributing to balance deficits. The measure also provides a composite balance score that is correlated with history of falls. Repeated use may have inherent therapeutic benefit by training visual, vestibular, and sensorineural systems to anticipate and adjust to balance challenges.</td>
<td>The measure cannot evaluate gait. In addition, ecological validity (correlation with daily function in the lived environment) may be low because of an inability to evaluate balance in dynamic real-world situations (e.g., getting up from a chair, turning around). The measure uses large, expensive, non-portable equipment usually available only in research settings and larger medical centers. The equipment is usually located off-site from the cancer center, requiring additional appointments and parking.</td>
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<td>Gait mapping</td>
<td>Computerized pressure-sensitive mats (about 4 meters long) or plates are connected to a computer. The patients walk over the mat while step length, time between each step, and elapsed time for each phase of the gait cycle are recorded by the computer. The computer then calculates summary measures, such as mean step length and step cadence (steps per minute).</td>
<td>The measure is psychometrically reliable and valid and evaluates spatial (step width, step length) and temporal (step cadence) items, identifying specific therapeutic intervention targets. Portable equipment is available. The measure is widely used in research, particularly among community-dwelling older adults and cancer survivors.</td>
<td>The measure cannot evaluate balance. The portable equipment is large, cumbersome, and expensive and usually available only at research settings and larger medical centers. The equipment is usually located off-site from the cancer center, requiring additional appointments and parking.</td>
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<td>Motion capture</td>
<td>The system consists of several sensor cameras mounted around the perimeter of the testing area. Small adhesive markers are worn at joints and other anatomic landmarks; cameras measure marker movement during walking and balance tasks. Newer systems use body-worn sensor suits that transmit body position data wirelessly to a computer for calculation of similar parameters.</td>
<td>The measure can be used to evaluate spatial and temporal gait parameters, static balance, dynamic balance, and joint function (e.g., degrees of flexion, extension). The measure is psychometrically reliable and valid. Computational algorithms can calculate numerous physical function parameters, including spatial and temporal elements of gait, centimeters of postural sway in anteroposterior and mediolateral planes, and joint range of motion.</td>
<td>The equipment is expensive, and the test preparation is time-consuming (e.g., applying camera-sensitive markers), which increases patient and staff burden. Use is primarily in research settings and not feasible for clinics, inpatient areas, or homes. In addition, the ecological validity has not been established.</td>
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WANG ET AL., 2010)
the individuals within the sensor’s field of capture, known as skeletal tracking (Clark et al., 2012), and by computing distances and locations of people and objects using the depth images to calculate body movements (Stone & Skubic, 2013). A software development kit downloadable from the sensor manufacturer’s website allows development of customizable application, such as calculating joint range of motion, postural sway, and step length. Criterion validity has been established by comparing gaming sensors concurrently with motion capture systems (Clark et al., 2012; Dubois & Charpillet, 2014; Mentiplay et al., 2015; Pfister, West, Bronner, & Noah, 2014).

Gaming Sensors in Practice

Clinical use of gaming sensors for balance and gait assessment is well established in older adult populations; however, it still is in the early stages of use with oncology care. Gaming sensors can be used for intermittent and continuous (long-term) characterization of balance and gait. Gaming sensors are superior to conventional video monitoring because they can preserve patient privacy by displaying depth images, showing silhouettes rather than actual video footage. Computational algorithms have been validated using depth image data to calculate gait parameters associated with fall risk, alerting staff when an actual fall has occurred (Skubic et al., 2016; Stone & Skubic, 2015; Stone, Skubic, Rantz, Abbott, & Miller, 2015), and permitting retroactive review of depth video to determine fall antecedents (Rantz et al., 2014). For intermittent patient assessments in an oncology inpatient or outpatient setting, the gaming sensor and laptop can be set up in any area that provides an unobstructed view for the sensor to a 3-meter walking path. Patients are instructed to perform clinical balance and gait tests within the sensor’s view, and the sensor calculates balance and gait parameters to export to a database that clinicians can review. These results can be used by oncology staff to identify performance change from baseline, or can be reviewed by physical or occupational therapists to identify specific rehabilitation treatments that should be initiated. Because the equipment is inexpensive, testing

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<th>TABLE 2.</th>
<th>CLINICAL MEASURES OF BALANCE AND GAIT ASSESSMENT</th>
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<td>MEASURE</td>
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<td>Berg Balance Test (Berg et al., 1992; Shirley Ryan Ability Lab, 2013)</td>
<td>The test is a 14-item rating of a patient’s ability to complete balance tasks of increasing difficulty. Item scores range from 0–4 based on clinician rating of the patient’s success in performing each task; item scores are summed to obtain total score.</td>
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<td>Short Physical Performance Battery (Guralnik et al., 1994)</td>
<td>This brief test of standing balance, gait speed, and functional leg strength measures number of seconds a patient can maintain each of 5 different standing positions (maximum = 30 seconds), the seconds it takes to walk 4 meters at self-selected usual pace, and the seconds it takes to perform 5 chair rises in succession without using arms. Seconds for each task are converted to an ordinal score.</td>
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<td>Tinetti Performance Oriented Balance and Gait Test (Canbek et al., 2013; Tinetti, 1986)</td>
<td>The 16-item test evaluates balance and gait ability, in which a clinician rates performance of various standing positions and walking tasks.</td>
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A promising new application of gaming technology involves in-home use of the sensors to assess balance, gait, and fall risk (Stone et al., 2015). A commercially available sensor is unobtrusively installed near the ceiling in the main living areas of the patient’s home, collecting data continuously to capture the patient’s typical in-home function. Data are transmitted wirelessly to a remote database, where calculation algorithms examine the patient’s movement patterns over about one week to identify patient-specific baseline average performance. Subsequently, ongoing data are compared with this self-normed baseline performance and alerts for a clinician (e.g., a nurse practitioner at the oncology or primary care clinic) are generated when changes in gait speed, stride length, and stride time are detected. Such continuous, passive monitoring can be used indefinitely to monitor physical function during and after cancer treatment.

Continuous, unobtrusive monitoring provides a unique opportunity for nearly real-time assessment of small changes in performance (Rantz et al., 2015) to detect the need for more detailed assessment and treatment. TigerPlace, an independent senior living community in Columbia, Missouri, has integrated continuous, long-term monitoring using environmentally embedded technologies, including commercially available gaming sensor-based systems (Phillips et al., 2016; Rantz et al., 2008). The aim is to facilitate early initiation of support services to prevent deterioration of health and function. At TigerPlace, sensors transmit health and functional data from residents’ apartments to clinicians, including cardiorespiratory data, nighttime restless sleep, amount of time in bed, gait parameters, and suspected falls (Phillips et al., 2016). Although senior living is somewhat different than independent, stand-alone living arrangements for most community-dwelling patients with cancer, continuous unobtrusive monitoring is commercially available and translatable to use in patients’ homes during and after neurotoxic chemotherapy treatments by wirelessly syncing to the patient’s high-speed wireless Internet for data transmission to the oncology or rehabilitation provider. Sensor-enabled identification of subtle early changes in balance and gait during or after cancer treatment would improve on the current standard of care by triggering timely physical therapy referrals for targeted balance and gait rehabilitation, minimizing the likelihood of chemotherapy dose reductions that could negatively affect survival.

**Implications for Practice**

Individuals with cancer experiencing PN may face balance and gait impairments that place them at high risk for decreased physical function, falls, and injuries. Nurses often are the primary point of contact for patients interacting with the healthcare team, and it is important that they educate patients regarding balance and gait impairments and their associated fall risks.

Unfortunately, a thorough and quantitative balance and gait assessment is usually not part of standard care for individuals treated with neurotoxic chemotherapy. Gold standard quantitative assessment methods provide sensitive, granular information regarding the amount and nature of impairment but are burdensome and impractical to patients already saddled with numerous procedures and appointments related to their treatment. Gaming technology offers a practical, low-burden, cost-effective method to assess balance and gait in patients treated with neurotoxic chemotherapy. The small size and easy setup and administration of gaming sensors lends itself to use in a variety of providers across the continuum of care, including inpatient, outpatient, and home health settings. Therefore, gaming sensors improve on current practice in which patient reports of PN are often not followed by functional assessment and are typically treated with additional medications (Smith et al., 2014) or by limiting the chemotherapy dose (Cavaletti & Marmiroli, 2004; Kudlowitz & Muggia, 2013). Data provided by assessment technology can support referrals to rehabilitation providers and facilitate rehabilitation treatment plans.

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**Note.** Images courtesy of University of Missouri Center for Eldercare and Rehabilitation Technology. Used with permission.
Limitations

Despite their ease of use and their clinical applicability, gaming sensors have several limitations in their functional assessment capabilities. First, the intermittent sensors require some assistance from a bioengineer or computer engineer for initial programming of the calculation algorithms. Partnering with university bioengineering and rehabilitation departments allows access to these resources. Secondly, although continuous, passive, in-home monitoring requires no such partnering, the service (which includes device, installation, and continuous monitoring) requires a monthly subscription that is currently not covered by insurance. Given the growing recognition of rehabilitation as a key piece of the oncology care continuum (Cheville, 2005; Silver, 2015; Silver, Baima, & Mayer, 2013), oncology nurses could advocate for policies requiring coverage of health and physical function monitoring and intervention during and after cancer treatment to make such devices more accessible to patients. Third, although any trained clinic staff member can administer the tests, partnering with a physical or occupational therapist or physiatrist (rehabilitation physician) is advisable to aid in interpreting test results and establishing a rehabilitation treatment plan. Finally, patient perceptions of sensor intrusiveness could limit acceptability of the technology for clinic and in-home implementation. However, previous research suggests that, when shown the anonymity of the depth images, patients quickly adjust to the use of sensors and do not perceive them to be intrusive (Demiris et al., 2004; Rantz et al., 2008).

Conclusion

Poor physical function, falls, and injuries are serious clinical problems among individuals with cancer. Commercially available gaming technology represents a new frontier in point-of-care assessment for patients experiencing PN-related balance and gait impairment. The real-world implementation of gaming sensors in gerontology clinical settings is ripe for expansion into

### TABLE 3
SENSOR-BASED MEASURES FOR BALANCE AND GAIT ASSESSMENT

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<td>Body-worn sensors (Alqahtani et al., 2017; Chaudhuri et al., 2015; de Bruin et al., 2012; Grimpampi et al., 2013; Horak et al., 2015; Mancini et al., 2011; Sejadić et al., 2015)</td>
<td>Small sensors are attached by a belt or strap to the ankle, wrist, or waist. The sensors transmit data to a computer through direct upload or wireless transfer; some researchers use cell phones for data processing and calculation. The sensors calculate the amount of body sway during standing tasks, as well as walking speed, cadence (steps per minute), and step length during gait tasks.</td>
<td>Sensors are small, portable, and less expensive than the equipment required for gold standard measures, such as CDP or gait mapping. In addition, the sensors can be used during performance of valid clinical tests, such as the SPPB or Tinetti Performance Oriented Balance and Gait Test, or during a simple walking task. No special training for the end user (patient) is needed.</td>
<td>Most body-worn devices are best for laboratory use; widespread testing for real-world use is lacking. In addition, clear consensus is lacking regarding best sensor placement for optimal accuracy. Devices are larger and less aesthetically pleasing than commercially available fitness trackers, potentially decreasing acceptability to patients. Patients must remember to consistently wear the device; however, evidence suggests low adherence to such devices. The ability of accelerometers or gyroscopes to provide a complete characterization of balance and gait function is unclear, and research is lacking.</td>
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<td>Gaming systems (Auvinet et al., 2015; Mishra et al., 2015; Rantz et al., 2015; Stone &amp; Skubic, 2011, 2013)</td>
<td>For intermittent testing, the gaming sensor (e.g., Microsoft Kinect® or Nintendo Wii®) is mounted on a tripod near the testing area and connected to a laptop computer. Testing using clinical balance and gait tests, such as the SPPB, are performed within the gaming sensor’s field of view. Laptop computer software calculates parameters of interest (e.g., centimeters of postural sway, step length and width). For in-home continuous monitoring, the sensor is mounted on a shelf near the ceiling in the patient’s main living area and directly connected to a laptop computer or wirelessly connected to a remote server. Data are collected continuously in the background while the patient moves throughout the living space. Parameters of interest similar to those for intermittent testing are calculated by the computer.</td>
<td>The system provides precise, quantitative calculation of key balance and gait parameters (e.g., centimeters of postural sway, stride length and width). Equipment is cost-effective compared to gold standard tests and can be used at the point of care for intermittent testing or in the home for continuous, unobtrusive assessment. Ambient, environmental sensors using depth images are likely to be perceived as less intrusive than wearable devices or conventional video monitoring. In addition, minimal special training is needed to operate the sensor system. A clinician-friendly results dashboard could be designed to present results and interpretation to clinicians in a clinically useful manner.</td>
<td>Computational algorithm software for calculating balance and gait parameters are not currently commercially available; partnering with a university computer engineering department for software development is recommended. With intermittent testing, it is unclear whether inter-assessment performance variation indicates clinically meaningful changes, or “noise” (e.g., patient did not sleep well or has a minor illness such as a cold). In addition, gaming sensors have not yet been tested in the oncology population for characterizing balance and gait.</td>
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CDP—computed dynamic posturography; SPPB—Short Physical Performance Battery
ONCOLOGY CARE SETTINGS AND THE LIVED ENVIRONMENTS OF PATIENTS WITH CANCER FOR IMPROVED IDENTIFICATION AND TREATMENT OF INDIVIDUALS WITH PN-RELATED BALANCE AND GAIT IMPAIRMENTS.

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The authors gratefully acknowledge Bradford Harris, BS, Anup K. Mishra, and Benjamin Hotrabhavananda, students at the University of Missouri Department of Electrical and Computer Engineering, and Zachary Campbell, student at the Behrend College Department of Engineering, Pennsylvania State University, for technical assistance during the author’s ONS Foundation Career Development Award and for assistance with the figures and the manuscript.

The authors take full responsibility for this content. During the writing of this article, Campbell was supported by funding from the Association of Rehabilitation Nurses and the ONS Foundation Career Development Award. Skubic has previously consulted for Medtronic, has received support from Nokia, and has patents planned for a range of motion measurement and patents pending for an in-home sensor automated health alert system. The article has been reviewed by independent peer reviewers to ensure that it is objective and free from bias.

REFERENCES


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