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Detecting Degeneration: Monitoring Cognitive Health in Independent Elders

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Abstract — **Australia has an ever increasing ageing population due to advances in healthcare and post-war booms in fertility. Estimations that over 22% of the population will be aged 65+ in 2050 provide a strong incentive to develop innovative assistive technologies to support elderly people to live safely at home longer. Extended independent living can improve quality of life for elders and their families and reduce costs associated with health and aged care. There is however, the need to monitor the elderly resident's safety, physical health and brain function. The Smarter Safer Homes project aims to develop a platform to facilitate independent living. The platform will aggregate sensor information at environmental, cognitive, physical, and physiological levels, allowing changes and trends in activities of daily living to be monitored. Such monitoring could potentially predict decline of brain function. Here we present how data derived from a sensor-based in-home monitoring system may be able to be used to provide a measure of neurological health. This measure could then facilitate tailoring of the home to meet the resident's changing needs, or to determine when a move to residential care is required.**

I. Introduction

The ageing proportion of the Australian population is increasing significantly due to advances in healthcare and a fertility boom from 1946–65. According to the Australian Bureau of Statistics, between 1990 and 2010 the proportion of the population aged 65 years and over increased from 11.1% to 13.6%, while the proportion aged 85 years or over more than doubled to comprise 1.8% of the total 2010 population (398,200 individuals). In two decades, the number of centenarians has increased by 170.6%, compared with a total population growth of 31%[1]. Increased life expectancy for both sexes has contributed to this rise, however female longevity is apparent with a ratio of 2:1 females:males in the 85+ group and 3:1 in the 100+ group.

Associated with this 'silver tsunami' is an increase in health expenditure. The cost of health care increases with age, for example, the average fee for hospital services for an insured patient of <14 years is $172, compared to $4135 for an insured patient of >85 years[2]. Correspondingly, health expenditure is rising faster than economic growth and in 2010 accounted for over 9% of GDP up from 7.5% in 1998[2]. Governments fund 70% of health expenditure in Australia (Federal 43.6% and state, territories and local governments 26.3%), with the remaining 30% primarily provided by individuals and private health or injury insurers. The cost of residential aged care services is also high, $40,000–50,000 per bed per annum[3], and is similarly subsidized by the government. With over 22% of the population predicted to be aged 65+ in 2050[4], there is a strong imperative to develop innovative assistive technologies to support elderly people to stay safely at home longer and therefore reduce costs associated with health and aged care.

To facilitate safe independent living, Australian scientists are developing assistive technologies and smart homes for the elderly. In order to provide a non-invasive monitored environment, scientists are drawing on the experiences and successes of smart homes and assistive technology advances around in the world, including in the US, UK and Japan[5]. Most smart homes contain a combination of sensors and monitoring systems, including but not limited to motion sensors, pressure sensors, thermometers, barometers, magnetic switches on doors; devices to record physiological measurements, pedometers, accelerometers, cameras, and an avenue for social engagement (usually through the internet). In-home monitoring has proved valuable in detecting changes in activity or routine that underpin health decline[6,7,8].

One of the concerns of elderly independent living for practitioners, family and the elders themselves is the decline of brain function. Dementia or Alzheimer's disease (AD) affects 24–40% of people aged over 85 and is forecasted to affect at least 463,000 people in 2031[9,10]. Parkinson's disease (PD) affects 3% of those over 75 years[10]. A study conducted in Perth, Australia, estimated the annual risk of stroke to be 1 in 45 for people between the ages of 75–84 and increasing to 1 in 30 for those over 85[11]. Prodromal (presymptomatic) signs are evident in dementia, AD and PD, and 'mini strokes', or transient ischemic attacks (TIAs)[12,13], often precede strokes. If detected, these indicators can act as a warning to instigate intervention. There is a high percentage of elderly people who experience severe or profound limitations as a result of neurological conditions, particularly for dementia or Alzheimer's disease (95%), but also for Parkinson's disease (81%) and stroke (77%)[2]. Early detection of degeneration is therefore important to be able to tailor smart homes to the needs of people with dementia[14,15] and to assess when care needs will prevent residents from remaining in their own homes. This allows the elderly, their families and carers time to discuss and decide on appropriate long-term care arrangements. Here we present how data derived from a sensor-based in-home monitoring system may be able to be used to provide a rudimentary measure of neurological health; and give insight into the assistive technologies required to facilitate continued independent living where possible.

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II. SMARTER SAFER HOMES PILOT STUDY

The Smarter Safer Homes project aims to develop a platform that enables older people to live longer at home, using connectivity provided by the national broadband network (NBN). The platform is a combination of hardware (sensors, monitors and iPad) and software (iPad app and portals) provided to participants and accessed by relevant parties nominated by researchers and participants. The platform will aggregate sensor information at environmental, cognitive, physical, and physiological levels. This information will provide a support mechanism for decision making by service providers examining the trends and changes in activities of daily living, including psychological, behavioral and vital signs of older people living at home. The platform also aims to enhance the psychological and physiological well-being of aged persons through interactive videoconferencing to significant others including adult children, direct care workers, and health care professionals. The pilot study will further determine if the platform can be tailored to varied levels of older people's support needs, to establish a framework for designs of future homes for independent living. The pilot study is primarily an observational study which will determine the variables to measure in a future controlled trial. A list of in-house sensors is provided in Table 1. Medical devices provided to residents and the data they gather are shown in Table 2.

Pilot participants (N=20) are over 70 years of age living independently with no home care support. They have internet access and connection to the NBN; and are willing to utilize a touch screen device (iPad). Each participant must remain in Armidale, New South Wales, for the duration of the study and have significant others who are not co-located in the same residence but are located in another town, region or location in Australia. Candidate participants will be excluded if they have a pre-existing condition with compromised cognition or early onset dementia.

III. DETECTING DEGENERATION

One of the greatest concerns of elderly independent living for practitioners, family and the elders themselves is the decline of cognitive or other neurological function. Each disorder has its own characteristic onset pattern, however, there are symptoms that are common across many age-related deficits. Evidence of neurodegeneration can manifest at the physical or physiological, psychological and/or behavioral level.

Physiological correlates of neurodegenerative decline include high blood pressure[16,17] sleep disturbances[18] and constipation[19]. Psychological signs include personality changes such as withdrawal, passivity or apathy, agitation, sexual disinhibition, anxiety and depression, as well as decreases in cognitive processing speed and impaired memory[19,20,21]. Evident behaviors include lack of personal hygiene (in wardrobe and bathroom attendance), inappropriate attire for ambient temperature, night wandering, changes in gait and postural instability [21,22,23,24].

There is significant interaction between these descriptors. For example, high blood pressure can give rise to anxiety or agitation, which in turn results in anxious or agitated behavior.

TABLE I. SMARTER SAFER HOMES SENSOR TYPE, PLACEMENT AND DATA GATHERED

Sensor type	***Data gathered***	***Place of installation***
Motion sensor	Incidents of motion within 5m of install, indoor walk speed	Ceiling in all rooms
Accelerometer	Water flow Bed movement	Water pipe Under bed
Plug meters	Current draw of various appliances and devices	Wall power outlets
Acoustic sensor	Fall detection Presence of visitors	All rooms Living
Temperature/ Humidity sensor	Temperature and Humidity readings	Kitchen Bathroom Living
Pressure sensor	Sofa/couch being attended	Under sofa cushion
Reed switch	Doors open/close	Entrance doors, wardrobe, pantry, freezer
Security Camera	Live video stream	Front door
GPS tracker	Outdoor trajectories	Key ring

TABLE II. SMARTER SAFER HOMES MEDICAL DEVICES AND DATA GATHERED

Sensor type	***Data gathered***	***Device***
Blood pressure and Heart rate sensor	Systolic/diastolic and heart rate	Blood pressure monitor
Reed switch	Record open/close of pill box compartments	Seven day pill box
Body weight sensor	Body weight, BMI, fat	Weight scale
Temperature sensor	Body temperature	Thermometer
Blood glucose sensor	Blood glucose	Blood glucometer
Spirometer sensor	Volume of air inspired/ expired by lungs	Spirometer
Sleep Sensor	Sleep quality and other sleep measurements	Sonomat

IV. ROLE OF SENSOR-DERIVED DATA

A sensor-based in-home monitoring system has the potential to provide information on many signs of neurodegeneration. We will be monitoring the indicators listed below for sudden or gradual change in patterns or routines over time.

A. Blood pressure

High systolic blood pressure (SBP) has been found to be associated with cognitive decline[17]. Daily SBP averages of over 135mm Hg, or sudden changes in SBP, have been shown to be significantly associated with total white matter hyperintensities (WMHs)[17]. These WMHs are considered to be a marker of declines in functional mobility and cognition. Further, participants with clinical SBP of at least 160mm Hg were found to be almost three times as likely to experience cognitive deterioration within a four year period, based on neuropsychological assessment[25]. In this pilot study, residents are trained and encouraged to regularly take their blood pressure using monitors provided.

B. *Medical compliance*

Medication compliance is an issue in a population of elderly residents who tend to forget their medications just due to age. A further drop in compliance of 12% is expected for people with mild dementia[14]. In this pilot study, medical compliance is monitored through sensors on a seven-day pill box and alerts sent to the resident. Compliance is recorded, as is the number of alerts required to obtain compliance.

C. *Processing speed*

Deficits in motor and cognitive processing speed are indicators of reduced function in elderly people and can be predictive of neurological impairment[17,21,26], particularly so for PD[28]. In this pilot study, measures of in-home gait speed are extracted from transition from motion sensor to motion sensor, for example from bedroom to bathroom. Changes in cognitive processing speed can be estimated from increasing delays between motion and power sensors, for example in entering the laundry and activating the washing machine.

D. *Postural instability*

Postural instability is common in the elderly population. It is a hallmark of PD and often becomes apparent in the prodromal phase[19,21,27]. In general, falls in the elderly can indicate underlying neurological deficits, are likely to be recurrent and can result in self-imposed restrictions that in turn underlie further functional decline[28]. Unfortunately falls are often unreported and/or undetected. For the pilot phase of this study, acoustic monitoring is employed for fall detection and residents are asked to wear their existing security alerts to verify the fall where accurate.

E. *Social interaction*

Social inclusion is an important aspect of wellbeing, particularly for the elderly. Loneliness and lack of social networks can lead to an increased risk of depression[29]. Depression is characterized and further compounded by social withdrawal. In the early phases of dementia and other neurological disorders, personality changes are often first evidenced in social interactions, with an increase in irritation, agitation or aggression. In the pilot study, the amount of social interaction is monitored through use of video conferencing, receipt of calls and number of visitors. Changes in voice pitch indicative of irritation or agitation are detected with the acoustic monitor.

F. *Sleep patterns*

Sleep apnea has long been associated with dementia, particularly in elderly people[30]. In addition to lack of oxygen during sleep, a fragmented sleep-wake cycle has recently been shown to be evident in prodromal AD[18]. In this pilot study, percentage of disturbed sleep is recorded through accelerometers attached to beds. More detailed sleep data is obtained using the 'Sonomat' developed by Professor Colin Sullivan[31]. The sonomat is a sensor mat on the mattress that acts as a stethoscope to provide heart and lung data.

G. *Wandering*

Wandering, where the resident goes walking at night or gets lost on familiar routes, can be a symptom of dementia and occurs with varying levels of severity[23]. Most wandering studies on have focused on institutions, due to the difficulty of monitoring domestic wanderers. In our pilot, instances of night wandering are recorded through front or rear door activity between 10pm and 6am, coupled with subsequent lack of motion detected within the home. Front door excursions can be further verified by the external camera, which also detects whether attire is appropriate for the venture – bed clothes versus street clothes and light versus heavy clothing. The propensity to get lost on familiar routes is detected through analysis of routes mapped with the GPS tracker fitted on the resident's key ring.

H. *Daily functioning*

Other deficits in daily functioning can give insight into neurological decline. These include failure to self-care, evidenced through lack of wardrobe or bathroom use; apathy, indicated by a sustained reduction in number of daily activities; and instances of forgetfulness, counted by alerts required for taps or stove tops left on and telephone misdials.

V. Validation of Sensor-Derived Data

Pre- and post-pilot measures of cognitive health taken using validated instruments (Mini cog[32], Stroop Test[33], Trail Making B[34], CASE-SF[35]) will be plotted against the sensor-derived data at the end of the pilot trial. Regression analysis will allow examination of the sensitivity and specificity of the sensor derived data to detect changes in cognitive health.

VI. Discussion

Together the data provided by the sensors provide a 'picture' of the resident, and highlight any changes in their physiological, psychological or behavioral profile that may indicate prodromal signs or symptoms of neurodegeneration.

The ultimate goal of the pilot study is to determine the level of monitoring and type of sensors required to improve quality of life for elderly residents and their families. This includes the knowledge that their physical and mental health is being accounted for and that services are in place to facilitate independent living for as long as possible. Insights gained from the pilot can then inform the design of future independent living environments based on residents' needs, and tailored to changing needs where and when appropriate.

Dementia is the leading cause of nursing home admission[36,37]. In Australia in 2008–2009, 59% of residents in aged care had a diagnosis of dementia[38]. The cost of sensor-based monitoring is yet to be determined, however, the aim is to make it cost-effective and interoperable with commodity sensor products sold. Therefore, we propose a system that is capable of tailoring smart homes for people with dementia and able to help reduce the health costs associated with aged residential care, estimated at $6.6 billion in 2008–2009[38].

The concept of smart homes for people with dementia is the focus of several initiatives in the UK, Europe and the US[14,15]. Projects vary from staffed homes to sole occupancy and provide a range of services for both residents and social workers. The challenge now is to use sensor technology to detect and identify early signs of neurological impairment to enable efficient deployment of required devices and services to delay or avert nursing home placement.

Assistive technologies for residents with dementia are not thought to be able to reverse neurodegeneration, but rather to maintain a level of independence. It is therefore important that these technologies are implemented with idea of interacting with the resident, rather than operating on their behalf. To this end, it is paramount that the resident has autonomy over the type of technologies and services provided and is actively involved in all discussions and decisions. By using sensor data to predict the onset of degeneration, residents and their families have an objective assessment on which to base discussions around future care needs. This allows resident input and the attainment of informed consent before these faculties are diminished. For the elder, this will ensure the greatest degree of autonomy possible in the twilight of their life.

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