Instructional Lecture: General Orthopaedics

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Evaluating physical function and activity in the elderly patient using wearable motion sensors

Bernd Grimm
Stijn Bolink

- Wearable sensors, in particular inertial measurement units (IMUs) allow the objective, valid, discriminative and responsive assessment of physical function during functional tests such as gait, stair climbing or sit-to-stand.
- Applied to various body segments, precise capture of time-to-task achievement, spatiotemporal gait and kinematic parameters of demanding tests or specific to an affected limb are the most used measures.
- In activity monitoring (AM), accelerometry has mainly been used to derive energy expenditure or general health related parameters such as total step counts.
- In orthopaedics and the elderly, counting specific events such as stairs or high intensity activities were clinimetrically most powerful; as were qualitative parameters at the 'micro-level' of activity such as step frequency or sit-stand duration.
- Low cost and ease of use allow routine clinical application but with many options for sensors, algorithms, test and parameter definitions, choice and comparability remain difficult, calling for consensus or standardisation.

Keywords: outcome assessment; physical function; gait analysis; activity monitoring; wearable sensors; accelerometry

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Introduction

Clinical outcome assessment serves both internal quality controls such as for the individual clinician or hospital, as well as external quality controls like joint registers, insurance assessments and wider society. It provides (bio) feedback to patients and caregivers, thus playing a role in patient empowerment and self-motivation. Outcome assessment in clinical trials, epidemiological studies or registers allows the identification of safe or unsafe procedures and the differentiation of therapeutic options to identify the best alternative. Evidence-based medicine relies on routine, valid and responsive evaluation methods including domains of function and activities as a major focus of orthopaedic intervention. Outcome-based evidence also guides the therapeutic innovation cycle and provides input into increasingly relevant health-economic considerations. Therefore, knowing, choosing and applying suitable outcome assessment methods is becoming increasingly relevant in clinical practice and research.

Evaluating physical function and activity

Function and activity have been captured by patient-reported outcome measures (PROMs), clinician-administered scales (CAS), and also by performance tests such as the Timed Up-and-Go (TUG),[1] or the 6-Minute Walk test (6MWT).[2] Lab-based gait analysis using tools such as video motion-capture, force-plates and electromyography (EMG) employs sophisticated biomechanical methods and produces highly accurate functional parameters (for example joint moments) for clinical research. All these methods have distinct disadvantages which have given rise to the development of wearable sensor techniques, which form the focus of this review.

The inherent subjectivity of PROMs affects the validity of assessing objectively measurable dimensions such as function or activity. In a recent review of PROMs for knee arthroplasty patients it was concluded that "a validated, reliable and responsive PROM addressing TKA patients has not yet been identified".[3] Another review studied twelve PROMs for the assessment of physical activities in osteoarthritis (OA) patients and concluded that there is "not enough evidence for any instrument to have adequate measurement properties".[4] Authors "recommend accelerometry for total joint arthroplasty follow-up studies",[4] a popular wearable sensor application. Also the Osteoarthritis Research Society International (OARSI) reviewed outcome assessment methods in a Delphi consensus study and besides recommending a core set of timed performance-based tests, assessment with wearable sensors is advocated to fully capture physical function in routine clinical outcome assessment.[5]

Wearable sensors

Low-cost wearable sensors promise to capture functional parameters identical or similar to those measured with lab-based techniques (e.g. opto-electronic motion capture systems). In particular inertial measurement units (IMUs) containing accelerometers and gyroscopes are widely available and used for orthopaedic outcome assessment.[6] While these techniques have been applied in younger orthopaedic patients, for example following sports injuries, this review focuses on clinical application in the elderly patient. Without applying a strict age limit this applies to patients at or beyond retirement age and focuses on disease and interventions most common in this group such as osteoarthritis, joint arthroplasty, fractures and falls.

Study aim

This review aims to give an overview of a) wearable sensor technologies in application, b) the available methods referring to algorithms and parameters used to analyse functional tests or activity monitoring data and c) the clinical application in elderly orthopaedic patients.

Wearable sensor technology

For evaluating physical function or physical activity, wearable sensors must capture kinematic or dynamic dimensions such as translational and rotational accelerations, velocities and displacements or forces and moments. Sensor measurement is captured either directly or indirectly and then further processed using additional information (e.g. boundary conditions) including those of human kinetics computer models.

The most commonly-used wearable sensors are inertial measurement units (IMUs). They contain individual or combined one-, two- or three-dimensional accelerometers and gyroscopes and have become accessible regarding measurement accuracy, size, cost, energy consumption or onboard pre-processing power through mass production, for example for automotive stability programmes and smartphones. Also magnetometers, GPS and barometer sensors are available, mostly in sensor fusion with an IMU. Wearable sensors that measure forces are yet less common and in orthopaedic publications seem restricted to pressure foils in shoe insoles. Wearable goniometers measuring deflection angles via elastic materials changing electrical resistivity are another class of sensors.

For the raw signal sensing units of IMUs there are only a few dominant manufacturers (for example Bosch, Invensene, STM) supplying to numerous hardware manufacturers producing specific solutions suitable for human motion analysis and activity monitoring. Thus, with regards to basic sensor resolutions, ranges and accuracies, many products are comparable. They differentiate themselves via design (shape, size, weight influencing patient compliance, skin movement artefact), functionality (for example control switches and LED, battery life, charging, configuration options, data output format), connectivity (cable, wireless) and data pre-processing which can produce derived parameters or use sensor fusion in combination with e.g. Kalman filters to increase accuracy. A few commercial offerings such as GaitUp (Renens, Switzerland) Dynaport (Den Haag, Netherlands), Xsens (Enschede, Netherlands), Delsys (Natick, MA) and Shimmer (Dublin, Ireland) also offer proprietary software algorithms for motion analysis or activity monitoring. Most published studies in orthopaedics have used self-developed algorithms.

When IMUs are attached to the human body in a multiple sensor array similar to markers in a lab-based video capture system, they produce similarly rich full-body motion analysis as with the commercial Xsens suit, which comprises up to 17 sensor nodes.[7] However, for routine clinical application such a multiple sensor, set-up is compromised by limitations of cost, time and analytical complexity, similar to lab-based motion capture. Thus many clinical applications have used mostly a single sensor or two accepting the compromise of limited but focussed motion parameters.

The routine clinical application usually focusses on detecting a few specific motion parameters or activity classes relevant to score the severity of a specific disease or recovery progress after an intervention. For this purpose, the application of wearable sensors for functional assessment usually involves a) the definition of a specific movement task (e.g. gait), b) the choice of location for a single sensor (such as sacrum) followed by a c) specific signal analysis for feature detection (acceleration peaks, for example) to be used to calculate a specific functional parameter (e.g. step frequency asymmetry) or in physical activity monitoring to classify a certain activity such as stair climbing.

Physical function

A thorough search of the literature demonstrated a broad heterogeneity of methods to assess physical function with wearable sensors. This section and Table 1 offer a brief overview of the different functional tests, wearable sensors and motion parameters that are most commonly used in orthopaedics.

Gait

Gait analysis is the most applied method for objective assessment of physical function in orthopaedics, and represents a main rehabilitation goal. As already described in recent reviews,[8-14] a wide variety of wearable sensors can be used for gait analysis, measuring different gait characteristics from various body parts. Wearable sensors include pressure insoles, footswitches, accelerometers, IMUs, and electromyography.

A sensor attached to the foot is most accurate to detect gait events (heel strike, toe off, for example) and is regarded as the reference method for other systems.[14] Footswitches and pressure insoles are load-dependant or force-sensitive wearable sensors placed between the sole

Table 1. Overview of available methods to assess physical function of the lower extremity with wearable motion sensors

Functional tests	Sensor type	Sensor location	Motion parameters	Clinical application	References
Gait	Pressure sensor	Shoe	Ground reaction force	Healthy persons	43
	Force sensitive insoles	Foot	Gait events	Post-stroke	44,45
	Ultrasonography	Heel	Gait phases	Healthy persons	46
	Accelerometer	Sacrum	Spatiotemporal	Osteoarthritis	18
		Heel and toe	Gait events	Healthy persons	47
		Ear	Gait events	Osteoarthritis	48,49
	Inertial sensor	Sacrum	Spatiotemporal Stride variability Pelvic range of motion	Osteoarthritis Frailty	29,50,51
		Trunk: sacrum–C7	Spatiotemporal Trunk range of motion Pelvic range of motion	Osteoarthritis	52
		Thigh and tibia	Gait events Spatiotemporal Knee range of motion Knee angular velocity Hip range of motion	Healthy persons Osteoarthritis Knee brace Ankle brace	29,53
		Shoe	Spatiotemporal Angular velocity	Hemiparetic patients Real time feedback	54,55
		Lower back, thigh, shank, foot	Hip range of motion Knee range of motion Ankle range of motion	Healthy persons	56,57
	Electromyography	Thigh and shank	Muscle activity Power spectrum Gait phases	Healthy persons Hemiplegia	21,22
Running	Inertial sensor	Sacrum, thigh and tibia	Knee flexion Knee angular velocity	Osteoarthritis	29
Sit-to-stand	Inertial sensor	Sternum, lower back, thigh and tibia	Angular velocity Acceleration	Frailty Fall detection	28
	Inertial sensor	Trunk: S1-L4	Phase detection Trunk range of motion Vertical Acceleration	Frailty Osteoarthritis Parkinson	6,58,59
	Flexible goniometer	Sewn into trouser: waist, thigh, knee	Temporal event detection	Osteoarthritis	27
Sit-to-walk	Accelerometer Foot pressure sensor	Trunk: L3-L4.	Acceleration Foot pressure Trunk range of motion	Healthy persons	60
	Inertial sensor	Sacrum, thigh and tibia	Knee flexion Knee angular velocity	Osteoarthritis	29
Timed up-and-go	Smartphone	Sternum	Trunk acceleration	Frailty	61
	Inertial sensor	Sternum, lower back, thigh and tibia	Angular velocity trunk Spatiotemporal gait	Frailty Fall detection	28
	Inertial sensor	Sternum, shank, wrist	Angular velocity trunk Spatiotemporal gait	Parkinson	62
	Inertial sensor	Trunk: L2	Acceleration Angular velocity	Fall detection	63
	Inertial sensor	Sacrum, thigh, tibia	Knee flexion Knee angular velocity	Knee osteoarthritis Frailty	1,29
Stair climbing	Inertial sensor	Sternum, hip	Acceleration Jerk Peak power Velocity	Frailty	30
Block step-up	Inertial sensor	sacrum	Trunk range of motion Trunk angular velocity Vertical acceleration Asymmetry	Osteoarthritis	25,33
Squat	Inertial sensor	Chest, thigh, ankle	Knee flexion Hip external rotation Trunk range of motion	Knee osteoarthritis	38
Straight leg raise	Inertial sensor	Chest, thigh, ankle	Raise angle Hip external rotation	Knee osteoarthritis	38
Joint motion					
– Patellofemoral	Accelerometer	Patella	Vibro-acoustic signals	Patellofemoral joint disorders	34,35
– Tibiofemoral	Inertial sensor Textile goniometer	Femur and tibia Knee brace	Range of motion	Healthy persons Multiple Sclerosis	64-66
– Hip joint	Inertial sensor	Thigh, shin and foot	Flexion Abduction External rotation	Healthy subjects	67
Joint stability					
– Pivot shift	Inertial sensor	Tibia and femur	Rotational rate Peak acceleration	ACL deficiency	36
Balance	Accelerometer	Sternum, waist, ankle	Acceleration	Fall detection	68
	Inertial sensor	Trunk	Trunk range of motion Angular velocity Acceleration	Healthy persons Parkinson Post-stroke	41,69,70
	Inertial sensor	Lower back, thigh, shank	Centre of mass sway Hip joint sway Angle joint sway	Frailty Peripheral artery disease	42

of the foot and the ground, which provide information during each gait phase.

Accelerometers are most often used to derive spatio-temporal gait parameters (e.g. cadence, step length). In previous studies, a single accelerometer positioned at the dorsal side of the lower back close to the body's centre of mass, has been advocated for optimal clinical feasibility and accuracy.[15-17] Spatio-temporal gait parameters can discriminate gait between healthy subjects and OA patients and have been used to objectively assess functional outcome following a total joint replacement.[18]

Inertial measurement units (IMUs) have become increasingly popular as they allow kinematic characterisation of gait, supplementary to spatio-temporal gait parameters. By attaching an IMU onto a body segment, the orientation of that body segment can be determined, and a previous systematic review of the literature[19] demonstrated high accuracy for most devices compared to gold standard optoelectronic motion capture systems. Clinical applications include single and multiple linked sensor set-ups to measure a wide variety of motion parameters including range of motion of the trunk and pelvis, joint angles of the hip, knee and ankle as well as angular velocity (i.e. angular rate; °/s) of the thigh and shank. Therefore, IMU-based gait analysis is a feasible and sophisticated tool for routine functional outcome assessment in orthopaedics.[20]

Electromyography (EMG) captures the electric activity from muscles and wearable EMG sensors have become available in fusion with IMUs to enrich kinematic gait analysis with muscle activity.[21,22]

Sit-to-stand test

Another frequently-used test to assess physical function with wearable sensors is the sit-to-stand (STS) test, as it is regarded as a biomechanically more demanding functional task than gait.[23] In literature, the STS test has been enhanced with single IMUs attached onto the trunk (lumbar spine, sternum) to measure trunk inclination as known compensation mechanism adopted to avoid pain or as a result of persistent muscle weakness.[24,25] To measure trunk movement with a single inertial sensor, it has been demonstrated that the optimal location of the sensor is achieved by locating the sensor at a level approximate to L1.[26] Multiple linked sensors have also been applied in literature and allow additional assessment of joint kinematics from the hip and knee.[27]

Timed Up-and-Go test

The Timed Up-and-Go (TUG) test is commonly used in clinical practice and has demonstrated good measurement properties in elderly populations.[28,29] The TUG test encompasses multiple activities including the transition from sit-to-stand, walking a short distance and turning while walking. A few studies have used wearable sensors for objective and precise timing of the TUG transition phases and to derive motion parameters from each transition phase. IMUs are most often applied and have been attached onto the trunk, sternum, thigh, tibia and shin to capture trunk acceleration, angular velocity of the lower limbs and range of motion of the hip and knee.

Stair climbing test

Stair climbing is a common activity limitation and rehabilitation goal in elderly orthopaedic patients to establish safety and independence. The preferred stair test for clinical application is a nine-step test with step heights of between 16 cm and 20 cm, and the use of handrails or assistive devices should be recorded.[5] IMUs attached at the sternum, sacrum, hip, thigh and tibia have been used in clinical studies, measuring trunk and lower limb acceleration and angular velocity to detect frailty in elderly patients[30] and to assess functional outcome after total joint replacement.[29]

Block step-up test

The block step-up test has been used in a few clinical studies as a practically more feasible surrogate for the stair climbing test[6,25,31,32] In block step-up one leg is isolated, providing asymmetry measures which make the test particularly suitable to monitor improvement after surgical procedures.[33] An IMU at the lower back has been used to derive trunk inclination, trunk angular velocity and vertical acceleration.[6,25,33]

Joint-specific functional tests

Patellofemoral joint motion has been assessed analysing the vibro-acoustic signals from an accelerometer attached onto the patella.[34,35] In addition, wearable motion sensors have also been used to assess joint stability tests such as assessment of ACL insufficiency by measuring rotational rate and peak accelerations with an IMU applied in the Pivot Shift test.[36] Furthermore, IMUs have been applied to measure shoulder joint function before and after orthopaedic interventions.[37]

Rehabilitation tests

Wearable sensors are used to objectively score functional outcome and to monitor rehabilitation in a more continuous modality. Several rehabilitation exercises such as straight leg raises and squats have been enhanced with wearable inertial sensors and additional interactive virtual interfaces have been developed to provide direct feedback.[38-40]

Balance tests

Balance is measured across a wide range of clinical populations, especially patients with neurological disorders such as elderly at risk for falls.[41] In many clinical balance tests such as the Romberg test and the Balance Error Scoring System (BESS), patients keep their eyes closed while performing specific tasks.[42] In the BESS, differences in support surface (foam and firm) and the base of support (single-leg, double-leg, and tandem stance position) across six tasks challenge a person's balance and wearable IMUs have been used to measure three-dimensional body sway from the centre of mass (COM), hips and ankles.[41]

Physical activity monitoring

Physical activity monitoring (AM) primarily refers to the quantitative analysis of activities performed in the habitual environment over various days. Physical activity (PA) has been recognised as a major factor in general health. The increased mortality documented for untreated hip OA is attributed to reduced PA. The need to measure PA in joint arthroplasty to provide evidence for treatment guidelines is recognised.[71] Furthermore, PA can be a protective factor (e.g. bone density[72]), but also a risk factor for orthopaedic disease (e.g. fatigue fracture). PA is also reviewed as largely independent of hip and knee function thus requiring separate assessment.[73] In addition, PA is a critical input to implant design where fatigue and wear are a function of use and not time.[73]

Patient-reported activity

Patient-reported activity measures assess perceived physical activity and thus suffer from subjectivity. In a systematic review of 12 PROMs to measure PA in hip and knee OA patients, it was concluded that there is "not enough evidence for any instrument to have adequate measurement properties"[4] and accelerometry was recommended. Accelerometry also revealed insufficient validity of another PROM, the 'Physical Activity Scale for the Elderly' (PASE).[74]

Objective activity measurement

Traditionally, sensor-based AM has focussed on energy expenditure measured as metabolic equivalent of task (MET), an important parameter in general health, obesity or sport, exercise and lifestyle. One-, two- or three-dimensional accelerometer peak counts are processed on-board the sensor to produce energy expenditure or classify, for example, 1-minute activity intervals into low-, moderate- and high-intensity activities, the latter two usually pooled into minutes of moderate and vigorous PA (MVPA).

In orthopaedics, energy expenditure is a rather unspecific parameter, and so this approach has not often been used. In one study,[75] patients indicated for THA or TKA burned the same calories/day as healthy controls and neither gender, nor hip or knee OA, had an influence. In another study,[76] energy expenditure was not different prior nor at any time point up to 12 months post-TKA, thus showing no responsiveness. Furthermore, no treatment effect has been measured six months after THA and TKA when only general, non-disease specific parameters like sedentary time were used.[77]

For evaluating orthopaedic conditions or interventions, specific activity events promise to be more indicative considering the frequency, intensity, time and type (FITT) components of PA described by the World Health Organization. Identifying specific activity types, counting and timing them, plus possibly deriving qualitative activity parameters (e.g. cadence) seem diagnostically relevant and responsive parameters.[78]

AM technology

Activity classification at clinical grade needs elaborated algorithms, usually requiring post-processing in a computing environment such as Matlab (Natick, MA). A review of signal processing and classification techniques[79] describes heuristic approaches where gravity for example defines the inclinometer reference for the accelerometer to differentiate sitting from standing, or where harmonic acceleration peaks identify steps. Other approaches involve machine learning techniques including neural networks, fuzzy logic, support vector machines, Markov chains, k-Nearest-Neighbors algorithm, decision trees, (un-)supervised learning, and others. In addition, parameters are derived using complex analysis such as wavelets or entropy measures. The algorithms depend also on the sensor type or modality (mostly accelerometers, increasingly IMUs plus barometers, for example) and the sensor location. Common sensor locations for identifying activities are the hip (belt), thigh, sacrum, chest, ankle and wrist compromising between accuracy (thigh) and user-friendliness (wrist).

The multitude of sensor, location and algorithm choices has led to a great proliferation of solutions for clinical use. First there are commercial devices with proprietary analysis software such as Actigraph (Pensacola, FL), StepWatch (Washington, DC), Shimmer (Dublin, Ireland), Dynaport (Den Haag, Netherlands), ActivPal (Glasgow, UK), Gaitup (Renens, Switzerland), RT3 and others. Algorithms are usually not disclosed or adaptable and mostly there is no specific validation for orthopaedic patients. Secondly there are research groups who use the devices above or any other multi-purpose accelerometer to post-process the raw signal with their own software. Algorithms are usually disclosed but validation for orthopaedic patients against a reference such as video observation is also rare. Even with validation available protocols and benchmark parameters (classification accuracy) are hardly comparable.

Most AM sensors comprise accelerometers where battery life and data storage capacity (up to 100 MB/day) match common measurement periods of 4-7 days. Typical g-ranges of ±2 g, ±4 g, ±8 g or ±16 g are fixed or can be configured with most human motions not exceeding 2 g but interesting high intensity events such as running or stumbles and falls requiring a ±4 g or ±8 g range.[72] Sample frequencies are set up to 50 Hz or even higher when also qualitative information (micro-level) from the macro-level activity events is to be measured. Fixation is via clips, bands or similar on clothes, or directly to the skin using adhesive tapes. Reported measurement periods in orthopaedic studies vary between one and 15 days.

A study comparing the standard 7-day to a 4-day protocol in TJA patients[80] showed agreement within ±5% while not recommending further reduction.

Activity studies in elderly orthopaedic patients

Clinical studies using AM in orthopaedics used accelerometers and investigated reference data, comparisons between patients and controls or guidelines,[81] correlations with disease severity or other scores (PROMs) and treatment effects.

In a meta-analysis,[81] it was shown that only small to moderate proportions of patients with knee or hip OA met physical activity guidelines (150 minutes/week MVPA) and recommended daily steps (10 000 or 7000). In a study on rheumatoid arthritis (RA) average daily MVPA minutes were less in RA patients (23 min) than in healthy controls (33 min) and correlated with RA disease activity.[82]

In a longitudinal study[83] comparing pre-op, 3 and 6 months' outcome of THA and TKA using PROMs, functional tests and two-sensor accelerometry, general activity parameters such as the total 'time upright' or 'time walking' and the 'number of sit-stand transfers' did not improve, while PROMs and functional tests increased significantly. This indicates that activity is a largely independent outcome measure and that activity parameters need to be more specific or more qualitative than quantitative alone. The same group showed in another study[84] that only qualitative 'micro-level' parameters such as 'stride frequency', a self-defined 'motility' as an intensity measure and 'sit-stand transfer times' improved significantly post-TJA. Four-year results published later[85] showed that general activity parameters like daily 'time active' actually fell below 6 months values while qualitative activity parameters such as 'sit-stand duration' continued to improve significantly.

In another longitudinal accelerometry study[86] TKA patients increased their mean daily gait cycles (1 cycle = 2 steps) from pre-op 4993 to 5932 cycles at 1 year. In a comparable study set-up,[87] TKA patients also increased average daily step counts but at lower levels from pre-op 5278 to 6473 steps at 1 year. However, more specific parameters with a qualitative or performance component were more responsive such as 'moderate to vigorous steps per day' which almost doubled from 1150 to 1935 steps while staying far below age-matched healthy controls.

Accelerometry has also provided evidence for the faster recovery following minimally invasive (MIS) versus standard surgery in TKA.[88] The mean number of days to reach 80% of pre-operative 'cumulative acceleration' levels was 3.3 for MIS and 7 days for standard surgery.

In a hip fracture trial,[89] a comprehensive geriatric care protocol led to a 28% higher 'upright time' (or 'time-on-feet') in the first post-operative days. Comparing activity[90] on admission and 2 weeks after hip fracture elderly subjects significantly increased walking time from 7.0 to 16.3 minutes.

Popular consumer activity monitors (e.g. FitBit) have been shown to lack the accuracy[91] required for clinical grade assessments. Especially in elderly patients with reduced mobility or walking aids, errors were > 60% for hip and wrist sensor locations.[92]

Discussion

Wearable sensor motion analysis and activity monitoring have been used in numerous orthopaedic studies including the elderly patient. For the routine objective assessment of physical functions many parameters for tests of gait, sit-stand, stair or step-up tests have been validated for single or multiple IMUs and used in clinical trials. With low cost and easy operation also by non-experts often requiring the same or less time than collecting a questionnaire, they supplement conventional clinical scores and provide additional diagnostic value or outcome evidence.

More widespread use seems to be hindered only by the vast variety of sensor, test and parameter options. It would be advisable to create consensus in the clinical and research community on a minimum, recommended or extended set of functional tests, sensor configurations and test parameters to standardise these outcome tools, popularise their valuable use and increase comparability between studies.

Similar statements can be made for activity monitoring. The evidence for the value of objective free field AM in orthopaedics and elderly patients is clear. However, too many variants of sensors, locations, algorithms and parameters exist to justify a clear choice. In a relatively young discipline, much standardization or consensus cannot yet be found nor may even be helpful. However, reporting the system's state of validation, parameter definitions and results in comparable formats would help the discipline to grow and be directed in a clinically useful way. Reference data boosts the value of new studies.

General quantitative activity parameters such as energy expenditure, time upright or daily steps seemed less discriminative and responsive in orthopaedic applications. More specific event counts such as steps in MVPA or climbing stairs were clinimetrically more powerful as were the calculation of qualitative parameters from the activity data at 'micro-level' such as step frequency or sit-stand duration.

In the future, the disciplines of wearable sensor assessment of function and activity will merge to the level permitted by technology, patient compliance but also context required to derive reliable functional parameters.

As wearable sensor technology is becoming more common, integrated into objects of daily living like smartwatches or clothes and connected to phones, the computational cloud or e.g. exercise equipment (internet-of-things), AM will be automated and pervasive. It likely goes beyond clinical outcome assessment to support biofeedback, exergaming or big-data analysis of activity related pathogenesis and remote health, something of particular value for the elderly orthopaedic patient.

AUTHOR INFORMATION

AHORSE Research Foundation, Zuyderland Medical Center, Heerlen, The Netherlands.

Correspondence should be sent to Bernd Grimm, AHORSE Research Foundation, Department of Orthopaedic Surgery and Traumatology, Zuyderland Medical Center, Heerlen, The Netherlands.
Email: bp.grimm@gmail.com

CONFLICT OF INTEREST

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