

## Ambulatory Assessment of Lifestyle Factors for Alzheimer’s Disease and Related Dementias

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### Abstract

Considering few treatments are available to slow or stop neurodegenerative disorders, such as Alzheimer’s disease and related dementias (ADRD), modifying lifestyle factors to prevent disease onset are recommended. The Voice, Activity, and Location Monitoring system for Alzheimer’s disease (VALMA) is a novel ambulatory sensor system designed to capture natural behaviours across multiple domains to profile lifestyle risk factors related to ADRD. Objective measures of physical activity and sleep are provided by lower limb accelerometry. Audio and GPS location records provide verbal and mobility activity, respectively. Based on a familiar smartphone package, data collection with the system has proven to be feasible in community-dwelling older adults. Objective assessments of everyday activity will impact diagnosis of disease and design of exercise, sleep, and social interventions to prevent and/or slow disease progression.

### Introduction

Not only are the work, social, and daily living functioning affected for individuals with Alzheimer’s disease and related dementias (ADRD), but caring for these individuals is a long-term progressive burden. In Canada, while the projected number of dementia cases is expected to increase 2.3 times to 1.1 million people by 2038, the projected associated economic burden attributed to dementia is expected to increase by 10 times to \$153.6 billion dollars annually (Smetanin, Koblak, Briante, Sherman, & Ahmand, 2009).

Few treatments are available to slow or stop the deterioration of brain cells in neurodegenerative disorders such as Alzheimer’s disease. The accepted view today is

that reducing modifiable risk factors is the most effective way of reducing the chances of developing or slowing progression of disease (Smetanin et al., 2009; Qiu, De Ronchi, & L. Fratiglioni, 2007). Specifically, promoting a healthy diet, physical activity, an active social life, and intellectual stimulation are the recommended strategies for reducing the onset risk and progression of ADRD (Smetanin et al., 2009; Qiu et al., 2007).

Lifestyle risk factors are assessed primarily through self-reporting, which is subjective and depends on good recall. Considering memory impairment is the hallmark of Alzheimer’s disease, self-report assessments of everyday activities may be misleading. For example, objectively determined greater physical activity is associated with lower incidence of cognitive impairment (Middleton et al., 2010). The purpose of this project is to develop an ambulatory sensor system to provide objective and



Figure 1: VALMA system components. Google Nexus One smartphone, headset, accelerometers and ankle straps.

accurate assessments of everyday activity related to risk factors for ADRD.

## Voice, Activity, and Location Monitoring for Alzheimer’s Disease (VALMA)

Drawn from population studies [1-3], lifestyle factors related to ADRD can be categorized into nutritional, physical, social, intellectual, and sleep activity domains. A candidate list of wearable sensors capable of capturing these activity domains in an ambulatory manner was first compiled, and screened using the system design criteria.

The overall system design criteria were based on applicability to the elderly population at greatest risk for ADRD. The system needed to be:

- i) unobtrusive (i.e., maintain regular appearance)
- ii) sensitive (i.e., high resolution)
- iii) simple to use and control
- iv) considerate of private data.

Sensors to capture limb motion, GPS location, and audio fit the design criteria and the data needs to profile physical, social, and sleep activities. Based on these sensors, the Voice, Activity, & Location Monitoring for Alzheimer’s disease and related dementias (VALMA) system was developed.

### System Description and Procedures

The VALMA system (Fig. 1) is comprised of 2 main components: 1) a smartphone, and 2) accelerometers placed on each ankle.

The core of the system is an application running on a smartphone (Nexus One, Google, Inc.), which runs Google’s Android mobile operating system. The phone contains a GPS receiver which the application uses to record location data. A wired headset is connected to the phone and audio data is recorded through the headset’s microphone. Both GPS and audio data are stored on the phone’s SD card. For privacy, the user interface includes the ability to stop, and later resume, the audio recording. In addition, the user may listen to any of the audio that was recorded and delete the files as they wish. For this purpose, the audio is recorded in five minute segments.

A pair of self-logging 3D linear accelerometers (X6-2 Mini, Gulf Coast Data Concepts, Inc.) are placed bilaterally on the ankles using custom-built velcro straps. These accelerometers operate independently of the phone and record data to their own internal memory, which is later retrieved via a USB connection.

To synchronize the clocks of the phone and accelerometers, a knocking procedure was adopted. Both accelerometers were held in one hand and 5 knocks to a table were performed with the microphone in close

proximity. This procedure produced sharp acceleration and noise records as a common time reference.

In pilot studies, the feasibility of collecting everyday activity using the VALMA system for 4 days was assessed in 2 healthy older adults and 1 ADRD patient. At the start of the collection, a 15 minute training session on how to operate the VALMA system was given to each participant. Each morning, participants started the VALMA application and attached the microphone and daytime ankle accelerometers, typically underneath clothing. In the evening, the smartphone and set of daytime accelerometers were recharged. A second set of accelerometers (charging throughout the day) were attached to the ankles to capture sleep activity during the night. A dedicated telephone support line was provided to provide technical assistance, if needed.

Initial feedback from the pilot study indicated that collection using the system is feasible in older adults, and in ADRD patients with caregiver assistance. Participants reported that the system did not interfere with their daily activities and demonstrated high compliance rates. The privacy function (i.e., audio off) was used once during pilot testing.

### Physical Activity Measures

Regular exercise, even low-intensity activity, has been associated with reduced risk of dementia and cognitive decline (Abbott et al., 2004). The VALMA system extracts the most common type of physical activity, walking, from the ankle accelerometers. To extract walking activity, ankle acceleration data were high-pass filtered to remove gravity, followed by identification of bilateral limb activity using a cross-spectral approach. Time segments with bilateral leg activity were then inspected visually to confirm walking ( $\geq 3$  steps). Figure 2 plots example acceleration records for the left and right ankles and identified walking segments.

Currently, the VALMA system measures total walking

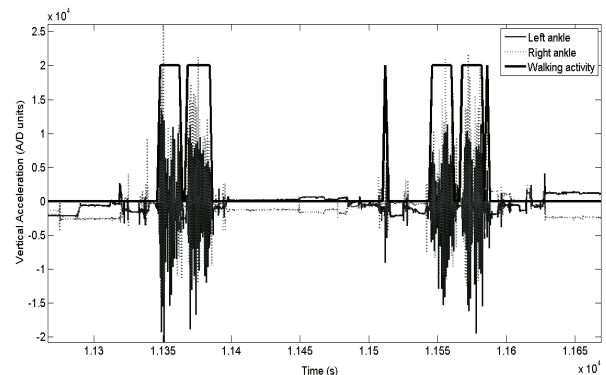


Figure 2: Sample ankle accelerometer record with identified walking activity. Walking activity is defined as reciprocal ankle motion with 3 or more steps.

duration and the number of walking bouts. Placing sensors at the ankle bilaterally permits measurement of gait events, such as heel strike and toe-off, to provide more detailed indices of gait. For example, step variability has been used to indicate balance control during gait (Sheridan, Solomont, Kowall, & Hausdorff, 2003).

### Sleep Measures

Disordered sleeping patterns, such as increased number of awakenings and reduced (deep) slow-wave sleep duration, have received increasing attention as a risk factor for AD (Yesavage et al., 2003). Initial assessments of sleeping behaviour rely primarily on patient self-reports, which are subjective and lack the sensitivity of laboratory measures. However, laboratory assessments are limited to snapshots in time that may not reflect natural everyday patterns and require expensive resources.

Motor activity measured by limb accelerometry has been used as a proxy measure for the resource-intensive sleep laboratory techniques that have characterized sleep

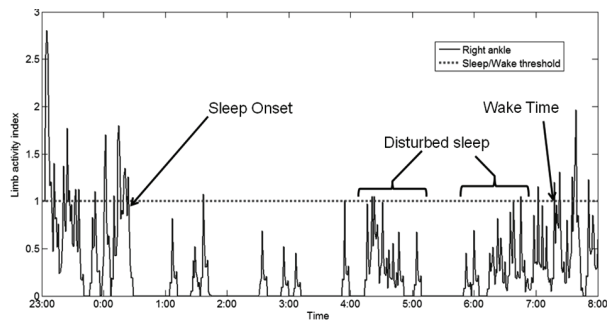


Figure 3: Sample accelerometer record of the right limb with identified sleeping periods.

principally using neurophysiological measures such as electroencephalography (EEG). The VALMA system extracts sleep timing measures using automatic sleep/wake identification algorithms. This algorithm uses the number of zero-crossings in 1-min epochs as activity counts, and computes a score based on the preceding 4, current, and following 2 epochs. The current minute was considered as sleep when the score < 1. Figure 3 plots an example night of activity count data, and indicates events including sleep onset, restlessness, and wake times.

### Social Activity Measures

There is mounting evidence to support the hypothesis that having and participating in rich social networks are protective of AD and related dementias (Laura Fratiglioni, Paillard-Borg, & Winblad, 2004). As a psychosocial factor, this domain is typically measured through questionnaire-based instruments. For example, marital status and number of organized social groups a person belongs to (e.g.,



Figure 4: Sample mobility envelope based on GPS location data.

church, bowling team) are indicative of social integration and network size (Helmer et al., 1999). We hypothesize that social activity may be reflected by mobility and verbal activity patterns to complement and extend traditional instruments. Specifically, the ability of GPS location and audio data streams to profile social activity will be examined.

From the GPS location data, a geographic mobility envelope that encloses all of the participant's activity can be determined. Potential measures to indicate social activity include the envelope area, perimeter, number of trips made outside of the home, and time spent away from home (Figure 4).

We hypothesize that a more socially active person would be more active verbally throughout the day. Early signs of Alzheimer's disease often manifest themselves in the speech of patients, such as a diminished lexical richness and increased repetitions (Thomas, Keselj, Cercone, Rockwood, & Asp, 2005). However, it is unknown whether measures such as the quantity of speech and the duration distribution of utterances are affected by the disease. To that effect, the system includes a voice activity detector (VAD) that segments talking versus not talking from the audio recordings. Initial evaluations of the G.729 VAD standard used by the telephony industry (Benyassine, Shlomot, & Su, 1997) demonstrated an overestimate of verbal activity (i.e., labels anything that might sound like a voice) and does not distinguish between the user's voice and background voices. To address these limitations, a VAD algorithm based on a conditional random field (CRF) (Lafferty, McCallum, & Pereira, 2001) was developed. Briefly, the CRF technique is a discriminative classifier for temporal processes that uses rich voice features trained on 5 min of labeled data for each participant. Preliminary results are encouraging, showing a high consistency between its classifications and manually annotated audio tracks (Figure 5). The automated nature of the classifier



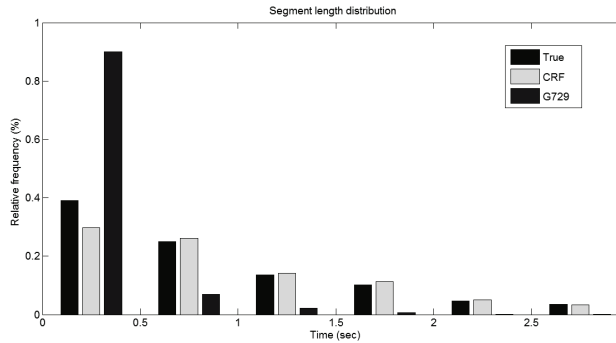


Figure 5: Histogram of speech segment durations identified by CRF and G729 Voice Activity Detection (VAD) algorithms. True speech segments were manually annotated.

allows extraction of statistics such as the amount of talking and the duration distribution of verbal activity segments.

### Composite Measures

While physical activity, sleep, speech and mobility factors are worthwhile measures in isolation, combinations of measures may prove to be insightful. For example, there is mounting interest in understanding the natural occurrence of dual-tasking behaviour, specifically simultaneously walking and talking, as a measure of attentional capacity. Decreased ability to perform dual-tasking in individuals with ADRD has been suggested to be a reason for a three-fold incidence of falling in this population compared to healthy older adults (Sheridan et al., 2003).

The VALMA system captures measures of both walking stability (i.e., step variability) and verbal activity to potentially provide an assessment of everyday occurrence of dual-tasking activities. Surprisingly, initial data from 2 pilot participants yielded occurrences of dual-tasking in greater than 1/3 of gait periods with a corresponding audio record [297/673 (44%) and 252/696 (36%), respectively].

Other potential composite measures under consideration include the frequency and duration of verbal activity collected in locations outside of the user’s residence as a measure of social activity, and the day-to-day pattern (i.e., circadian rhythm) of physical and sleep activities.

### Discussion

VALMA represents a novel ambulatory sensor system designed to capture natural behaviours across multiple domains to profile lifestyle risk factors related to AD and related dementias. A summary of the current measures is shown in Table 1. Lower limb accelerometry provides quantitative measures of physical activity (i.e., walking) and sleep duration. Audio and GPS location records provide objective measures of verbal and mobility activity, respectively. Pilot studies indicate that everyday collection

using the system is feasible, given appropriate training and support.

While objective physical activity measures have yielded greater sensitivity over self-report in assessing the risk of cognitive decline (Middleton et al., 2010), there is a lack of studies examining the relationships between cognitive function and profiles of everyday sleep and social activity. On-going work features a study examining the everyday behaviour of a sample of community-dwelling mild to moderate ADRD patients and a control group of healthy age-matched controls. Participants will undergo a battery of cognitive, language, and gait tests, followed by a 4 day everyday activity collection period.

We expect that the objective measures of everyday activity provided by the VALMA system will have significant relationships to cognitive functioning. For example, we hypothesize that healthy individuals will be more socially active than ADRD patients. A benefit of the multidimensional nature of the VALMA system is the examination of interactions between domains. Individuals with higher physical activity profiles, for example, may demonstrate longer sleep durations and less night-time awakenings.

Table 1: Summary of VALMA measures by activity domain

Domain	Measures
Physical	<ul style="list-style-type: none"> <li>• Walking duration</li> <li>• Bouts of walking</li> <li>• Step time (cadence)</li> </ul>
Sleep	<ul style="list-style-type: none"> <li>• Sleep duration</li> <li>• Number of awakenings</li> </ul>
Location	<ul style="list-style-type: none"> <li>• Mobility envelope (area)</li> <li>• Number of trips outside home</li> <li>• Time spent outside home</li> <li>• Verbal activity duration</li> </ul>
Composite	<ul style="list-style-type: none"> <li>• Dual-tasking (walking and talking)</li> <li>• Verbal activity duration outside home</li> <li>• Circadian rhythm of physical and sleep activities</li> </ul>

Individual assessment of everyday activity will impact the design and prescription of exercise, sleep, and social interventions. For example, a walking exercise intervention may be more effective when targeted to individuals with low baseline physical activity volume. Similarly, group support interventions may be more effective for individuals with lower social activity profiles. Furthermore, VALMA may be applied as an outcome measure to evaluate the effectiveness of interventions on everyday behaviour.

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