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Mobility monitoring using smart technologies for Parkinson's disease in free-living environment

Heesook Son [a], Won Seok Park [b], Hyerang Kim [c,*]

[a] Chung-Ang University, Red Cross College of Nursing, Seoul, South Korea
[b] Chung-Ang University, Subject Information Service Team, Seoul, South Korea
[c] Chung-Ang University, Red Cross College of Nursing, Seoul, South Korea

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ABSTRACT

Background: Technological advances in the monitoring, intervention, and rehabilitation of Parkinson's disease have increased dramatically in recent decades. Integrating such technologies into free-living environments ensures continuous monitoring of patients' symptomatic movement for better assessment and provision of quality care.
Aim: To review studies testing the feasibility and usability of technology for continuous mobility monitoring among patients with Parkinson's disease in free-living environments.
Methods: Using electronic databases, 31 original studies were identified. We classified the mobility monitoring devices and systems used in the feasibility tests for monitoring Parkinson's disease during daily activities in free-living environments.
Findings: The choice of technology for Parkinson's disease management varied in its advantages, including cost, usability, design and functionality, or quality of information. The major developments in home monitoring approaches can be classified as: (1) wearable sensors only; (2) smartphone applications; (3) web-based applications combined with wearable devices; and (4) ambient sensors combined with wearable devices. The findings from this review suggest that mobility monitoring devices are highly feasible for monitoring the daily activities of patients in a habitual free-living environment. However, there are still relatively few studies testing the feasibility and effectiveness of such devices in free-living environments.
Conclusions: Experimental studies seeking to validate monitoring systems in unstructured real-life environments remain limited. However, the major findings of this study indicate that new technologies can be useful and supportive tools for Parkinson's disease related mobility monitoring. The use of these technologies for Parkinson's disease management may provide qualified clinical evidence and improve clinical decision-making and quality of care.

1. Introduction

Parkinson's disease (PD), a neurodegenerative brain disease, is one of the most common chronic movement disorders, affecting an estimated 5 million individuals worldwide at present (de Lau & Breteler, 2006; Dorsey et al., 2007). As the population ages, the incidence and prevalence of PD are expected to increase exponentially, with the number of patients reaching upwards of 40 million in 2020 (Xia & Mao, 2012). The high prevalence of PD and its complex associated medical demands impose a considerable social and economic burden on health care in this patient group. This has urged healthcare providers to develop a more efficient management system to meet patients' needs as the disease progresses.

PD is characterized by symptoms such as resting tremor, bradykinesia, postural instability, and gait disorders (Xia & Mao, 2012), all of which become progressively worse as the disease advances (Zwartjes, Heida, van Vugt, Geelen, & Veltink, 2010). Although the cause and aetiology of PD remain unknown (Wider & Wszolek, 2008), its major motor symptoms are clinically associated with losses in the dopaminergic neurons of the basal ganglia (Galvan & Wichmann, 2008). This disease-specific impairment leads to gait disturbance and imbalance, thus disrupting mobility and functional independence, restricting normal performance of daily activities, and consequently impairing quality of life (Chaudhuri, 2011; Shulman, 2010).

* Corresponding author at: Chung–Ang University, Red Cross College of Nursing, 84 Heukseok–ro, Dongjak–gu, Seoul 06974, Korea.
E-mail addresses: hyerangkim@cau.ac.kr, hkim167@hotmail.com (H. Kim).

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Summary of relevance

Problem or issue

Despite increasing use of technology in mobility monitoring, relatively little is known about the feasibility and usability of such technology for patients with Parkinson's disease in free-living environments.

What is already known

Smart technology has been integrated into healthcare, and is becoming an increasingly viable option for assessing mobility among patients with Parkinson's disease.

What this paper adds

Experimental studies seeking to validate monitoring systems in free-living environments remain limited. New technologies can be useful and supportive for mobility monitoring of patients with Parkinson's disease. The use of these technologies for Parkinson's disease management might provide useful clinical evidence as well as improve clinical decision-making and quality of care.

The features of gait impairments can be classified into chronic and episodic. The chronic features are, overall, hypokinetic in nature, and comprise slow speed, underscaled step length, reduced foot clearance, narrow step width, reduced counter-rotation of the trunk, and decreased arm swing (Morris, 2006). The episodic features, by contrast, are unpredictable and intermittent, tend to include festination, hesitation of gait initiation, and a 'freezing of gait', which refers to when gait cannot be voluntarily initiated or maintained (Giladi, 2001). The symptoms of gait impairment not only lead to altered walking pattern, but are also major contributors to falls among patients with PD (Boonstra, van der Kooij, Munneke, Bloem, 2008; King & Horak, 2009). Falls are one of the most severe health-related outcomes of disturbed gait and balance among patients with PD (Kerr et al., 2010), and are a cause of a number of negative outcomes such as injuries (Johnell, Melton, Atkinson, O'Fallon, & Kurland, 1992), fear of falling (Adkin, Frank, & Jog, 2003), reduced mobility and a concomitant development of weakness (Sato, Kikuyama, & Oizumi, 1997), deterioration in fitness, loss of independence, increased risk of institutionalization (Hely et al., 2001), and reduced quality of life and survival (Bloem, Hausdorff, Visser, & Giladi, 2004).

Healthcare providers and researchers have relied on performance-based clinical scales and subjective reports from patients and their caregivers to obtain information on impaired motor symptoms. Various clinical rating instruments have been validated and widely used to objectively measure motor symptom severity in clinical practice. For example, the Motor Examination (Part III) portion of the Unified Parkinson's Disease Rating Scale (UPDRS) is an internationally accepted measure of motor symptoms for use in both routine clinical practice and clinical trials (Goetz et al., 2008). Motor impairments and symptom severity can also be assessed via informant-report from patients or caregivers. Self-report measures and diaries are useful for contextualizing patients' performance across multiple unstructured environments and over an extended period of time (Sikkes, de Lange-de Klerk, Pijnenburg, Scheltens, & Uitdehaag, 2009). However, these traditional approaches have limited capability to evaluate everyday functional abilities in a comprehensive manner. In particular, they are subject to restricted data collection, notable inter-rater variability, and reporters' perceptual and recall biases (Schmitter-Edgecombe, Parsey, & Cook, 2011; Zwartjes et al., 2010). This signals a compelling need to develop continuous and objective measures of functional mobility.

Recently, advances in technologies such as wearable sensors, ubiquitous networking, and embedded sensors have enabled healthcare providers to automate assessment of patients' movement in real-life environments (Schmitter-Edgecombe, Parsey, & Lamb, 2014). This has led to the creation of so-called 'smart environments', where sensors are used to collect data about residents' movements while they perform their normal daily routines without needing to modify such behaviour. This enables continuous assessment of normal movement and a better understanding of the behavioural impacts of various health conditions. Devices and systems that can assimilate contextual information to support care decisions have been defined as 'intelligent health care technology' or 'smart technology'. This can provide data that aid in clinical assessment and elucidate the comprehensive behavioural patterns that arise in certain circumstances as the disease progresses. Additionally, the advancement of wearable and wireless networking systems has led to the development of numerous tools and services for real-time monitoring in unsupervised, habitual environments while the individual performs his or her independent activities of daily living (called free-living). However, relatively little is known about the progressive features of mobility monitoring using such advanced technology among patients with PD in real-life situations.

2. Related works

With the growing interest in objective assessment of PD symptoms using technology-based devices, considerable attention has been given to the reliability and validity of such devices in clinical settings (Godinho et al., 2016; Hubble, Naughton, Silburn, & Cole, 2015; Ossig et al., 2016). Given the heterogeneity and complexity of outcomes of technology-based measurement, researchers have made efforts to ensure the relevance and reliability of objective sensor-based measurements. Horak and Mancini (2013) and Hubble et al. (2015) summarized sensor types and outcomes through by utilizing sensor-based metrics of postural balance and gait stability as surrogate biomarkers of gait and balance impairment. Ossig et al. (2016) summarized the features of current wearable sensor-based devices to quantify various PD motor symptoms. However, these reviews focused on the reliability and validity of sensor-based measurement for observing or identifying differences in symptoms in comparison with surrogate indicators and clinical screening tools in supervised environments.

Godinho et al. (2016) performed a systematic review to determine the validity of monitoring technologies for assessing the motor symptoms of PD in clinical settings. They classified heterogeneous monitoring devices as wearable, non-wearable, and hybrid devices and then ranked devices in terms of validity and feasibility. Unlike previous reviews, which conducted validation and feasibility tests in controlled experimental studies, Del Din, Godfrey, Galna. Lord, and Rochester (2016) extracted data from tests of wearable monitoring technologies in free-living environments and summarized their detection, accuracy, validity, and utility. They measured the volume and patterns of habitual behaviours during activities of daily living as well as used standardized tasks to detect discrete features of movement, in order to provide a snapshot of clinical assessment. Furthermore, they included comparatively more advanced technology such as mobile devices in addition to wearable sensors. Other monitoring technologies such as ambient sensors and embedded sensors were not included and multimodality approaches were not considered. They concluded that there were insufficient validated systems for continuous monitoring of clinical symptoms of PD in free-living environments because of methodological heterogeneity (i.e., device placement, experimental settings, comparisons, duration, measurements) and inconsistent outcome measures. Particularly, the sustainability and practicability of technology-based devices as clinical endpoints for monitoring symptoms and supporting the clinical care of patients with PD remained compromised. Overall, previous litera-

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