EARLY DETECTION OF COGNITIVE IMPAIRMENT IN OLDER ADULTS: TECHNOLOGY USE IN FUNCTIONAL ASSESSMENT

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Contents

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Abbreviations

AAMI: Age-associated memory impairment

ACE III: Addenbrooke's Cognitive Examination - Third Edition

AD: Alzheimer's disease

ADCS-ADL: Alzheimer's Disease Cooperative Study–Activities of Daily Living Inventory

ADCS/MCI/ADL24: Alzheimer's Disease Cooperative Study/Activities of Daily Living scale adapted for people with MCI

ADL: Activities of daily living

A-IADL-Q: Amsterdam IADL Questionnaire

A-IADL-Q-UK: Amsterdam IADL Questionnaire UK

AUC: Area under the curve

BADL: Basic activities of daily living

C-IADL: Cognitively focused IADL

COSMIN: Consensus-based standards for the selection of health measurement instruments

CRN: Clinical Research Network

CRT: Choice reaction time

CSF: Cerebrospinal fluid

CWIT: Color-Word Interference Test

DSB: Digit span backwards test

ET: Everyday technology

ECog: Everyday Cognition scale

EPSRC: Engineering and Physical Sciences Research Council

FAQ: Functional Assessment Questionnaire

FCRST: Free and Cued Selective Reminding Test

FDA: Food and Drug Administration

GDS: Geriatric Depression Scale

IADL: Instrumental activities of daily living

IPA: Intelligent personal assistants

IQCODE: Informant Questionnaire on Cognitive Decline in the Elderly

IRT: Item response theory

JDR: Join Dementia Research

MCI: Mild cognitive impairment

aMCI: amnestic MCI

naMCI: non-amnestic MCI

MoCA: Montreal Cognitive Assessment

ML: Machine learning

MLM: Multi-level model

MRI: Magnetic resonance imaging

NIA-AA: National Institute of Aging/Alzheimer's Association

NINCDS-ADRDA: National Institute of Neurological and Communicative Disorders and Stroke and the Alzheimer's Disease and Related Disorders Association (now known as the Alzheimer's Association)

PIS: Participate information sheets

PET: Positron emission tomography

QoL: Quality of life

RCT: Randomised controlled trial

ROC: Receiver operating characteristic

SAMS: Software Architecture for Mental Health Self-Management

SAS: Starkstein Apathy Scale

SCD: Subjective Cognitive Decline (alternative terminology includes but is not limited to SMI: subjective memory impairment; SCI: subjective cognitive impairment; SMC: subjective memory complaints; SCC: subjective cognitive concerns)

SCD-I: Subjective Cognitive Decline Initiative

SPSS: Statistical Package for the Social Sciences

SRT: Simple reaction time

SV-ADLQ: Spanish version of the Activities of Daily Living Questionnaire

T-ADLQ: Technology - Activities of Daily Living Questionnaire

TMT: Trails making test

VaD: Vascular dementia

VR: Virtual reality (VR)

VRFCAT: Virtual Reality Functional Capacity Assessment Tool

WA: Weighted average

Abstract

Introduction: Effective assessment of functional capacity, such as the ability to use technology, is vital to recognising the earliest signs of cognitive decline in neurodegenerative disorders. Yet, commonly used assessments of functional capacity lack cultural and technological relevance, are not sensitive to early change, and are measured sporadically. In this PhD, I aimed to improve methods of measuring and detecting functional impairment in people with early cognitive decline by i) providing a culturally adapted measure of instrumental activities of daily living (IADL) for use in the UK, and ii) exploring the potential of computer-use behaviours as an objective digital biomarker of functional and cognitive decline.

Methods: Four studies are presented. In study A, the Amsterdam IADL Questionnaire (A-IADL-Q) was culturally adapted for use in the UK in three iterative steps involving 190 stakeholders. Study B was a pilot study to assess the feasibility and acceptability of monitoring computer-use behaviours. In study C, semi-directed computer tasks and cognitive and functional assessments were completed by older adults with cognitive impairment (n = 20) and cognitively healthy controls (n = 24). In study D, people with subjective cognitive decline (SCD) or mild cognitive impairment (MCI) (n = 32) took part in a longitudinal study that used bespoke software to monitor in-home computer-use behaviours lasting approximately nine months.

Results: In study A, iterative modifications to the A-IADL-Q resulted in a 55-item adapted version appropriate for UK use (A-IADL-Q-UK). New and revised items performed well; all activities were perceived as more difficult by at least one participant per item and four new items correlated with the total score. An exploratory analysis of convergent validity found correlations with cognitive and functional abilities. Study B showed that monitoring computer-use was feasible and acceptable. In study C, cognitively impaired participants displayed more frequent pauses, slower typing, and a higher proportion of mouse clicks compared to cognitively healthy controls. These behaviours were significantly associated with performance on selected memory and functional assessments. In study D, no change in computer-use behaviour was detected over the study period. Computer use behaviours were associated with recall, recognition, task switching, task inhibition and visual attention. People with MCI had slower keystroke speed and used the computer less than people with SCD.

Conclusion: This PhD has made an important contribution to the literature by taking a step forward in the way technology is incorporated into functional measurement. Firstly, the A-IADL-Q-UK informant report version and new self-report version, incorporates a range of culturally relevant activities including technology use. Secondly, the measurement of computer use behaviours shows promise as a potential novel digital biomarker to measure cognitive and functional ability. Future work will be to expand the cultural relevance of the A-IADL-Q-UK for multicultural groups in the UK and beyond and to further investigate the relationship between computer use and functional ability in a larger and more diverse sample, with the ultimate aim of finding a pragmatic, unobtrusive and continuous digital biomarker for the earliest detection of functional and cognitive change.

Lay abstract

Introduction: Information about how well people can perform everyday activities, such as taking medication and using the computer, can help to detect early problems with cognition (such as memory) which can indicate dementia. The way that ability to perform everyday activities is measured is problematic. For example the questions are not always relevant to the lives of older adults and are not always able to pick up on early problems. In this PhD, I aimed to improve the way that ability to perform everyday activities is measured in two ways: First, by changing a questionnaire to make it more relevant to the lives of older adults in the UK. And second, by seeing if people's computer use, such as their typing speed and mouse clicks, could provide information about their cognition or their ability to perform of everyday activities.

Method and Results: There were four studies in this thesis. In the first study (Study A), a questionnaire that measures ability to perform everyday activities was changed to make it more relevant to the lives of older adults. The final version contained 55 daily activities and included some new activities. The results showed that the questionnaire measured similar things to other tests of memory and performance of everyday activities and that the new activities could pick up on difficultly performing everyday activities.

The second study (Study B) was done to try out some of the activities that we planned to use in studies C and D. In particular, we wanted to see if older adults could complete the computer tasks that we had chosen, and also see how they would feel about having their computer use recorded. On the basis of the results of this study, we made some changes to studies C and D. This included providing participants with a laptop similar to what they use at home, and giving them more information about data privacy and security.

In the third study (Study C), forty-four older adults with and without cognitive problems completed tasks on a computer to see if this was related to their cognitive ability. We found that people with memory problems paused more, had slower typing and clicked the mouse more compared to people without memory problems.

In the fourth study (Study D), thirty two older adults with cognitive problems, or worries about their memory, had their home computer use recorded for nine months. This was done to see if their computer use behaviour, such as typing speed, changed over time, and if it was related to scores on cognitive tests. The study showed that participants' computer use behaviour did not change over time. However, people with cognitive problems had slower typing speed, and used the computer less than people with worries about their memory.

Conclusion: In this PhD I have improved the way that ability to perform everyday activities can be measured in two ways: First, I improved a questionnaire used for measuring performance of everyday activities to make it more relevant to older people. Second, I showed that measuring computer use behaviours, like typing speed, can provide important information about older adults' cognitive ability. This work was important because it could provide ways to spot early signs of cognitive problems which could help with detecting dementia.

Declaration

No portion of the work referred to in the thesis has been submitted in support of an application for another degree or qualification of this or any other university or other institute of learning.

Copyright statement

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This thesis is dedicated to my beautiful daughter Laika who was born during my PhD and is my biggest achievement, distraction and motivation.

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undergraduate degree results, I've never heard you shout so loud, I hope I can continue to make you proud. My mum, who helps me so much when she visits and who despite living in another country and me being nearly 40 still provides a lot of my clothes! My wonderful brother, who never grew tired of asking me when my PhD was going to be finished. And last but by no means least, thank you to my little family Dan and Laika. Laika, you are smart, strong, tenacious and independent and I am so proud of you. When I'm working you run over to hug me, sit on my knee and ask me to Google search for pictures of Jessie from Toy Story! I strive to be the best mum I can and I hope I can inspire and support you to dream big and reach your goals, whatever they may be. Dan, for the endless nights that you worked on the database and program to help me extract my data, for putting up with my stress levels and supporting me every day to complete this goal and in all aspects of my life. I have faced some health challenges during this PhD and you have been there for everything. You are my source of strength and I could not have got through it all without you. You and Laika are the best team I could ever wish for, I love you both so much and I cannot wait for what the future holds for us.

The Author

I have a Bachelor of Science degree in Psychology and Criminology, a Masters in Criminology and Research Methods and a PGCE in Social Science specialising in Psychology. As a teacher I taught Psychology A Level, Sociology A Level and a number of other GCSE subjects. As a researcher I have worked for both the Home Office and the Ministry of Justice, completing a number of projects relating to crime and reduction of reoffending. As a Senior Research Assistant at Manchester Metropolitan University I worked on a project investigating facial expressions and dementia. Following this I worked as a Research Associate on the SAMS (Software Architecture for Mental Health Self-Management) project and my PhD was embedded into this project. During my PhD I also worked as a Governance Research Associate for Manchester Mental Health NHS Trust, developing and implementing a monitoring process for non-clinical trials. In my next Research Associate post I will be working on a project investigating the use of locum doctors in the NHS.

During my time at Manchester I have supervised a number of students completing their Masters or clinical research placements. I have volunteered for projects such as the Dementia Matters Project, where I delivered dementia-themed interactive workshops to local schools to improve awareness of dementia. I was involved in the organisation and delivery of a Dementia Event focusing on faith and dementia in an African-Caribbean church community in Greater Manchester. I have presented my research at local community groups for older adults such as Age UK and University of the Third Age and provided educational talks to organisations working with older adults such as the Later Life CMHT in Manchester.

In addition to the papers in my thesis, I have co-authored five other papers during my PhD on a range of topics which extend beyond the scope of the thesis, including requirements elicitation, data mining and software development. I was also commissioned to write a book chapter in the textbook The Preservation of Memory: Theory and Practice for Clinical and Non-Clinical Populations (Bruno, 2016). I have presented my work at local and international conferences including the International Psychogeriatric Association Congress (San Francisco, 2016) and The British Society of Gerontology Annual Conference, (Stirling, 2016 and Swansea, 2017). I was awarded first prize for my presentation at the IBBMH PhD Showcase in Manchester in 2015.

CHAPTER 1: Introduction

1.1. Introduction

Functional independence is of central importance in distinguishing between normal aging and cognitive impairment (Gold, 2012). To be diagnosed with dementia due to AD, an individual has to have experienced cognitive symptoms that interfere with the ability to function in usual daily activities and represent a decline from previous levels of functioning (McKhann et al., 2011). Functional decline is measured by assessing a person's ability to complete basic activities of daily living (BADL), such as eating and dressing, and instrumental activities of daily living (IADL), such as using a telephone and managing finances (Jekel et al., 2015). IADL require a greater complexity of neuropsychological organisation than more basic activities and are therefore more likely to be vulnerable in the early stages of cognitive decline (Jekel et al., 2015). The differentiation of dementia from mild cognitive impairment (MCI) rests on a clinician's judgement of whether or not the functional decline is significant enough to constitute a diagnosis of dementia (Knopman and Petersen, 2014). Measuring IADL is therefore an important component in identifying the early signs of dementia (Sikkes et al., 2009).

Existing measures of functional ability are limited for a number of reasons. First, there is a lack of reliable measures that can detect changes in IADL performance in people with MCI, and even fewer that can detect performance changes in clinically healthy individuals, or in people with subjective cognitive decline (SCD), who may be at risk of AD dementia (Marshall et al., 2019). One reason for this is that most IADL measures have been constructed and validated for people with dementia and therefore may not be sensitive to subtle changes in more complex daily activities (Jekel et al., 2015). Second, many existing IADL measures have not been through a thorough assessment of basic psychometric properties (Weintraub et al., 2018b) such as content validity (Sikkes et al., 2009). Third, the majority of assessment tools do not include questions about the use of computer or other types of technology (Jekel et al., 2015). This is particularly important given that the use of computers is rising in older adults. For instance, in the UK, internet use in retired older adults aged 65 to 74 has increased from 52% in 2011 to 83.2% in 2019 (Office for National Statistics, 2019b). Furthermore, the assessment of everyday technology use has been shown to provide

sensitive measures of early change in functional ability (Hedman et al., 2018; Malinowsky et al., 2010; Rosenberg et al., 2009). Fourth, there are a limited number of self-report options available and people may not have someone who can act as an informant (Jekel et al., 2015). Finally, activities contained in assessment measures are not always considered conceptually relevant to the lives of the people they concern (Hartry et al., 2018). The Food and Drug Administration (FDA) emphasise the need for meaningful outcome measures, measures that have conceptual relevance to the lives of the people they concern. This can be achieved by establishing the content validity of instruments with respect to patient concerns relevant to the concept being addressed (Food and Drug Administration, 2009). One approach to this would be to incorporate the views and suggestions of patients and caregivers in the development of measurement items and to evaluate patient understanding of items through cognitive interviews.

Another problem with the measurement and potential detection of functional decline relates to the current episodic and clinic-based assessment paradigm. Generally an individual is not assessed until they themselves or their relatives have noticed a change in their daily functioning, by which point the decline in cognition or function may be quite significant. Furthermore, the infrequent administration of conventional functional tests does not allow within-person variability over time to be measured (Seelye et al., 2018), which has been shown to be a strong predictor of incident cognitive decline (Dodge et al., 2014; Dodge et al., 2015). There is therefore a need for reliable and valid instruments that are able to measure subtle cognitive changes as they develop in presymptomic and MCI older adults' daily lives with greater individualisation and precision (Jekel et al., 2015).

Increases in the use of technology have created a new higher order activity of daily living (Kaye et al., 2014) and presents opportunities for developing more sensitive and effective methods for detecting underlying cognitive and functional impairment. Indeed, studies have shown that assessing everyday technology use in older adults with dementia and MCI can be a sensitive way to detect subtle differences in everyday activities (Hedman et al., 2018; Malinowsky et al., 2010; Nygard and Kottorp, 2014; Nygard et al., 2012; Rosenberg et al., 2009). Furthermore, specific measurement of computer use behaviours in older adults has the potential to distinguish between those with and without cognitive impairment (Kaye et al., 2014; Seelye et al., 2015; Seelye et al., 2016; Seelye et al., 2018). Continuous assessment

of individuals' day-to-day functioning makes it possible to more accurately track and measure relevant intraindividual changes in daily functioning than may emerge using conventional functional assessment methods periodically. Moreover, unobtrusive monitoring embedded within regularly used computer devices results in information that is representative of actual daily functioning under normal conditions.

In summary, the way that functional capacity is measured can be improved by: 1) addressing the limitations of current methods, such as those that rely on the subjective reporting of function and behaviour or 2) developing new methods that take a different approach to estimating functional ability. Paper-based and electronic subjective assessments of functional ability are recognised methods that have known efficacy and utility, and can be incrementally improved. Therefore improving current methods would be fairly low risk, but also likely to yield relatively small gains. Whereas, investigating potentially new methods of assessment has a higher risk of failure, but the potential to make a more significant, step-change in utility. Utilising a dual risk approach increases the chance of successfully contributing to an improvement in the field of functional assessment.

1.2. Aim

The aim of this PhD is to explore ways to improve the methods of measuring and detecting functional impairment in people with early cognitive decline. This will be achieved in two ways: first by reporting the cultural adaption of an existing measure of IADL (the Amsterdam IADL Questionnaire) in order to improve the current IADL measurements in the UK - in particular those that include questions about technology use; and second by investigating the potential of assessing directed (set tasks with instructions) and non-directed (normal, home computer use) computer use behaviours (e.g. mouse clicks and keystroke speed) unobtrusively and continuously as a marker of cognitive and functional decline.

1.3. Overview of thesis

This PhD thesis describes four inter-related studies focusing on improving the ways in which functional ability is measured in older adults for the detection of cognitive decline: one mixed methods questionnaire cultural adaptation study (study A: chapter 3, and published in the journal International Psychogeriatrics), an observational, qualitative pilot study (study B: chapter 4), a quantitative cross-sectional (study C: chapter 5, and published in the

International Journal of Geriatric Psychiatry) and a quantitative longitudinal study (study D: chapter 6, and currently in preparation for submission). Alongside the studies, a literature review (chapter 2) is presented, providing a broad overview of the research to date. The thesis is presented in 'Journal format', which is comprised of a sections that are in a format suitable for submission for publication in a peer-reviewed journal or that have been submitted to or published in academic journals.

The **literature review** in **chapter two** begins with a detailed description of the prevalence and characteristics of dementia, MCI and SCD. It then continues with a discussion of the current assessment tools used to measure functional capacity, and details of the patterns of cognitive and functional impairment in IADL in people with SCD, MCI and early dementia. What follows is an overview of the developments in technology-based assessments of cognition and IADL. Recent research detailing the impact of MCI on functional capacity and the associations between IADL decline and progression to dementia are then discussed. All key findings are highlighted and the more complex activities - those more likely to be affected early in people with SCD and MCI - are explored in more detail.

Study A, described in **chapter three,** is a cultural adaptation of the Amsterdam IADL Questionnaire, and the development of a self-report version. 148 participants took part in the study across three steps. In step one, the relevance and clarity of the items described in the questionnaire were reviewed by professionals (n = 14); people with SCD, MCI and dementia due to AD (n = 8); and relatives or carers of people with MCI and dementia due to AD (n = 6). In step two, the cultural relevance of the refined items was assessed using a 6-point Likert scale questionnaire administered to 140 British adults aged over 65 years. In step three, to assess how well the new items performed, the questionnaire was administered to 28 older adults with SCD or MCI, 7 of whom self-reported and 21 had informants. The chapter concludes by highlighting that the newly adapted A-IADL-Q-UK provides a measurement of functional decline for use in the UK that captures culturally relevant activities and that a new self-report version has been developed and is ready for testing.

In **chapter four** a pilot study (**study B**) is described that aimed to maximise the feasibility and acceptability of studies C and D: firstly by assessing feasibility of a series of semi-

directed computer tasks and the hardware and software used in study C, and secondly by evaluating the perceived acceptability of recording daily computer use as a proxy measure of cognitive health for study D. For this, seven participants were observed whilst completing a series of semi-directed computer tasks, in order to identify any problems they had completing the tasks and any issues they had using the hardware or software. Semi-structured interviews, with a mixture of close- and open-ended questions, were also completed with participants to evaluate their perceived acceptability of recording daily computer use as a proxy measure of cognitive health. On the basis of this study, the design of studies C and D was refined to increase the feasibility and acceptability.

Chapters five and six contain descriptions of studies C and D. These studies were embedded in a larger project called SAMS (Software Architecture for Mental Health Self-Management): a three-year EPSRC funded project investigating the effectiveness of monitoring data from computer-use activity for the detection of subtle signs of cognitive impairment. **Study C**, described in **chapter five,** is a cross-sectional reliability and proof of concept study with the aim to investigate whether multiple computer use behaviours can distinguish between cognitively healthy controls and people with early cognitive impairment, as well as investigate whether these behaviours are associated scores on tests of cognitive and functional ability. A comparison of semi-directed computer tasks and cognitive and functional assessments was completed with a group of older adults with cognitive impairment (n = 20) and cognitive healthy controls (n = 24). The chapter concludes by suggesting that capturing computer use behaviours unobtrusively offers the potential for early detection of cognitive impairment.

Study D (described in **chapter six**) was a 7-9 month exploratory longitudinal study of 32 older adult computer users with MCI and SCD**.** Participants completed a battery of cognitive tests and functional assessments at three time points (start, middle and end). The SAMS software was installed on participants' home computers, with usage recorded continuously for the duration of the study. In this study, patterns of computer use behaviours obtained from continuously-assessed routine home computer-use were investigated to see whether they: i) could show change over time; ii) were associated with cognitive or functional ability; and iii) could discriminate between people with subjective cognitive decline (SCD) and people with mild cognitive impairment (MCI). In this chapter it is demonstrated that, passive

monitoring of time spent on the computer and keystroke speed can differentiate between groups with SCD and MCI. What is more, keystroke speed was associated with a number of neuropsychological test scores and shows potential as an indicator of a person's cognitive status.

In **chapter seven** the research is drawn together by summarising the findings of the studies, discussing them in the context of previous research and providing a critical analysis. Three main contributions of the thesis are discussed in detail. In addition, an overview of ethical considerations is provided, along with implications for healthcare practices, recommendations for future research and overall conclusions.

1.4. Framework of the thesis

The framework for the thesis follows a modified version of the Centre for eHealth Research and Disease Management (CeHreS) roadmap (van Gemert-Pijnen et al., 2011). The original roadmap serves as practical guidance for the participatory development process of eHealth technologies. This roadmap is appropriate for the work in this thesis in three ways. Firstly, the CeHReS roadmap focuses on how technology can be used to innovate health. This is relevant because the aim of the work in this thesis is to improve methods of measuring functional ability with an emphasis on the use of technology. Secondly the CeHReS roadmap is an approach for the development of eHealth technologies. This is relevant to the work in this thesis because existing measures and novel measures of functional ability are developed and piloted. Thirdly, the CeHReS roadmap emphasises the central importance of involving users in the development of eHealth technologies. This is applicable because in this thesis a number of different methods are implemented to involve users (i.e. older adults with cognitive impairment) in the development process. Instead of eHealth technologies, for this thesis I have adapted the roadmap to create a framework (Figure 1) that outlines the process for development of two 'measures': 1) a culturally adapted functional ability questionnaire (A-IADL-Q-UK) and; 2) a novel digital biomarker for the assessment of computer use behaviours as a proxy measure of cognitive and functional ability.

The CeHRes roadmap includes five key stages of development – contextual inquiry, value specification, design, operationalization and summative evaluation. 'Contextual inquiry' involves information gathering from intended users and the environment in which the

technology will be implemented. For this thesis, the contextual enquiry stage occurs in study A, through a thorough process of face and content validity that includes consultation with a range of stakeholders, including people with cognitive impairment and their relatives. In study B, contextual inquiry is realised through observations and interviews with older adults to assess the feasibility of the computer activities for study C and the prospective acceptability of recording home computer use in study D.

The second stage of development is 'value specification'. Value specification implies the recognition and quantification of the economic, medical, social, or behavioural values of key stakeholders and elaborates on the outcomes of the contextual inquiry. This is conducted in study A through a questionnaire with older adults, which asks about the relevance of the activities refined in the previous step (contextual inquiry).

The third stage of development is 'design' and refers to the building of prototypes that fit with the values and user requirements. The studies that are part of this thesis have been designed to test the developed measures. In study A the A-IADL-Q-UK was designed based on the results from the 'contextual inquiry' and 'value specification' stages, this process included a discussion with the developer after each stage. The results from Study B were used to improve the design of both studies C and D. This included increasing the number of operating systems for study C, so that participants could use the system they were most familiar with, and also improvements to the participant information sheets for study D to address participants concerns about privacy and data security.

'Operationalisation' is the fourth stage of development and concerns the introduction, adoption and employment of the technology in practice. In study A, the final 55-item version of the questionnaire was piloted in a sample of older adults with SCD and MCI and the internal consistency and construct validity of the questionnaire was evaluated. In studies C and D computer use behaviours were measured in both semi-controlled and uncontrolled environments to explore their potential as an objective digital biomarker of functional and cognitive decline. Further design steps are needed in future work before full operationalisation will be possible. This is considered in the discussion in the section on implications for healthcare, policy and practice. For Study A, the A-IADL-Q-UK can be used by researchers and clinicians to provide information about functional health. With further

development the results of studies C and D can be used as part of home monitoring of cognitive and functional well-being.

The fifth and final stage of development is ‘summative evaluation’. This refers to the actual uptake of the technology and the assessment of its impact in regard to clinical, organisational and behavioural outcomes. This is considered in the discussion section in terms of how this might be adopted by clinicians and the clinical utility of the two measurement approaches.

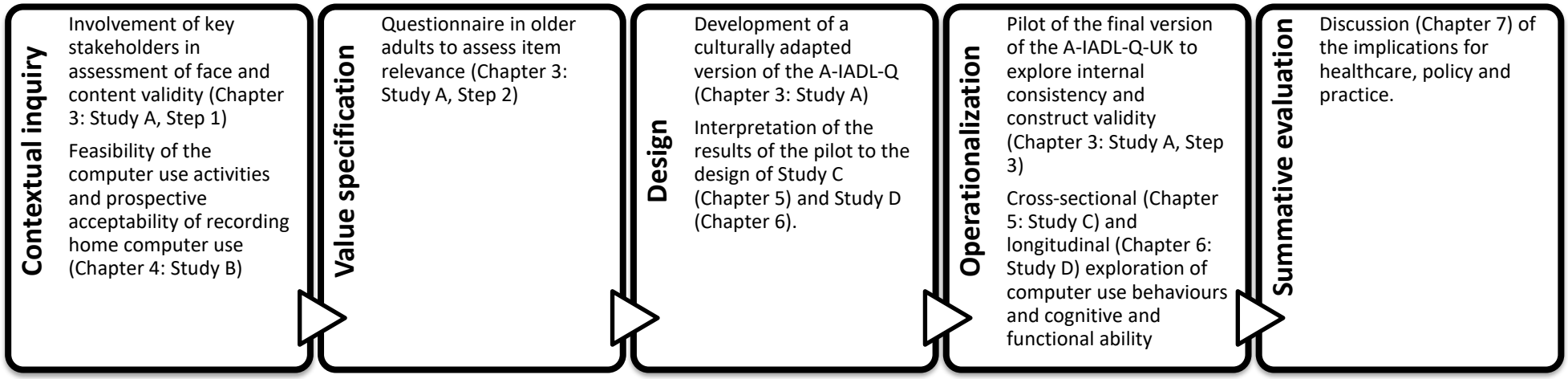

Figure one: Thesis framework adapted from van Gemert-Pijnen et al's (2011) CeHRes roadmap

CHAPTER 2: Literature Review

The aim of this review is to provide a background to the work reported in the thesis across five key areas. This narrative review provides an account of the broad range of key issues that underpin the thesis. Firstly, in section 2.1. I provide a detailed overview of the continuum of pathological cognitive decline, followed in section 2.2. by a description of the functional changes associated with each stage of this spectrum. In section 2.3 I detail the advantages and disadvantages of current methods for measuring functional capacity, and in section 2.4. I provide an overview of technology use in older adults and the role this can play in identifying cognitive and functional impairment. More specifically, in section 2.5. I describe the associations between functional ability and computer use behaviours, and how information about computer use behaviours can be used to provide information about cognitive and functional decline. Finally, in 2.6. I outline the ethical considerations when recording data passively via home-based software. In this literature review I critically appraise existing research in the area, highlight any gaps or areas for improvement, and provide a foundation for the aims and outcomes of the thesis.

2.1. Pathological cognitive decline in older age

Cognitive decline in advanced age has been described as a continuum, with no simple cut-off between normal and pathological changes (Deary et al., 2009; Stott, 2006). Stott (2006) argues that there are a number of stages along the spectrum of cognitive decline in older age, including age-associated memory impairment, mild cognitive impairment (MCI) and dementia (Stott, 2006). A number of terms have been developed for clinical situations where no other cause for memory loss has been found (Burns and Zaudig, 2002). Benign senescent forgetfulness was the first descriptor to characterise older adults who were more forgetful than their age peers, yet had superior memory function to people with dementia (Kral, 1962). This was characterised by an awareness of memory problems, an inability to recall remote rather than recent events, and loss of memory for minor details (Burns and Zaudig, 2002). Age-associated memory impairment includes the presence of subjective memory decline, objective evidence of impairment on a standardized memory test as compared to young adults, evidence of adequate intellectual function, and absence of

dementia or any medical condition that could produce cognitive deterioration (Crook et al., 1986). The criteria for age-associated memory impairment quantified the degree of memory impairment required for the diagnosis (a decline of at least one standard deviation below the scores for young adults) and a more severe form of impairment (late-life forgetfulness) which was defined as between one and two standard deviations below age adjusted scores (Burns and Zaudig, 2002). In summary these conditions are regarded as being variants of normal aging. Whereas MCI is seen as a transitional stage between normal cognitive aging and dementia. MCI refers to an individual who has memory complaints and objective evidence of cognitive decline but does not yet meet criteria for dementia (Burns and Zaudig, 2002). Those with MCI are at an increased risk of continuing cognitive decline and subsequent dementia (Roberts et al., 2014). However, as Stott (2006) explains, the boundaries between these different states are unclear, and vary depending on the particular definitions applied and the pathological overlap between dementia and milder degrees of cognitive decline. This makes it difficult to tease out a distinction between age-related cognitive impairment, MCI and dementia (Stott, 2006). In addition, cognitive decline in advanced age is not a single continuum, and the majority of people with MCI do not go on to develop dementia (Tarawneh and Holtzman, 2012). This suggests that this continuum is unlikely to represent a single disease process, and the course of cognitive decline varies considerably between individuals.

2.1.1. Dementia

Neuronal dysfunction and loss causes progressive cognitive decline and ultimately dementia (Nasrallah and Wolk, 2014). Dementia is a clinical syndrome resulting from the progressive deterioration of cognitive functions that is sufficiently severe to interfere with social or occupational functioning (American Psychiatric Association, 1987)[1]. The cognitive and functional changes of dementia are typically accompanied by changes in behaviour and personality, but these have not become core criteria as they are considered to lack diagnostic specificity (Chertkow et al., 2013). Alzheimer's disease (AD) is the most common cause of neurodegenerative dementia (Nasrallah and Wolk, 2014). Other common forms of

[1] In more recent versions of the DSM (DSM-IV, DSM-IV-TR and DSM 5), dementia is either encompassed within the specific causes of dementia (i.e. AD) or the term has been replaced with major neurocognitive disorder. However, this is not yet in wide clinical use and therefore for the purposes of this PhD the term 'dementia' will be used.

dementia include dementia with Lewy bodies and vascular cognitive impairment (Masellis et al., 2013). There are also less common syndromes, such as Parkinson's disease dementia (PDD), and atypical Parkinson's-like syndromes, including progressive supranuclear palsy and corticobasal degeneration (Scaravilli et al., 2005).

Clinical phenotypes based on changes in cognition, behaviour, function and physical health are of central importance in the diagnosis of dementia. According to the 2011 National Institute of Aging/Alzheimer's Association (NIA-AA) revised core clinical criteria, all-cause dementia is diagnosed when there are cognitive or behavioural (neuropsychiatric) symptoms that (McKhann et al., 2011):

1. Interfere with the ability to function at work or in other daily activities
2. Represent a decline from previous levels of function and performance
3. Cannot be explained by delirium or major psychiatric disorder
4. Cognitive impairment is detected and diagnosed using both history taking from the patient and informant and an objective cognitive assessment (neuropsychological testing is performed when the latter cannot provide confident diagnosis)
5. Cognitive or behavioural impairment involved at least two of the following domains:
    a. Impaired ability to acquire and remember new information
    b. Impaired reasoning and handling of complex tasks
    c. Impaired visuospatial abilities
    d. Impaired language
    e. Changes in personality, behaviour or comportment

Changes in behaviour and physical health are not core diagnostic criteria as they are considered to lack diagnostic specificity (Chertkow et al., 2013). Therefore there is a dependence on the measurement of changes in the clinical phenotypes cognition and function. Despite the clinical relevance of functional capacity and the required assessment of function to diagnose dementia, classify patients accurately, and interpret the clinical significance of medications that affect cognition, assessment of function has remained relatively underdeveloped. Few studies have explicitly investigated the association between measures of cognition and functional status and it is unclear, for example, how much variance in functional status can be explicitly attributed to cognition independent of major

noncognitive correlates (Royall et al., 2007). These issues are of particular importance in the study of dementia because diagnosis requires that dementia-defining cognitive impairments are associated with functional capacity. In addition, differentiating dementia from MCI requires a clinical judgement as to whether or not there is significant interference in functional ability or daily activities (McKhann et al., 2011).

The behavioural and functional impairment that accompanies dementia constitutes one of the major causes of disability worldwide, and it has a significant impact on the lives of affected individuals (Cotelli et al., 2012). Unfortunately, the diagnosis of dementia is often difficult, particularly in the early stages. The diagnosis is frequently made very late in the course of the condition, and may take a long time (Hakensen, 2012). At present, it is estimated that 34% of people with dementia have yet to receive a diagnosis in the UK (Alzheimer's Research UK, 2018). A diagnosis and earlier intervention might increase the chances of delaying the progression of dementia (Barnett et al., 2014). If the onset can be delayed by five years, by 2050 the AD population would be reduced by 41% compared with the projections without a delayed onset (Zissimopoulos et al., 2014).

The concept of an 'early' diagnosis has been recently brought into question. The reported benefits of an early diagnosis include the implementation of interventions to maintain independence for longer; providing time for decisions about the future (i.e. legal and financial); and providing time to connect with support systems and services (Rasmussen and Langerman, 2019). However, given that there is as yet no cure or treatment that can significantly slow progression of dementia, early diagnosis could be irrelevant or even detrimental to the patient's emotional wellbeing. Consequently there has been a recent shift of focus away from the pursuit of an early diagnosis to the benefits of a 'timely' diagnosis, which reflect a person-centred care movement. A timely diagnosis refers to the disclosure of the diagnosis at the right time for the individual with consideration of their preferences and circumstances. However, despite this shift in thinking, recent studies suggest that the desired time for a diagnosis is still earlier than is currently being achieved. For example, Dubois and colleagues define timely diagnosis as the diagnosis made at a time when a person first becomes worried enough to seek the help of a clinician and can still be free of dementia and functionally independent (Dubois et al., 2016). Other studies indicate that people want early diagnostic testing for AD (Blendon et al., 2012) and want a diagnosis

of dementia to be disclosed as soon as possible (Watson et al., 2018) to both them and their relatives (Riva et al., 2014; Werner et al., 2013). A study of public attitudes to early diagnosis of AD dementia found that over 94% of people would want to be told if they had AD dementia (Harvard School of Public Health/Alzheimer Europe, 2011). Moreover, early detection of dementia was considered the highest priority in a survey of AD patients, their carers and the general public with an interest in dementia (Law et al., 2013). A "timely" diagnosis of dementia can enable patients and their families to make sense of what is happening, make lifestyle changes and plan for the future (Dubois et al., 2016). Burns (2012) argues that a timely diagnosis of dementia can decrease carer burden, improve access to support systems, and enable older adults to live active and independent lives for longer. A timely diagnosis can also give people a definitive answer to complaints that have caused them anxiety and distress. This avoids unnecessary admission and institutionalism which has clear economic benefits (Burns, 2012). It is important to note that if disease modifying drugs are licensed in the future (i.e. aducanumab (Schneider, 2020)), this shift in thinking may change back again to an emphasis on early diagnosis.

Up until very recently, dementia has been a clinical diagnosis, for which laboratory and imaging tests provided only supportive diagnostic evidence (Chertkow et al., 2013). The clinical diagnosis of dementia is conducted through a combination of history-taking from the patient and a knowledgeable informant, and objective cognitive and functional assessment (McKhann et al., 2011). A careful history is often obtained using a semi-structured interview with an informant (for example, the Clinical Dementia Rating scale (Morris, 1993). Cognitive assessments often include brief assessment tools such as the Montreal Cognitive Assessment (MoCA) (Nasreddine et al., 2005). Structured or informal functional assessment is used to establish the presence and severity of functional disability. In recent years, the focus in tool development has been on more sensitive cognitive measures that are able to detect subtle cognitive and functional impairment at the earliest possible stage and to improve methods for monitoring disease progression along the continuum and responses to therapeutic interventions (Aisen et al., 2017). Increasing regulatory approval of positron emission tomography (PET) tracers and improvements in the precision of cerebrospinal fluid (CSF) markers are part of an increasing effort to integrate biomarkers into clinical-decision making (Aisen et al., 2017). Despite biomarkers now being a central component in the

recruitment of participants and the analysis of outcomes in AD clinical trials, their use in a clinical environment is restricted by a number of factors: biomarker assessment is expensive and invasive (Humpel, 2011), and many general healthcare providers do not have access to advanced imaging and CSF measures (Croisile et al., 2012). Moreover, the biomarkers currently used have limited ability to predict the clinical disease course (Aisen et al., 2017). However, the widespread use of biomarkers will be facilitated by low-cost and minimally invasive biomarkers (e.g., blood or saliva) that are now emerging (Mattsson et al., 2017; Nakamura et al., 2018; Ovod et al., 2017). A focus on affordable, simple and non-invasive biomarkers are therefore needed to support the existing clinical diagnosis processes.

2.1.2. A biological definition of Alzheimer's disease

An initiative led by the National Institute on Aging and Alzheimer's Association (NIA-AA) aimed to update the 2011 NIA-AA guidelines for AD and led to the development of a research framework (Jack et al., 2018). The research framework focuses on the diagnosis of AD with biomarkers in living persons and utilises the ATN classification system (Jack et al., 2016). In the ATN system the main Alzheimer disease (AD) biomarkers are grouped into 3 categories: the "A" class corresponds with an amyloid beta (Aβ) biomarker (amyloid PET or CSF Aβ42); the "T" class with a tau biomarker (CSF p-tau or tau PET); and "N" with a neurodegeneration biomarker (CSF t-tau, FDG-PET, or structural MRI). The authors emphasise that the research framework is appropriate for biological biomarker-based research and should not be used to restrict approaches to hypothesis testing that do not use biological biomarkers. The NIA-AA research framework is not implemented in the current thesis because the use of biological biomarkers to diagnose AD was not part of the research goals. However, it is important to highlight how the staging schemes described in the research framework fit with the categories of people with cognitive decline that are described in the thesis, specifically people with subjective cognitive decline (SCD) and MCI. The NIA-AA research framework presents both a syndromal categorical cognitive staging scheme and a numeric clinical staging scheme. The syndromal cognitive staging scheme divides the cognitive continuum into three traditional categories—cognitively unimpaired (CU), MCI, and dementia. In this scheme, they suggest that a subset of CU individuals may report subjective cognitive decline. The numerical clinical staging scheme avoids traditional syndromal labels and is applicable for only those in the Alzheimer's continuum. This staging

scheme which ranges from stage 1 through to stage 6 reflects the sequential evolution of AD from an initial stage characterized by the appearance of abnormal AD biomarkers in asymptomatic individuals (stage 1). As biomarker abnormalities progress, the earliest subtle symptoms become detectable (stages 2 – 3). Further progression of biomarker abnormalities is accompanied by progressive worsening of cognitive symptoms, culminating in dementia (stages 4 to 6). In this scheme, stage 2 which is also referred to as transitional cognitive decline encompasses both SCD and MCI categories. Subjective report of cognitive decline can occur at stage 2 and people with mild cognitive impairment syndrome could come under both stage 2 or stage 3.

2.1.3. Mild cognitive impairment (MCI)

Mild cognitive impairment (MCI) is a syndrome defined by clinical, cognitive and functional criteria (Albert et al., 2011), and has been conceptualized as an intermediate stage between normal aging and dementia (Jak et al., 2009; Kim et al., 2009). People meeting criteria for MCI are at elevated risk of subsequent progression to dementia (Roberts et al., 2014). The Peterson criteria (Petersen et al., 2001) (also known as the Mayo criteria) are the most commonly used criteria for diagnosing MCI (Jekel et al., 2015). These criteria require: 1) subjective cognitive complaint; 2) normal activities of daily living (ADLs); 3) normal general cognitive function; 4) impaired memory function for age and education; and 5) absence of dementia (Petersen et al., 2005). MCI cannot be currently diagnosed using a laboratory test (Albert et al., 2011). However, typically, individuals with MCI score 1 to 1.5 standard deviations below the mean on cognitive tests compared with age and education matched peers (Albert et al., 2011).

MCI has been criticised as a clinical entity for having poorly defined neuropsychological parameters (Portet et al., 2006). However, since the develop of the Peterson criteria, the MCI concept has been expanded to include the clinical phenotypes of amnestic (aMCI) and non-amnestic (naMCI) (Csukly et al., 2016; Jekel et al., 2015). aMCI results predominantly in memory loss and has a high risk of conversion to AD (Petersen et al., 2001). People with naMCI have deficits in other domains than memory and have a higher risk of converting to other forms of dementia, such as diffuse Lewy body dementia (Ferman et al., 2013). A

further categorisation is single-domain or multiple-domain, based on whether impairment exists in only one or multiple cognitive domains (Jekel et al., 2015; Seelye et al., 2013).

Revising the MCI construct into subtypes has improved the characterization of the underlying aetiology and trajectory of MCI (Seelye et al., 2013). However, difficulties with the MCI criteria include the lack of specific methods of measurement for assessing cognitive or functional capacity, and the lack of cut-off points to differentiate MCI from mild dementia (Jekel et al., 2015). For example in a study of 112 people with MCI, assessing which neuropsychological tests best distinguish people with MCI from cognitively healthy controls, people with MCI displayed significant cognitive impairment across all cognitive domains (Nordlund et al., 2005). This highlights the need for more precise guidelines as to what neuropsychological instruments should be used when assessing different MCI subtypes. Furthermore, the underlying physiological process of MCI is not accurately defined. MCI by definition is heterogeneous, a syndrome not a disease process, which limits its utility in a clinical and research context. This emphasises the need for biomarker based diagnosis.

There are a number of widely publicized measures of cognition that are being used in the detection of MCI. One example of this is the LASSI-L developed by Loewenstein and colleagues (2017). The LASSI-L, requires learning of 15 words that belong to one of three semantic categories and measures vulnerability to semantic proactive interference by presenting a competing set of semantically similar words (Crocco et al., 2018). The LASSI-L has been show to differentiate between participants with aMCI and suspected dementia due to AD from cognitively unimpaired older adults (Crocco et al., 2014; Matías-Guiu et al., 2017); and has been associated with volumetric loss and cortical thinning among those with aMCI (Loewenstein et al., 2017b) (Loewenstein et al., 2017b). The LASSI-L is one example of the many measures for detecting cognitive decline at the stage of mild cognitive impairment and preclinical AD. This represents a very large body of literature and a detailed description is beyond the scope of this thesis which focuses on measures of functional ability.

2.1.4. Subjective cognitive decline (SCD)

Research on AD dementia has moved from referring to the MCI stage to the preclinical stage of AD, which has extended the focus from the early signs of cognitive impairment measured with neuropsychological tests to the purely subjective report of cognitive decline (SCD) in

unimpaired individuals (Jessen, 2014). The reported experiences of cognitive decline have also been conceptualized as subjective cognitive impairment (SCI), subjective memory decline (SMD), subjective memory impairment (SMI), and memory complaints, among other terminologies (Abdulrab and Heun, 2008). The Subjective Cognitive Decline Initiative (SCD-I) was started to (amongst other aims) develop a common research concept for SCD (Jessen et al., 2014). The SCD-I working group states that an individual with SCD would have self-experienced decline in cognition compared to their previous status, and not in relation to an acute event, in addition to normal scores on standardised cognitive tests used to classify MCI or prodromal AD. SCD is sometimes referred to as pre-MCI SCD (Jessen et al., 2014). In line with SCD-I conceptualisation, in this PhD the term SCD will be used to refer to individuals with self-experienced cognitive decline. However, given the varied, widespread and often contradictory terminology used to refer to SCD, any deviations from this term, or the way it is conceptualised, within the cited literature will be highlighted.

There are a variety of different strategies used for the assessment of subjective concerns, ranging from a single question (such as "Do you have difficulties with your memory?" (Ellis et al., 2009), a cut-off score on a number of items (Wang et al., 2004), through to more comprehensive questionnaires that tap multiple cognitive domains, such as the Subjective Cognitive Decline Questionnaire (Rami et al., 2014). For example, one study used a composite score created by combining subscales from subjective questionnaires (Amariglio et al., 2012), whereas another study classified participants if they had recently been referred for the assessment of cognitive complaints but were not impaired according to neuropsychological tests (Visser et al., 2009). There is no single accepted assessment to classify a person with SCD, whether that be a neuropsychological test or a self-/informant rated measure (Molinuevo et al., 2017). The variety of conceptualisations and assessment methods highlight the need for improved understanding of the subjective experience of cognitive decline. A recent opinion article by the SCD-I working group provides recommendations on how to begin operationalizing and implementing SCD criteria, a set of guidelines for detection and assessment, as well as suggestions for what information to report in an SCD study to ensure consistency and learning over time (Molinuevo et al., 2017). However, this is just a starting point and further work is needed to be able to provide a gold standard for detection and outcome measurement.

SCD is increasingly recognised as a risk factor for incident dementia (Molinuevo et al., 2017). For instance, in a study of 1547 participants without dementia, after adjusting for depressive symptoms and objective memory performance, self-reported memory failures were found to be predictive of future dementia or AD (Ronnlund et al., 2015). The same study also found that subjective reports from family and friends were an even stronger predictor of preclinical impairments. A similar study of 2415 participants without cognitive impairment aged over 75 years reported that SCD (which they term SMI) at baseline was associated with greatest risk for conversion to any dementia after one and a half years and three years (Jessen et al., 2010). Further support comes from a study by Reisberg and colleagues (2010) who assessed 213 participants during a seven-year mean follow-up period and found that people with SCD (which they term as SCI) declined more rapidly compared with participants with no subjective cognitive concerns. Similar results, from a two-year follow up study of a community sample of older adults found that people with SCD (they use the term SMI) were at a four-fold increased risk of developing dementia (Tobiansky et al., 1995).

Jessen and colleagues (2010) suggest that the prediction of dementia in AD by SCD (which they term SMI) with subsequent amnestic MCI supports the model of a consecutive 3-stage clinical manifestation of AD from SCD via MCI to dementia. However, Abdulrab and Heun (2008) argue that SCD (they use the term SCI) is predominantly underlined by psycho-affective factors rather than subtle memory impairment, with research indicating associations between SCD and emotional state and personality (Abdulrab and Heun, 2008; Derouesne et al., 1999; Hanninen et al., 1994; Smith et al., 1996). In a response to the conceptual framework proposed by Jessen et al. (2014), Canevelli and colleagues (2014) argue that disentangling the relationship between SCD and potential confounders such as psychiatric disease is likely unfeasible due to the extent of comorbidities in elders with subjective cognitive complaints.

Despite the arguments concerning links between SCD and psycho-affective factors, longitudinal research indicates that SCD is a valuable predictor of increased risk of dementia (Slot et al., 2019). Other research indicates that the risk of dementia increases in SCD, and increases further with white matter lesions and cortical atrophy present (Sacuiu et al., 2018). Consequently, the clinical usefulness of the SCD label may require additional

resources such as CT scans to be most effective. Additionally, careful consideration of confounding factors such as psychiatric disease is required to enable a clear understanding of the predictive potential of SCD.

2.2. Functional impairment

Functional disability is a defining feature of all dementias. The 2011 NIA-AA revised core criteria state that, for a diagnosis of dementia, cognitive deficits must be of sufficient severity to "interfere with the ability to function at work or at usual activities"; and "represent a decline from previous levels of functioning and performing" (McKhann et al., 2011: p.3).

In dementia, functional impairment is associated with two major types of abilities: basic activities of daily living (BADL) and instrumental activities of daily living (IADL). BADL are the fundamental self-maintenance skills typically needed to manage basic physical needs in the following areas: grooming/personal hygiene, dressing, toileting/continence, transferring/ambulating and eating (Desai et al., 2004). These functional skills are typically mastered early in life, and the ability to perform them is relatively preserved in the early stages of dementia compared to higher level tasks (Mlinac and Feng, 2016). The ability to perform BADL deteriorates to a greater extent during the later stages of dementia and physical functioning is often a significant driver of BADL ability (Cahn-Weiner et al., 2007).

IADL are more complex, higher order skills related to independent living in the community, such as managing finances, using the telephone, driving a car, taking medications, planning a meal, shopping and working in an occupation (Jekel et al., 2015). The ability to perform BADL and IADL is dependent upon cognitive (e.g. reasoning and planning), motor and perceptual abilities (Mlinac and Feng, 2016). One study has shown that successful performance in IADL is critically dependent on executive cognitive function, whereas change in IADL functioning over time is predicted by baseline memory functioning (Gross et al., 2011). Compared with BADL, impairment in IADL is considered to require more complex neuropsychological processing capacity, and is therefore strongly correlated with cognitive decline (Royall et al., 2007). IADL impairment can often present in MCI and early dementia (Farias et al., 2013), and problems in performing more complex IADL may be the first indication of the disease to the person or family (Desai et al., 2004).

Rogers and colleagues (1998) proposed an additional category of functional impairment: enhanced activities of daily living (EADLs) to refer to activities that require the ability to adapt to a changing environment (Rogers et al., 1998). EADL activities include hobbies, new learning (often related to technology) and social engagement. They suggest that a willingness to learn new skills and overcome new challenges might be central to maintaining functional independence.

Decline in the ability to perform everyday activities, and the eventual loss of independence, are major concerns for older adults (Rog et al., 2014). Moreover, functional impairments are associated with carer burden (Kang et al., 2014; Razani et al., 2007), patient distress (Thurston-Hicks et al., 1998), increased use of healthcare services (Singh et al., 2005), nursing home placement (Kales et al., 2005) and reduced quality of life (QoL) (Giebel et al., 2014; Rog et al., 2014). Despite the association between dementia and the loss of ability to function independently in major areas of life, and the link between MCI and mild decrements in the ability to carry out higher level functional abilities, much of the variability in everyday function remains unexplained (Gold, 2012; Royall et al., 2007).

2.2.1. Functional impairment in dementia

As previously discussed, the presence of functional impairment is a core diagnostic criterion of dementia (McKhann et al., 2011). Each subtype of dementia has a characteristic cognitive and behavioural profile that will influence the nature of the functional deficits (Poulos et al., 2017). This information can then be used to design the most appropriate care plan for the management of those specific functional disabilities. Despite the importance of functional status in the diagnosis of dementia there is limited information about the differences in functional limitations by dementia subtype. In an attempt to address this gap, Gure and colleagues (2010) examined 856 older adults who were grouped into three subtypes of dementia: vascular (VaD), AD and dementia due to other aetiologies. VaD was associated with significantly greater ADL limitations than AD. This information is important when considering the effective design of community-based programs and institutional services to address the needs of patients with dementia and to lessen the burden on caregivers and the health care system (Gure et al., 2010).

The assessment of functional impairment is also an important factor in understanding the progression of the disease. A strong correlation exists between the stage of dementia and ability to function in daily activities (Liu et al., 2007). People with dementia are likely to change slowly from requiring assistance in more advanced daily tasks in the community to needed support with self-care tasks as the underlying disease progresses (Stavitsky et al., 2006). Liu et al. (2007) found that when dementia severity progresses, basic ADL ability declined. This is supported by the results of a study by Talmelli et al. (2013) who found that functional performance was significantly associated with dementia severity and that as dementia becomes more advanced functional performance worsens (Talmelli et al., 2013). The assessment of functional ability is an essential part of the diagnosis of dementia and as the disease progresses. The assessment of functional ability helps to determine the impact of the disease on the person and their family/carers and it provides vital information about their care needs. Deficits in ADL have been found to contribute to increased carer burden (Kang et al., 2014) and reduced QoL in people with dementia (Beerens et al., 2016).

2.2.2. Functional impairment in MCI

Earlier diagnostic criteria for MCI required that performance of IADL, such as medication management, remain normal (Peterson, 1997). However, since the publication of the original criteria, evidence began to accumulate to suggest that subtle changes or preclinical disability in performance of IADL may be apparent in individuals with MCI (Rodakowski, 2014). A number of studies have demonstrated people with MCI do have disabilities in performing complex everyday life activities, and the BADL/IADL criterion has been challenged. For example, Nygard (2003) analysed studies of BADL and IADL in MCI, dementia and healthy controls and found that IADL deficits are demonstrated prior to dementia onset and should therefore be differentiated from BADL in the diagnosis of MCI (Nygard, 2003). Recent revisions of criteria do acknowledge supervening mild problems while performing complex functional tasks (Albert et al., 2011; Hedman et al., 2013) and this is supported by a growing body of literature demonstrating functional limitations in complex everyday tasks in people with MCI compared with people with dementia and healthy controls (Albert et al., 2011; Bombin et al., 2012; Farias et al., 2005; Farias et al., 2006; Gold, 2012; Jefferson et al., 2008; Jekel et al., 2015; Lindbergh et al., 2016; Peres et al., 2008; Perneczky et al., 2006; Puente et al., 2014; Reppermund et al., 2013; Rodakowski et al., 2014; Wadley et al., 2007;

Weston et al., 2011; Zoller et al., 2014). For example, in their meta-analysis of 106 studies, Lindbergh et al (2016) found a large overall summary effect size demonstrating that MCI was associated with significant difficulties in the performance of everyday tasks (Lindbergh et al., 2016).

Cross sectional findings have shown that, based on findings from a performance based measure, older adults with MCI have decreased ability to perform BADL and IADL compared with cognitively healthy controls. However, these functional deficits were not detected by self-report or informant-report questionnaires, suggesting that performance-based testing may be more sensitive to subtle functional disability (Puente et al., 2014). Evidence also suggests that MCI subtype predicts the type of IADL restriction. Kim et al. (2009) examined IADL impairment in four different MCI subtypes (amnestic single and multiple domain and non-amnestic single and multiple domain) . They found that individuals with single domain naMCI reported problems using the telephone and household appliances, whereas those with multiple domain aMCI had difficulties using the telephone, using transportation and managing finances. These findings suggest that scores on specific IADL items could help to identify MCI subtypes. However, despite the array of literature detailing the impact of functional decline in MCI, consensus is still lacking regarding what should be considered mild problems in IADL (Hedman et al., 2013). Therefore, further clarification is required so that information about functional impairment can be used appropriately for MCI diagnosis.

2.2.3. Functional impairment in SCD

Identifying functional change in individuals who are, by definition, asymptomatic remains a significant challenge (Atkins et al., 2018). The first consensus concept of SCD developed by the Subjective Cognitive Decline Initiative (SCD-I) includes suggested features of SCD that increase the likelihood of preclinical AD in SCD (Jessen et al., 2014). This list of features does not include functional decline, but the SCD-I acknowledge it is not exhaustive, implying further features could be added. Slight difficulties in performing IADL are acknowledged to be consistent with SCD (Molinuevo et al., 2017). Montejo (2012) found a significant association between subjective memory complaints (SMC) and every item of the Lawton Scale, which measures ability to perform IADL, and the Katz Index, which assesses independence in BADL (Montejo et al., 2012). In another study, people with high amounts of

self-reported subjective cognitive concerns (SCC) had significantly more difficulties with IADL compared to those with low amounts of SCC; difficulties with IADL was also recognised by informants for the high SCC group (McAlister and Schmitter-Edgecombe, 2016). Stogmann et al (2016) found that SCD participants had decreased ability to perform IADL (referred to as ADL) compared to controls (Stogmann et al., 2016).

Similar results have also been found in longitudinal studies. For instance, one study found that participants who reported that their memory problems interfered with their daily activities had an almost 4-fold increase in risk of MCI at follow-up and were at higher risk of cognitive decline (Sargent-Cox et al., 2011). In the same study, a one point increase on a functional health measure was associated with a 3-4% increased risk of mild cognitive disorder, but not MCI, and an increased risk in cognitive decline in cognitively healthy participants. Cognitive healthy older adults recruited from clinics because they had concerns about their memory were at an increased risk of conversion to MCI (Chen et al., 2017). In this same sample greater difficulty in everyday function was associated with increased risk of conversion to MCI. However, there is a lack of research regarding risk of AD dementia in SCD in relation to IADL functioning. In an attempt to address this gap in the literature Roehr and colleagues (2017) analysed data from cognitively unimpaired individuals who reported SCD at baseline and found that although IADL function was largely well preserved in people with SCD, when difficulties with IADL were present risk of conversion to AD dementia increased (Roehr et al., 2019). These findings indicate that there may be subtle functional changes that occur early in the spectrum of cognitive decline and therefore screening for IADL impairment could serve as a useful indicator for assessing risk of conversion to MCI and even AD dementia.

2.2.4. Difficulties with IADL can be predictive of subsequent cognitive decline

Functional impairment in SCD and MCI has also been shown to be predictive of subsequent MCI and dementia. For instance, Sikkes et al (2011) found that participants with IADL disabilities at baseline had a higher conversion rate (24.4%) to dementia than those without (16.7%) and that IADL disability predicted progression to dementia at 1 and 2 year follow up. Furthermore, in an 8 year longitudinal study of 2,386 individuals, Carlo and colleagues (2016) found that incidence of dementia was significantly higher when baseline IADL was

impaired: Incident dementia (per 1,000 person-years) with increasing IADL impairment ranged from 3.02 to 8.71 in cognitively impaired participants without dementia, and from 1.83 to 8.21 in MCI participants (Di Carlo et al., 2016).

Tabert (2002) suggests that obtaining both self and informant report of IADL impairment can help in the prediction of long term outcome. In their study, they found that a discrepancy between informant-reported IADL deficits and self-reported IADL deficits can significantly predict the development of AD (Tabert et al., 2002). This suggests that an individual's overestimation of their own higher-level functional ability predicts a future diagnosis of AD. Performance on specific IADL can be especially sensitive in detecting early functional change in healthy individuals at risk for AD. Marshall et al. (2015) found that information about decline in specific daily activities (paying bills and turning off the stove) predicted greater risk of progression from cognitively healthy to MCI (Marshall et al., 2015b). Furthermore, when functional measures are combined with other markers of AD dementia, this can produce sensitive models for predicting MCI to dementia progression. This is demonstrated in a 3 year longitudinal study of people with MCI, where it was found that the best performing model for predicting MCI to dementia progression, combined cognitive and functional markers with magnetic resonance imaging (MRI) measures and had an accuracy of 80% (83% sensitivity, 76% specificity, AUC = 0.87) (Korolev et al., 2016). The results from these studies suggest, that assessment of subtle change in IADL provides vital information at the preclinical and prodromal stage of AD to support an early diagnosis. However, the results are difficult to compare because the selection of items, participants, and IADL measurements differ greatly between studies.

2.3. Measuring IADL

There are three main methods for assessing IADL impairment: self-report, informant-report and performance-based tasks. Self-report is where the individual provides their own information about their subjective cognitive concerns or lived-experiences. An informant report is a report given by anyone who has observed the person in their day-to-day living (e.g., friend or relative). Performance-based measures require the observation of an individual carrying out IADL, such as preparing a meal or using the telephone. This can happen either in the community or in a clinical setting.

Measuring impairment in IADL is controversial for several reasons. First, no objective standard exists as to the practical or theoretical definition of minimal functional impairment in MCI (Jekel et al., 2015). It is therefore unclear whether functional impairment is based on deficits in some or certain IADL or difficulties across a wide range of IADL (Gold, 2012). Furthermore, the assessment of IADL is mostly limited to questionnaires that often rely on informants' reports, which suffer from biases and inaccuracies in informants' perceptions or the lack of informants being available to comment (Konig et al., 2015). Clinician and researchers are therefore left without guidance relating to how to assess impairment in MCI. Different methods of measuring IADL produce varying estimates of IADL independence and each approach has advantages and disadvantages. These are discussed in detail in the following sections.

2.3.1. Self-report measures

The benefit of self-report is the potential to capture aspects of the disease that are uniquely accessible to the individuals themselves (Frank et al., 2011). However, disruptions to communication, attention, memory and judgement that occur as a result of cognitive decline may interfere with the ability to complete a questionnaire accurately (Trigg et al., 2007). Loss of insight that occurs as a result of disease progression could also affect a patient's ability to self-report. Indeed, evidence suggests that MCI can result in impaired insight and even anosognosia (an unawareness of loss of function (Ries et al., 2007)) (Vogel et al., 2004). In a review of sixteen studies evaluating awareness among people diagnosed with MCI, Roberts and colleagues found strong evidence for variability in levels of awareness and a number of studies suggesting that people with MCI have limited awareness (J. L. Roberts, Clare, & Woods, 2009). However, some empirical reports conclude that people with MCI have preserved insight. For example Farias et al (2005) found that self-report by people with MCI was concordant with reports of others, suggesting people with MCI do not under report functional ability (Farias et al., 2005). The findings from these studies suggest that changes in self-reported everyday function may be useful early in the disease process, but that this becomes increasingly less valid as cognitive impairment becomes more pronounced.

Similar conclusions can be drawn when considering the capabilities of self-report measures for discriminating between people with MCI and healthy controls. In a 2017 study by Farias and colleagues, self-rated scores on the Everyday Cognition scale (ECog: an informant-based measure of cognitively-relevant everyday abilities) were equal or potentially better predictors of progression from healthy cognition to MCI compared with informant report (Farias et al., 2017). However, in a study by Edmonds et al. (2018) cognitively healthy control participants consistently over reported on the ECog, and participants with MCI demonstrated an increasing unawareness of their cognitive decline that was associated with cerebrospinal fluid AD biomarker positivity and progression to AD (Edmonds et al., 2018). These studies suggest that self-report can be useful in discriminating healthy adults from people with MCI, but that caution should be taken when using self-report in the latter stage of MCI.

The quality and appropriateness of content of self-report measures of functional ability has been questioned. In a systematic review of self-reported questionnaires on disability, Yang et al. (2014) concluded that the range of assessments is somewhat lacking. They considered 24 questionnaires in detail, and found that the most frequently used assessments in research with older adults were the Barthel Index, Lawton and Brody Instrumental Activities of Daily Living Scale, and Katz Index of Activities of Daily Living. However, only the Lawton and Brody Instrumental Activities of Daily Living Scale was actually developed specifically for older adult populations. They concluded that the content and format of the questionnaires varied considerably, but none of the questionnaires covered all essential elements of the International Classification of Functioning, Disability and Health framework (Yang et al., 2014). This suggests that more self-report measures need to be developed that cover a broader variety of elements.

Despite, the disadvantages of using self-report measures given the variation in insight in people with MCI, evidence suggest that people with MCI may have knowledge of deficits before these problems are clinically identifiable (Cook and Marsiske, 2006; Reisberg and Gauthier, 2008; Reisberg et al., 2008). In addition self-report is a vital option for understanding a person's personal experiences and subjective concerns, this becomes even more important when an older adult lives alone and does not have someone who can act as an informant.

2.3.2. Informant-report measures

After a certain point in the disease progression, self-report is no longer viable and, at this point, the informant's report (if available) will provide a more reliable overview of the person's functional ability (Weintraub et al., 2018a). The practice of using an informant's perspectives is important as it can provide an overview of the individual's performance in a range of different environments over an extended period of time (Gold, 2012). Empirical evidence suggests that informant report on the ECog is more strongly associated with disease bio-markers than self-report (Rueda et al., 2015). Moreover, informant measures of IADL can discriminate people with MCI from cognitively healthy older adults. However, although they are the most frequently used of the three methods (Sikkes et al., 2009), they are subject to biases and inaccuracies in the informants' perceptions. For instance, informant reports have sometimes been shown to overestimate functional disability, with the extent of over-estimation related to caregiver burden (Puente et al., 2014). In addition, characteristics of the informant, such as anxiety, depression and general health, can influence their perceptions of the person for whom they care (Sikkes et al., 2009). Inaccuracies have also been associated with the amount of time spent with the individual and the type of relationship. In particular, informants living with the individuals and spouses were found to be more accurate than those living separately (Ready et al., 2004). A further limitation of informant reports is that some older adults do not have an individual who can comment on their daily functioning (Gold, 2012).

Current informant methods for IADL assessment are frequently inadequate and psychometric information is lacking. Sikkes (2009) provides an overview of structured informant-based IADL questionnaires, developed or validated for use in AD. This study evaluated the psychometric properties of the questionnaires across eight measurement properties including content validity, internal consistency, criterion validity, construct validity, reproducibility, responsiveness, floor- and ceiling effects and interpretability. They identified twelve informant-based questionnaires for the evaluation of IADL in dementia. Despite over 50% of the information required to evaluate the quality of the instruments being unavailable, they assessed all twelve questionnaires in relation to the eight measurement properties, summarising each property as good, doubtful or poor. A total of 8.1% of the ratings were good and 7.2% were poor. A further 32.4% were indeterminate and

this was often due to inadequate data analyses or sample sizes. Overall the Disability Assessment for Dementia (DAD) and the Bristol Activities of Daily Living Scale (Bristol ADL) received the best ratings. However, they found that it was impossible to give judgement on several important quality criteria such as responsiveness, reproducibility, construct validity and interpretability due to a lack of information. This review highlights the need for further investigations to assess the psychometric properties of current measurements (Sikkes et al., 2009).

Although subjective evaluations are important, they do not directly assess ability or performance competency, and nor do they assess ability to perform composite tasks within a single domain. For example, medication use requires an individual to remember to take the medication, take the correct dose and understand the label instructions. Self-report and informant report scales classify ability into broad categories (e.g. dependent or independent) and typically do not capture subtle differences in functional ability. Therefore subjective evaluations of functional ability may not be accurate enough to capture the complexities of everyday functioning (Allaire et al., 2009).

2.3.3. Performance-based measures

Performance-based assessments, while more complex and costly, can provide a more objective behavioural measure of an individual's symptomology. Evidence suggests that direct functional performance tasks simulating IADL and performed in front of a clinician or examiner is more sensitive to identifying IADL deficits in MCI (Kaye, Mattek et al. 2014). Several studies have shown that performance-based measures may be more sensitive compared to other methods in identifying subtle functional change (Allaire et al., 2009; Goldberg et al., 2010; Pereira et al., 2010). Allaire (2009) compared the performance of participants with and without MCI on objective (performance-based) and subjective (participant-rated) measures of everyday and real world memory. Significant differences between the two groups were found for the subjective evaluations of food preparation and finance but not for medication use or shopping. However, for the objective measures, significant differences were found for all the IADL domains (medication use, financial management, nutrition and food preparation) (Allaire et al., 2009). These findings are compatible with a study published by Pereira (2010) who found that a performance-based

measure, the Direct Assessment of Functional Status (DAFS-BR), had higher accuracy than a subjective measure, the Informant Questionnaire on Cognitive Decline in the Elderly (IQCODE), in identifying MCI (Pereira et al., 2010). Similarly, Goldberg and colleagues (2010) found when everyday function was deemed normal on an informant based measure (the Alzheimer's Disease Cooperative Study–Activities of Daily Living Inventory; ADCS-ADL), significant impairment can still be observed on a performance based measure (Performance-Based Skills Assessment; UPSA). Taken together, these results suggest that objective measures may be more sensitive in detecting subtle IADL impairment.

Whilst performance-based methods may be more objective, they can be affected by the setting in which they are taken, such as clinical versus home. For instance, removing the individual's chosen routines and environmental cues that typically facilitate IADL has been shown to impact on accurate assessment of functional ability (Desai et al., 2004). In addition, although direct observation has clear advantages in terms of validity, the time and resources required to undertake performance-based measures result in them rarely being used for clinical assessment or research trials (Gold, 2012). Furthermore, performance-based assessments only consider a single demonstration of the activity, whereas a questionnaire allows for reflection of behaviour over an extended period of time (Gold, 2012).

Despite these limitations, performance based measures have the sensitivity to discriminate between people healthy controls and people with MCI. A number of performance-based instruments have shown promise in detecting early clinically meaningful changes in preclinical AD (Weintraub et al., 2018a). Studies have shown that The Harvard Automated Phone Task can discriminate between those who are cognitively healthy, young healthy and have MCI (Marshall et al., 2015a) and correlates well with other sensitive measures of everyday functioning (Marshall et al., 2019). Another performance-based measure, The Financial Capacity Instrument, can detect declining financial skills in patients with amnestic MCI in the year before their conversion to AD dementia (Triebel et al., 2009). The studies demonstrate the promise of performance based tools in detecting the earliest functional alterations in preclinical and prodromal AD.

However, the psychometric properties of performance-based measures have been questioned. In their systematic review, Wesson and colleagues (2016) evaluated the psychometric properties of 21 observational assessments using the Consensus-based Standards for the selection of health Measurement Instruments (COSMIN) checklist. They reported that there was insufficient evidence on the psychometric properties of the instruments particularly in respect to reliability. Information about validity was restricted to hypothesis testing and assessment of content validity was non-existent. The study authors recommend urgent improvement of these instruments and further evaluations to ensure that they meet the needs of the patients being assessed (Wesson et al., 2016).

A further issue with performance-based measures is the need for administration by trained observers. To overcome this issue, Czaja and colleagues (2017) developed the University of Miami Computer-Based Functional Assessment Battery (UMCFAB). The UMCFAB assesses performance on a variety of everyday activities including: using a cash machine, a repeat prescriptions task, and a visiting the doctor task. The UMCFAB can discriminate between aMCI and cognitively healthy older adults, and has been shown to have good test-retest reliabilities and adequate concurrent validity with cognitive measures (Sara J. Czaja et al., 2017). The authors indicate that computerised performance-based tasks have potential importance in the assessment of functional ability, especially in situations where a reliable informant is not available.

2.3.4. Comparison of IADL assessment methods

Jekel (2015) conducted a systematic review summarising research regarding IADL sub domains in people with MCI compared with healthy controls and people with dementia. In addition they investigated the IADL scales used in the studies and evaluated the types of methods used. Their review included thirty-seven studies, within which they identified thirty-one different instruments for assessing IADL in people with MCI. Of the thirty-seven studies, fifteen used informant rated questionnaires, ten used performance based assessments and six used self-report rating instruments. Three studies used both informant and performance-based assessments and in three studies the IADL of people with MCI were rated by informants whereas healthy controls self-rated their IADL functioning. The authors argued that the use of such a wide variety of instruments complicates comparisons amongst

studies. In addition they highlighted the fact that few of these scales have been constructed or validated for the assessment of IADL in people with MCI and therefore may not be sensitive enough to detect subtle differences (Jekel et al., 2015). Similar to the results found by Sikkes (2009) and Wesson (2016), Jekel (2015) found that the data on the psychometric properties of the IADL scales discussed are not sufficient enough to make a judgement on the quality and appropriateness of the range of scales available.

Comparing different types of IADL measurement could be problematic as it has been suggested that different types of instrument measure different skills. Performance–based measures tap into the use and application of everyday problem solving skills whereas questionnaires apply knowledge gained from multiple experiences completing everyday activities (Schmitter-Edgecombe and Parsey, 2014). This suggests that information should be sought from a combination of types of IADL measurements in order to gain the most comprehensive overview of an individual's functional independence.

Each method for assessing functional ability captures information unique to that form of assessment and, in an ideal world, a comprehensive assessment of IADL functioning would incorporate all three methodologies. However, practically and financially this may not be viable. Therefore developing alternative methodologies for assessing IADL that incorporate the benefits of performance based measurements without requiring the time and resources to complete them would improve the current ways we assess functional ability.

2.3.5. Recent developments in virtual reality (VR) assessments of IADL

Virtual reality (VR) technology has been applied to directly measure IADL task performance to investigate whether behavioural results using VR mimic actual IADL performance. Allain et al. (2014) found that virtual and real coffee-making tasks were highly correlated in terms of behavioural results . Other studies have found that VR daily living tasks can also distinguish between diagnostic groups. Seo et al. (2017) found that performance on daily living tasks presented in an immersive virtual reality environment classified patients with MCI (n=22) from healthy controls (n=20) (Seo et al., 2017). In a more recent study, Atkins and colleagues have demonstrated that performance on the Virtual Reality Functional Capacity Assessment Tool (VRFCAT), a virtual environment performance based IADL assessment, can differentiate between participants with SCD (n=61) and age-matched

normative controls (n=247) (Atkins et al., 2018). In the SCD group, VRFCAT performance was also significantly correlated with cognitive performance across nearly all tests. A limitation of this study is that they included six people with MCI in their SCD group which could have increased the probability of objective decline on the functional assessments. Another limitation is the unequal sample sizes which can result in unequal variances between samples which affects statistical power and Type I error rates. Overall, the results from these studies demonstrate that VR tools could provide sensitive methods for the evaluation of IADL functioning in people with early cognitive decline. It also more generally demonstrates the potential of using technological methods for the measurement of ability to complete daily tasks.

2.3.6. Distinguishing MCI from cognitively healthy older adults using IADL measures

A number of studies have found that IADL measures can discriminate MCI from cognitively healthy older adults. In a review of questionnaire-based assessments of IADL, Gold (2012) concluded that MCI can be distinguished statistically from healthy older adults and dementias using information about performance of complex everyday activities (Gold, 2012). Using an informant-report scale, Zoller and colleagues (2014) found that four IADL best discriminated between cognitively healthy older adults and people with MCI: participating in games involving retrieving words; navigating to unfamiliar areas; performing mental tasks involved in a former primary job; and fixing things or finishing projects (Zoller et al., 2014).

Some IADL are more cognitively demanding than others. Studies have shown that impairment in IADL with high cognitive demand (such as doing two things at the same time) in cognitively healthy individuals at baseline can predict MCI and dementia at follow up (Reppermund et al., 2013). Rodakowski and colleagues (2014) use the term cognitively focused (C-IADL) to describe more cognitively demanding IADL, such as medication management, compared with more physically-focused IADL such as home maintenance (Rodakowski et al., 2014). In their study they found that C-IADL can discriminate MCI from cognitively healthy older adults. More specifically, individuals with MCI had significantly more preclinical disability in shopping and cheque book balancing than those with healthy cognitive function (Rodakowski et al., 2014). In a similar study over a 3 year period, Wadley

(2007) found that all MCI groups showed faster rates of decline in everyday function than cognitively healthy participants with no MCI (Wadley et al., 2007).

Research has shown that financial capacity consistently differentiates people with MCI from healthy controls, and reveals large effect sizes (Griffith et al., 2003; Marson et al., 2009; Martin et al., 2019; Triebel et al., 2009). In one study, group differences were found for bill payment and financial concepts (Griffith et al., 2003). This is supported by a longitudinal study where people with MCI performed worse on all financial domains at baseline and, of those that converted to dementia, scores were worse than those who did not convert on financial conceptual knowledge, cash transactions, bank statement management and bill payment (Triebel et al., 2009). Further support comes from a recent six year longitudinal study by Martin et al. (2019), which showed that people with MCI had significant financial skill decline compared with cognitively healthy controls, with particular problems in financial judgement and large interaction effects for areas such as financial conceptual knowledge and bill payments (Martin et al., 2019).

These results demonstrate that all types of IADL measures, including performance-based, self-report and informant-report, as well as measures that focus on financial capacity, can discriminate MCI from healthy controls. However, drawing conclusions from a wide variety of measurements with different properties is problematic because most of the existing IADL measures lack psychometric rigour and the contents of the measures are disparate (Gold, 2012). Therefore it is important that measures of IADL with better psychometric properties are developed.

2.3.7. Using technology to support and assess IADL

As discussed in section 2.3.3, research suggests that subjective assessment may not be sensitive enough to detect the complex and multidimensional changes in IADL associated with MCI, and that objective assessments may be a more sensitive tool. However objective assessments can be time consuming and costly. An alternative approach to the assessment of daily function is to bring assessment into the home through the use of technology, such as remote sensors, to track daily activities in real time. Such technologies have the potential to enable people to continue to carry out IADL by detecting when assistance is needed and delivering reminders or prompts.

Video monitoring is one method that has been used to assess daily activity in people's homes or in testbed environments. One study investigated the use of a video monitoring system for automatic event recognition for the assessment of IADL in people with MCI and healthy controls (Konig et al., 2015). Participants were asked to complete a standardized IADL, such as making a phone call, while being video recorded. Kinematic parameters detecting activities were extracted and the quality of activity and cognitive health were predicted. This prediction was then compared to observation and neuropsychological assessment scores. They found that the video monitoring software was 85% sensitive and 76% accurate[2] in correctly detecting activities automatically. They also found that the frequency levels of activities such as preparing a pill box and making tea differed significantly between people with MCI and healthy controls. However no significant difference was found between these groups according to the IADL scale. These results suggest that it is possible to assess IADL functioning through video monitoring, and that video monitoring can detect differences between people with MCI and healthy controls that may not be detectable through informant report.

Sacco and colleagues (2012) used a video monitoring system to obtain quantifiable assessment of IADL in AD and MCI. Participants were asked to undertake a set of daily tasks in the setting of a "smart home" equipped with video cameras and everyday objects. A daily activity scenario (DAS) score was calculated that could differentiate AD and MCI (Sacco et al., 2012), indicating the potential of such systems to detect changes in function in the home. However no control group was used so it is unclear whether people with MCI could be differentiated from cognitively healthy older adults.

One method for supporting people in the completion of everyday tasks in their own homes is through the use of prompting technologies. Seelye (2013) tested the effectiveness and user acceptance of an IADL prompting technology. Participants with single and multi-domain MCI were asked to complete eight scripted IADL activities in an apartment testbed equipped with web cams and sensors. Seelye (2013) found that a multi-domain MCI group made more errors and required more prompts than a single-domain MCI group and healthy

[2] Konig el al. (2015) describe how the precision index evaluates the performance of the system at discriminating the various activities. They calculated precision using the following equation: TP/ (TP+FP) where TP is the True Positive rate and FP is the False Positive rate.

controls, suggesting that deficits in multiple cognitive domains could result in increased difficulty in IADL. All groups responded well to the prompting technology and perceived it be very helpful (Seelye et al., 2013), indicating high levels of acceptability. These studies show potential for using technology to detect or monitor functional impairment. However, despite aiming to set up a "home-like" environment, participants in both studies were asked to perform scripted activities in an unfamiliar setting. Therefore the resulting behaviour and performance would differ to a normal home (Jekel et al., 2016). In addition, there were not the normal interruptions or distractions that would occur in a normal home environment (Schmitter-Edgecombe and Parsey, 2014), which means that the scripted tasks might have been less cognitively demanding, especially considering that tasks were completed one at a time as oppose to at a multi-task level. Conversely, knowing you are being monitored and are part of an experiment could increase cognitive load (Seelye et al., 2013). The effect of this would be increased stress on the participants that could lead to more errors being made in the activities. A solution for this would be to create more naturalistic measurement technologies that blend or are part of an individuals' actual home environment.

Using video cameras to record people in their own homes would not be an ideal solution for many. Formal healthcare providers can be reluctant to make use of video surveillance because of ethical concerns in capturing and storing media of people living with dementia (Mulvenna et al., 2017). Niemeijer (2011) explains that views regarding the use of surveillance technology are often divided between the moral conflicts of safety versus freedom (Niemeijer et al., 2011). Mulvenna et al. argues that, in relation to video surveillance, increasing a person's safety does not always lead to a decrease in that person's privacy (Mulvenna et al., 2017). However, these concerns and moral arguments present a need for other technological solutions that do not involve such high potential for overt invasion of privacy. In addition, technically smart homes and testbeds such as those in the outlined studies are expensive and time-consuming and are a potential obstacle to the deployment of such technologies for the monitoring of large numbers of older adults (Lussier et al., 2019). Studies to develop technology that can monitor routine behaviour in the home in an unobtrusive, practical and inexpensive way are therefore required to enable the collection of more valid, naturalistic data providing information about functional capacity.

The use of smart home technologies in research labs compared to actual home environments was considered in a recent systematic review by Lussier and colleagues (2019). They investigated the effectiveness of smart home technologies for the detection of MCI through the monitoring of everyday activities. Of the seventeen studies that they included in the review, thirteen were based on real-life monitoring in the home using sensors and four studies used scenario-based assessments in a research lab. The real-life monitoring studies were divided into three broad categories: (1) mobility, which included walking speed and also movement or activity within the home; (2) computer usage and (3) self-care, which was just based on one study that considered medication intake. They concluded that that smart homes can provide ecological assessments over long periods of time which is particularly relevant for follow-ups of persons with MCI, especially as the time trajectory of MCI is not well understood. However, they suggested that future studies need to provide information on how data such as walking speed and activity in the home relates to standard neuropsychological and functional measures in order to determine what types of information provides the most reliable indicators (Lussier et al., 2019).

2.3.8. The relationship between cognition and IADL

Individuals with MCI demonstrate deficits in a wide range of everyday functioning and some studies suggest that the magnitude of these changes is greatest for those functional abilities that rely heavily on memory. For instance, Weston (2011) found that patients with MCI experience mild functional deficits that vary according to type of MCI. They found that patients with MCI were more likely to have difficulty remembering lists and recalling recent events and less likely to have difficulty eating and with continence compared with those with nonamnestic MCI (Weston et al., 2011). There is a need to determine the specific cognitive processes underlying IADL changes in MCI to improve understanding of the relationship between cognitive impairment and functional restriction in MCI (Okonkwo et al., 2006).

It is relatively unsurprising that studies are finding prominent changes in memory-related functional abilities given that large proportions of their samples have MCI of the amnestic type. Farias (2006) investigated the degree of impairment in an MCI group relative to healthy controls and found that 45% of their sample had MCI of the amnestic type. The

study considered informant ratings of participants' abilities across different functional domains relating to memory, language, visual spatial abilities, planning organization and dividing attention. Farias (2006) found that functional activities presumed to be heavily dependent on memory-related abilities, such as remembering the current date or day of the week or repeating stories, were most consistently and robustly impaired compared with the other functional domains examined. The items on this everyday memory scale mostly required episodic memory for recently acquired information (Farias et al., 2006). Similarly, a study by Perneczky and colleagues (2006) with 90 older adults, examined functional impairment across 18 complex ADL and concluded that, compared with age-matched controls, ADL involving memory such as finding things at home and complex reasoning such as organising travel, were most affected in people with MCI (Perneczky et al., 2006) . Executive functioning has been strongly linked to functional impairment (Lopez et al., 2006; Zanetti et al., 2006). Therefore it is important when examining which IADL are memory dependent that executive ability is controlled for. In a study by Seligman and colleagues (2014) of 45 older adults, deficits in episodic memory predicted a range of different types of functional errors, even after controlling for executive functions (Seligman et al., 2014). However, they used a single task to measure executive function, which may not have covered the range of executive functions that apply to functional deficits. Also in order to detect small but meaningful effects it might be necessary to use a larger sample size.

These studies suggest that the largest changes in IADL in people with MCI are seen in those activities that rely heavily on memory. This could be explained in part by the greater proportions of people with amnestic MCI within the study samples. However, studies do not always differentiate their samples by clinical phenotype. Also, a number of studies have found that functional change is related to other cognitive domains, not just memory.

Other studies suggest that functional deficits that best discriminate between MCI and healthy controls draw on multiple cognitive domains as opposed to just memory. The four IADL that most effectively discriminated MCI from healthy controls, have been shown to draw on executive function, language, memory and visual spatial processing (Zoller et al., 2014). This is supported by other studies that have indicated that executive dysfunctions, as well as more global cognitive impairment, are involved in IADL deficit (Reppermund et al., 2013; Rodakowski et al., 2014; Royall et al., 2007).

In a two year longitudinal design, Reppermund (2013) examined functional abilities in people with MCI compared with cognitively healthy older adults. They focused on functional abilities with high cognitive demand associated with cognitive performance in several domains. They found that informant reported IADL with high cognitive demand, such as finding the way in an unfamiliar place or doing two things at the same time, showed impairment predating the diagnosis of MCI (Reppermund et al., 2013). Another study found that eight cognitively focused IADL demonstrated 81% accuracy in discriminating cognitive status between an MCI group and older adults with healthy cognitive function and two tasks (shopping and chequebook balancing) correctly classified the cognitive status of 80% of older adults (Rodakowski et al., 2014). The results from these studies demonstrate that a range of IADL drawing on multiple cognitive domains, not exclusively memory, are effective in discriminating MCI from healthy controls and that those activities that require higher level cognitive resources are more vulnerable to early cognitive changes.

Understanding which IADL become challenging for people with MCI is important because it can support earlier detection of cognitive change and can also enable support to be tailored to specific difficulties. Information about those IADL most likely to decline in the early stages of cognitive decline can be used as a focus in studies aiming to develop technology for the detection of preclinical MCI, for example sensors could be placed in the kitchen to monitor multi-tasking or near to medication to monitor medication management. Using theory and data to specify in advance the variables you are most confident in and selecting those variables for analysis has a number of benefits. Not only is it more time and cost effective, especially when considering the cost of specific types of technology, it also helps to reduce the number of variables you test and thus minimises the risk of Type 1 errors.

2.4. Older adults use of technology and the relationship with early cognitive change

2.4.1. Increasing use of technology amongst older adults

Current research shows that older adults are becoming increasingly involved in the use of technology, as evidenced by ownership of technological devices such as mobile phone, tablets and e-readers (Gitlow, 2014; McCausland and Falk, 2012). For instance, mobile phone ownership/access in people aged 55 to 75 in the UK increased from 40% in 2013 (Deloitte, 2013) to 71% in 2017 (Deloitte, 2017). Older adults also make up the fastest

growing group of internet users (Hart et al., 2008). In the UK, recent internet use in people aged 65 to 74 has increased from 52% in 2011 to 80% in 2018 and internet use in people over the age of 75 has increased from 20% in 2011 to 44% in 2018 (Office for National Statistics, 2018).

In terms of the types of computer activities that are common among older adults, a survey of 127 Finnish adults aged over the age of 55 found that the most popular online services for older adults include e-mail, general information searching, and e-banking (Vuori and Holmlund-Rytkönen, 2005). In depth interviews with 35 UK adults aged over 60 years found that the main purpose for using the computer is word processing, keeping in touch with others, and generally increasing the experience and ability on a computer. It was also found that older adults' computer use mainly takes place at home and, if support is needed, it most often comes from immediate family members and close relations (Selwyn, 2004).

The next generation of older adults will be even more dependent on technology than the present generation. In 2018 almost all adults aged 16 to 44 years (99%), 97% aged 45 to 54 years, and 92% aged 55-64 years were recent internet users (Office for National Statistics, 2018), suggesting that unobtrusive computer based assessments in relation to health and well-being will be relevant to an increasing proportion of people in coming years.

2.4.2. Use of everyday technology as a marker of subtle cognitive change

Jekel suggests that the development of IADL measures focused on IADL domains likely to be sensitive to subtle changes in functional decline, such as financial capacity and the use of everyday technology such as computer skills, are needed (Jekel et al., 2015). Unfortunately, the majority of IADL assessment instruments do not take specific measurements of the use of technology. However, a number of studies have found that use of everyday technology is a sensitive measure of subtle impairment (Jekel et al., 2015). One aspect of IADL where people with MCI have been identified as being significantly more disabled than healthy controls is in activities that require the use of electronic equipment, such as using telephones, managing money and using transportation (Hedman et al., 2013; Nygard and Kottorp, 2014). Other researchers have suggested that early signs of disability in people with MCI may be detected in these activities (Schmitter-Edgecombe et al., 2012).

A number of studies have also found that people with MCI perceive more difficulties, and show impaired performance, in the use of everyday technology in daily life activities in comparison to people without known cognitive impairment (Hedman et al., 2017; Malinowsky et al., 2010; Nygard et al., 2012; Rosenberg et al., 2009). Using the Management of Everyday Technology Assessment (a standardized, observation-based tool) to evaluate ability to manage everyday technology (e.g. remote controls and mobile phones), Malinowsky (2010) found significant differences between people with MCI, mild AD and controls. However, this study did not control for other aspects that may influence older adult's ability to manage ET, such as ability to focus, familiarity with the ET, and the specific ET design. A later study by the same group aimed to identify aspects that influence older adults with and without cognitive impairment ability to manage ET (Malinowsky et al., 2012). They found three aspects had a significant effect upon ability to manage ET: variability in interpersonal capacities, such as the capacity to pay attention and focus; environmental characteristics, such as the impact of the design and diagnostic group; and diagnostic group. In this study a significant difference was only found between healthy controls and people with dementia, compared with all diagnostic groups in the previous study. These findings suggest that differences in the use of everyday technology are influenced by factors other than cognitive level or diagnosis. In addition the regression model explained 51.7% of the ability to manage ET compared with 35.9% in the earlier study, suggesting that adding information regarding intrapersonal capacities and environmental characteristics to a diagnostic evaluation can better predict ability to manage ET.

Empirical evidence suggests that perceptions about the relevance of ET and the ability to use ET are related to cognitive ability and diagnostic grouping. In a 24 month longitudinal study of 37 older adults with MCI, perceived ability to use everyday technology decreased or fluctuated in 50% of the sample, although (unlike cognitive function) these changes were not statistically significant (Hedman et al., 2013). This suggests people with MCI are still able to maintain their use of everyday technology, despite a reduction in confidence and cognitive ability. In contrast, Rosenberg (2009) found significant differences between samples with AD, MCI and controls in the perceived difficulty of using everyday technology, reported using the self-rated Everyday Technology Use Questionnaire, and of the amount of

technologies that were considered relevant to each group, suggesting that measurement of perceived difficulty in everyday technology use could detect changes resulting from MCI and dementia. This study was supported by Nygard (2012) using the same questionnaire. They found that people with MCI, AD and controls differed significantly in their perceptions of the relevance of everyday technology as well as the difficulties in using it. This highlights the importance of taking perceptions of everyday technology into account in assessments and targeted interventions (Nygard et al., 2012).

Amount of use of ET could also be a marker of cognitive decline. A number of studies have found that the use of everyday technology declines over time in older adults with MCI. For instance, in a longitudinal study of everyday technology use in older adults with MCI, Hedman (2015) found a significant decrease in the amount of everyday technology use over time (Hedman et al., 2015). In a study comparing engagement in IADL, social activities and use of everyday technology in older adults with a without cognitive impairment, Nygard (2014) found that the association between activity engagement and difficulty with everyday technology use was stronger in people with MCI and Alzheimer's disease (AD) than in controls. This is supported by findings from a more recent study by the same group, which showed that a decrease in the number of everyday technologies used were associated with a decrease in activity involvement (Hedman et al., 2017). Nygard and colleagues (2014) suggest that the challenges of managing technology outside the home (for example driving, paying for shopping etc.) are restricting people with cognitive impairment more than they restrict controls. This has implications for clinicians to pay increased attention to investigating activity engagement and difficulties with everyday technology in people with MCI to promote the continuation of engagement in activities of everyday life.

2.5. Computer use: an emerging IADL

Computers have become an integral part of daily life in the modern world (Tun and Lachman, 2010). The increasing use and incorporation of computer based devices into daily life has, in effect, created a new higher order or instrumental activity of daily living (Kaye et al., 2014). Medeiros describes computer use as an IADL equal to other IADL ,such as shopping for groceries, using public or private transportation and managing finances (Medeiros Fde et al., 2012). In fact, in today's society, an increasing number of IADL are

conducted using a computer: examples of which include buying food online; online banking to manage finances; online telephony services such as Skype; watching television; and keeping track of appointments using online calendars. In a survey of 505 veterans assessing which IADLs were being completed using Information and Communications technology (ICT), Melrose (2016) found that 70% were regular ICT users, and that, of this 70%: 76% used ICT for finances, 86% for shopping, 72% for health management, 75% for transportation and 97% for communication. They conclude that veterans are using ICT to support IADL and that IADL assessments need to include questions about ICT to assist in detecting subtle change in functional ability (Melrose et al., 2016).

Daily activities increasingly include ICT regardless of whether people have the ability to use the technology or not, and the ability to use ICT will likely become essential for autonomous functioning in society (Munoz-Neira et al., 2012). With an increasing number of older adults needing to use technology in daily life, it is essential to understand how effectively older adults function in such tasks and how cognitive change can impact on ability.

2.5.1. Assessing computer use and other technologies as part of functional assessment

Although technology has permeated all aspects of contemporary life, many existing functional assessment scales for dementia and MCI do not incorporate assessment of computer skills or the handling of "new" technology (Jekel et al., 2015; Munoz-Neira et al., 2012). A number of new scales and subscales are now emerging which assess competence in the use of common technology in older adults. For example, a newer version of the Alzheimer's Disease Cooperative Study/Activities of Daily Living scale adapted for people with MCI (ADCS/MCI/ADL24) (Galasko et al., 1997) has been developed recently with the addition of a set of questions asking about technology use (D. Galasko, personal communication, 24th June 2015). However, the new version of the scale has not been extensively validated by the authors and therefore future research considering the clinical usefulness of the additional questions is required.

Some newly developed technology subscales have also undergone validation. Munoz-Neira and colleagues (2012) have developed the Technology - Activities of Daily Living Questionnaire (T-ADLQ), a technology based subscale of the Spanish version of the Activities of Daily Living Questionnaire (SV-ADLQ). The SV-ADLQ is a 4-point informant-based scale of

functional abilities composed of 6 subscales including self-care and shopping and money. The T-ADLQ was created with the same structure as existing subscales of the SV-ADLQ and incorporates five common domains of technology use including internet access and email. They found that although the T-ADLQ had adequate validity and reliability for functional assessment of ADL in people with dementia, it did not improve the overall performance of the original scale. They suggest that this reflects the lack of widespread technology use by older adults. The new scale could differentiate the dementia group from the MCI and healthy control groups; however it could not distinguish between the MCI and healthy control group. This could be due to their small MCI sample, suggesting further research with larger samples is needed to be able to determine the differences in functional disability between people with MCI and cognitively healthy controls. Munoz-Neira (2012) also highlights the need for longitudinal research to investigate change over time in the use of technology for both healthy older adults and people with MCI, as their study found deficits in the use of technology for both groups (Munoz-Neira et al., 2012).

A new scale developed by Sikkes (2012) also addresses the need for an IADL assessment that incorporates the use of advanced technology such as mobile phones, computers and household appliances. The Amsterdam IADL Questionnaire (A-IADL-Q) is a Dutch informant-based questionnaire for assessing IADL in the earliest stages of dementia both for clinical and research purposes. The researchers addressed the lack of information about the psychometric qualities of existing IADL measures by assessing the content validity, internal consistency and reliability of the new scale. The scale is computerised for ease of administration and also means that individuals do not have to answer questions that are not relevant to them. Using an algorithm based on the respondent's previous responses, no irrelevant item response options or items are presented. Asking participants only those questions that are relevant has the advantage of reducing the complexity of the questionnaire and avoiding unnecessary burden placed on the person completing the scale. For example, the informant is asked if the individual uses a computer; if their answer is 'no' then no further questions are asked about computer use, and the next question will ask about a different activity (e.g. washing). However, if the answer is 'yes', then further questions about specific aspects of computer use (e.g. printing documents) are presented.

During the piloting process the computerized questionnaire received positive feedback from informants, who found it easy to complete (Sikkes et al., 2012).

Since its development, in a study with 206 informants, the A-IADL-Q has been shown to have good construct validity (Sikkes et al., 2013). Another study of 102 patients and their informants who visited their Alzheimer Center, found that the A-IADL-Q was sensitive to change over time in IADL functioning and can be used in evaluating treatment effects and assessing individual disease progress. People with dementia were found to show a faster rate of decline in A-IADL-Q score over time compared with MCI and people with subjective memory complaints (SMC). They also found that A-IADL-Q scores were related to change in global cognition, memory and executive functioning. Although they did not assess the ability of the A-IADL-Q to differentiate the three groups over time, the inclusion of people with MCI and SMC strengthens the generalizability of the results and suggests that this scale could be applicable as a measure in broader populations (Koster et al., 2015). A short version of the A-IADL-Q has recently been developed (Jutten et al., 2017) and a study considering the cultural diversity of the measure, found no meaningful item bias and similar correlations across countries (Dubbelman, 2019). The versions of the A-IADL-Q used in the Dubbelman et al. (2019) study were cross-culturally adapted translations of the measure, which emphasises the importance of appropriate adaption of an instrument to the country of use in order to ensure minimum item bias. Future studies investigating the responsiveness of the A-IADL-Q in other clinical or cultural populations are needed as part of this on-going questionnaire validation process. A development of a UK version of the questionnaire is also needed.

2.5.2. Daily computer use is related to functional capacity

Older adults' use of computers has the potential to provide information about functional capacity. Using a computer depends on multiple cognitive domains (e.g., attention, working memory, episodic memory & executive function). It is therefore likely that computer use behaviour would be highly sensitive to cognitive change (Kaye et al., 2014). For example, computer-use errors, such as incomplete requests and repetitive or idiosyncratic computer use behaviour patterns, might be early indicators of cognitive pathology, while text mining could identify expressions of memory loss and frustration in user-generated content, or

early deficits in language function (Stringer et al., 2016). Support for this comes from an expert reference group who agreed on 21 computer-use behaviours that offered a 'strong indication' of decline in a specific cognitive function across memory, executive function, language and perception and action domains (Couth et al., 2019). For example repeatedly typing an incorrect password was linked to memory and executive functioning and repeated mouse clicks on programme icons despite the programme not opening was linked to inhibition.

Using a computer is also a highly interactive activity that presents special challenges to older adults linked to age related changes. For example, increased difficulty in psychomotor ability could lead to problems using the mouse, and slowed performance could result in a greater number of errors (Charness and Boot, 2009; Tun and Lachman, 2010). In this manner, computer use can be used as a proxy measure of distinct cognitive functions through the deconstruction of computer actions of varying complexity. This fertile source of information can be used to develop a profile which enables people to become more aware of changes in their cognitive functioning and to seek further clinical assessment as appropriate (Stringer et al., 2016).

2.5.3. Daily computer use provides information about functional independence.

Computer use also presents a way of passively monitoring functional activity. Current methods for assessing IADL are problematic and the use of technology to monitor IADL is costly and intrusive. A number of studies have investigated the impact of daily computer use on functional capacity, showing the important links between technology and functional independence (Mcconatha et al., 1994; Medeiros Fde et al., 2012; Wilson et al., 2002). However, to date there is a limited amount of research investigating the potential of monitoring computer use to provide information about functional change over time.

In a recent examination of online survey metadata, Seelye and colleagues (2018) found that earlier survey start time of day was associated with better scores on memory and visuospatial tests and that longer survey completion time was an indicator of progression to MCI. However, they found no relationship between the online survey metadata and functional ability, as measured by the Functional Assessment Questionnaire (FAQ). Also, the FAQ was unable to discriminate between people who went on to develop MCI and people

who remained cognitively intact. Therefore, although this study suggests that computer use behaviour can inform us about change in IADL performance, it is unable to provide information about how functional ability reflected by personal computer use is related to paper-based IADL measures. Moreover, the FAQ may not have been the most appropriate measure for distinguishing between cognitively healthy people and people who go on the develop MCI. Previous research has demonstrated that the total impairment score from the FAQ has significant floor effects for clinically healthy individuals and is therefore not useful when trying to distinguish between people who are clinically healthy and people at risk of cognitive decline (Marshall et al., 2011; Morris, 2012). However, certain questions on the FAQ have been found to be sensitive to earlier functional changes in cognitive healthy older adults at risk for AD (Marshall et al., 2015b). Seelye and colleagues did not investigate the relationship of specific questions on the FAQ with the online survey metadata. This emphasises the importance of developing sensitive subjective scales for assessing IADL that are meaningful to affected individuals and their loved ones that can then be used in studies investigating the potential of computer use behaviours as a marker of early functional decline.

2.5.4. Computer use and cognitive function

Despite a lack of evidence for how monitoring of computer activity can provide information about functional capacity, new methods in unobtrusive monitoring of cognitive function in a home environment are emerging and present the possibility of detecting changes in performance in a natural setting (Austin, Hollingshead, & Kaye, 2017; H. Jimison, Jessey, McKanna, Zitzelberger, & Kaye, 2006; Kaye et al., 2014; A. Seelye et al., 2015; A. Seelye et al., 2016; A. Seelye et al., 2018). Previous studies have demonstrated the feasibility of measuring computer-use behaviours in older adults to distinguish between those with and without cognitive impairment. Jimison and colleagues have conducted a number of studies to develop software for monitoring computer interactions in the homes of elders (Jimison et al., 2006; Jimison et al., 2004; Jimison et al., 2007). In their 2006 study they developed a monitoring program to record data about a user's keyboard, mouse and use of applications in Windows. They found that computer use activity, keyboard typing speed and variability in performance were promising measures for inclusion in algorithms for predicting and monitoring cognitive decline (Jimison et al., 2006). However, not all of the participants

recruited had used a computer before and only a small percentage of the participants at the time of the study had a computer in their home, had used email and been online. Consequently they found training participants in the use of computers quite challenging, especially for those participants with MCI.

Kaye (2014) sought to determine whether long-term changes in remotely monitored computer use differ in persons with MCI in comparison with controls. The computer use of 113 older adults living independently was monitored over a 36 month period. The study measured older adult's days of use, mean daily use, and coefficient of variation of use. Although they found no difference at baseline between MCI and cognitively healthy controls, which likely reflects the initial training period, over time there was a significant decrease in the number of days of use, the mean daily use and an increase in day-to-day use variability. This study demonstrates that computer use can be monitored unobtrusively in older adult's homes over a number of years without disrupting normal routine. In addition, this study shows that compared to people with intact cognitive functioning, people with MCI have reduced frequency and duration of daily computer use. This presents an ecologically valid and efficient approach to track subtle, clinically meaningful change associated with cognitive decline and daily function.

A number of other studies have also demonstrated differences in the computer use behaviours of people with MCI and cognitively healthy controls. In a study by Seelye et al. (2016) people with MCI took longer and needed more assistance completing an online questionnaire (Seelye et al., 2016). Seelye and colleagues (2015) also demonstrated that people with MCI make significantly fewer mouse movements, take longer pauses between movements, and have higher variability in the trajectory of mouse movements, and that these behaviours also correlate with test scores of executive function, attention, visual-spatial ability, and global cognition (Seelye et al., 2015). Using a series of semi-structured typing tasks, Vizer and Sears (2015) demonstrated that keystroke speed and linguistic content is associated with cognitive impairment in older adults (Vizer and Sears, 2015). Another computer based study examined internet searches in relation to language and cognitive function in older adults (Austin et al., 2017). Internet searches were continuously tracked using computer monitoring software and the results suggested that the search terms people use on the internet could be an indication of early cognitive decline. However,

as mentioned for the Jimison (2006) study, some of the previous studies included novice or non-computer users in their participant sample (e.g. (Jimison et al., 2004; Kaye et al., 2014; Seelye et al., 2015; Seelye et al., 2016; Seelye et al., 2018)), meaning that the added cognitive burden of training and learning to use new equipment may have impacted on computer-use behaviours. Future research needs to determine the extent to which prior levels of experience or training influences decline in computer use (Kaye et al., 2014) and test and research software on older adults who are regular computer users for results to be reliable and valid.

2.6. Ethical considerations when recording data passively via home-based software

There are a number of ethical concerns when collecting large amounts of data passively via home-based software. Existing ethical and regulatory frameworks for the provision of mental healthcare do not clearly apply to digital phenotyping, meaning that it is critical to understand the possible ethical, legal and social implications (Martinez-Martin et al., 2018). Ethical issues include privacy, data protection, informed consent and ownership of data (Gold et al., 2018). Each of these is discussed below.

The concept of privacy is of particular relevance to any data collected unobtrusively from within a persons' home. At the end of the nineteenth century, Warren and Brandeis (1890) argue that the 'right to be left alone' (p. 193) could be derived from the right to property, protecting the individual from 'invasion either by the too enterprising press, the photographer, or the possession of any other modern device for the recording or reproducing scenes or sound' (Warren and Brandeis, 1890: p.206). Fast forward to today, and technological developments including high velocity data flows are creating risks to the life and liberty of human beings that require stronger privacy protections than had previously existed (Buttarelli, 2017). Our homes are traditionally perceived as one of the most private spaces, and yet are becoming increasing equipped with ambient technology (Kraemer and Flechais, 2018). Ensuring privacy and autonomy is paramount as digital biomarkers are incorporated into healthcare, self-management programs and research. Data use agreements should contain clear statements on conditions for data usage especially for tools that collect near-continuous data, like use of computers and digital devices (Coravos et al., 2019).

Data protection is important in all research but is particularly important when recording people's every day computer use. Research involving the use of personal data is required to fully comply with the provisions of the EU General Data Protection Regulation (GDPR) (Information Commissioner's Office, 2018) and the UK Data Protection Act 2018 (2018). Any organisation or individual processing personal data must ensure that personal data in their possession is managed in accordance with the Act's key rules. GDPR safeguards include the need to anonymise or pseudonymise where possible and to understand the importance of privacy, confidentiality and security. This is relevant when dealing with data from people's computers that could contain or be linked to their personal information.

The process of informed consent warrants special considerations when data are being collected from people with cognitive impairment (Gold et al., 2018). The basic components for informed consent are described by Petrini (2010): the possession of competence; voluntariness, the provision of information and enrolment (Petrini, 2010). A diagnosis of MCI or mild AD does not necessarily mean that the person cannot consent to take part in a study. The Mental Capacity Act (2005) states that researchers should assume that a person has capacity to make a decision, unless there is proof that they do not have capacity to make a specific decision, and that a prospective participant must receive support to try to help them make their own decision (Department of Health, 2005). However, in some longitudinal studies, a participant may lose capacity to consent prior to the conclusion of the project (Palmer et al., 2013). Researchers have an ethical duty to ensure that participants are giving competent voluntary consent throughout study participation (National Commission for the Protection of Human Subjects of Biomedical and Behavioral Research, 2014). Therefore, it is important to carefully check, before and during a research project, participants' capacity to understand information and to consent to continued participation (Shamoo, 1997).

Another ethical consideration when passively recording data in a home environment relates to data ownership i.e. who owns the data; how the data should be shared; and who is ultimately accountable (Kostkova, 2015). Failure to address concerns over ownership of data can lead to a loss of patient and citizen trust, and patients withdrawing their co-operation from data collection and sharing activities. This was demonstrated in the UK in 2016 when the care.data programme (NHS Choices, 2014), intended to enable large NHS individual data

sharing with researchers and, controversially, with businesses, was paused and eventually terminated due to concerns about patient trust, social license, consent, and data security (Goldacre, 2014). Reasons for opting out of sharing data include suspicion that data will be used for commercial purposes, scepticism about the supposed benefits, and lack of confidence in data security (Watts, 2019). Ballantyne (2020) argues that clinical data are co-constructed, and therefore the patient has relevant interests. By virtue of these interests patients are entitled to have their concerns considered and addressed.

2.7. Conclusion

Although the diagnostic criteria for MCI acknowledges there may be some degree of impairment when performing complex daily activities (Albert et al., 2011), tools for assessing IADL in MCI are frequently inadequate. Many IADL measures currently in use have limited information on their psychometric properties, do not include modern activities such as computer use, lack relevance to the lives of those completing them, and may not be sensitive enough to detect early functional changes. The emergence of new technology to monitor and support older people to continue to complete everyday activities in their homes is very promising. However, current methods are obtrusive, expensive, and are typically focused on supporting completion of IADL rather than detection of impairment.

Computer use is increasingly becoming an essential activity of daily life: in itself as an IADL, but also a method for conducting other complex daily activities such as financial transactions, food shopping and communication with friends and family. The numbers of older people who use and depend on computers to complete daily tasks and retain independence will only increase in time. Identification of associations among IADL and specific aspects of computer use has the potential to improve the diagnosis of dementia. This can provide vital information to support clinical decisions about functional disability and cognitive decline and increase current understanding of the cognitive and functional correlates of computer use. The use of computers to monitor functional decline is a very new field of enquiry. It remains to be established whether older adult's normal daily computer use can provide information about functional change over time and differentiate between people with MCI and cognitively healthy older people.

Critical developments are needed to ensure that functional impairment is assessed sensitively, accurately and in a culturally appropriate way. Therefore, first, functional assessment instruments need to include instrumental daily activities that are up-to-date, and culturally relevant to the lives of the people completing them. Secondly, there is a need to develop tools that are more sensitive to early change, offer continuous assessment, and are non-intrusive, such as the passive monitoring of computer use.

To address these needs, the aim of this PhD is to explore ways to improve the methods of measuring and detecting functional impairment in people with early cognitive decline. This will be achieved in two ways: first by reporting the cultural adaption of an existing measure of IADL (the Amsterdam IADL Questionnaire) in order to improve the current IADL measurements in the UK - in particular those that include questions about technology use; and second by investigating the potential of assessing directed and non-directed computer use behaviours (e.g. mouse clicks and keystroke speed) unobtrusively and continuously as a marker of cognitive and functional decline.

CHAPTER 3 (Study A): Enhancing 'meaningfulness' of functional assessments: UK adaptation of the Amsterdam IADL questionnaire

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Gemma Stringer conceived the original idea for the paper; adapted the original methodological design; wrote the clinical protocol and ethics application; designed the interview schedules and questionnaire; obtained ethical approval; recruited study participants; conducted and transcribed qualitative interviews; collected the questionnaire data; adapted the online questionnaire; collected the online questionnaire data; carried out the qualitative and quantitative analysis; and interpreted the data. Gemma Stringer wrote the first draft of the manuscript and completed all revisions following review by the co-authors. Dr Sietske Sikkes designed the original A-IADL-Q and contributed to all the developer discussions. Dr Laura Brown, Dr Sietske Sikkes and Professor Iracema Leroi provided clinical guidance and methodological guidance. Dr Laura Brown contributed to all developer discussions and provided statistical guidance. Professor Daniela Montaldi, Dr Laura Brown and Professor Iracema Leroi provided supervisory input. All authors critically reviewed and agreed on the submitted manuscript for publication.

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Enhancing 'meaningfulness' of functional assessments: UK adaptation of the Amsterdam IADL questionnaire

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Abstract

***Objective*:** Commonly used measures of instrumental activities of daily living (IADL) do not capture activities for a technologically advancing society. This study aimed to adapt the proxy/informant-based Amsterdam IADL Questionnaire (A-IADL-Q) for use in the UK, and develop a self-report version.

Design: An iterative mixed method cross-cultural adaptation of the A-IADL-Q and the development of a self-report version involving a three-step design: (1) interviews and focus groups with lay and professional stakeholders to assess face and content validity; (2) a questionnaire to measure item relevance to older adults in the UK; (3) a pilot of the adapted questionnaire in people with cognitive impairment.

Setting: Community settings in the UK.

Participants: 148 participants took part across the three steps: (1) 14 dementia professionals; 8 people with subjective cognitive decline (SCD), mild cognitive impairment (MCI) or dementia due to Alzheimer's disease; and 6 relatives of people with MCI or dementia; (2) 92 older adults without cognitive impairment; and (3) 28 people with SCD or MCI.

Measurements: The cultural relevance and applicability of the A-IADL-Q scale items were assessed using a 6-point Likert scale. Cognitive and functional performance was measured using a battery of cognitive and functional measures.

Results: Iterative modifications to the scale resulted in a 55-item adapted version appropriate for UK use (A-IADL-Q-UK). Pilot data revealed that the new and revised items performed well. Four new items correlated with the weighted average score (Kendall's Tau -.388, -.445, -.497, -.569). An exploratory analysis of convergent validity found correlations in the expected direction with cognitive and functional measures.

Conclusion: The A-IADL-Q-UK provides a measurement of functional decline for use in the UK that captures culturally relevant activities. A new self-report version has been developed and is ready for testing. Further evaluation of the A-IADL-Q-UK for construct validity is now needed.

Keywords

Instrumental activities of daily living (IADL), mild cognitive impairment (MCI), subjective cognitive decline (SCD), cross-cultural adaptation, Amsterdam IADL Questionnaire (A-IADL-Q)

Running title

UK adaptation of the Amsterdam IADL Questionnaire

Introduction

Functional ability refers to an individual's capacity to complete the everyday tasks necessary for independent living (Lindbergh et al., 2016). It is typically divided into basic activities of daily living (BADL), which are simple self-care tasks such as feeding and toileting, and instrumental activities of daily living (IADL), which are more complex, higher order skills such as managing finances and taking medication (Jekel et al., 2015; Lawton and Brody, 1969). The most recent criteria for mild cognitive impairment (MCI) due to Alzheimer's disease (AD) recognize the presence of subtle problems performing complex functional tasks, however the preservation of independence in functional abilities is a defining criteria (Albert et al., 2011). Nevertheless, difficulties performing IADL in MCI can be predictive of subsequent dementia (Di Carlo et al., 2016; Korolev et al., 2016; Marshall et al., 2015; Sikkes et al., 2011; Tabert et al., 2002). Assessment of subtle change in IADL could therefore provide vital information at the preclinical and prodromal stage of AD to support timely diagnosis and intervention.

Despite the clinical importance of sensitive IADL measurement, current measures of IADL are problematic for a number of reasons. First, although many of these questionnaires are used to assess IADL in people with MCI, they have most often been constructed and validated for people with dementia, and are therefore less sensitive for MCI populations and less able to detect subtle changes in more complex daily activities (Jekel et al., 2015). Second, existing measures fall short in important basic psychometric properties such as reliability and validity (Weintraub et al., 2018). For instance, in a systematic review of 12 IADL scales, only five were rated 'positive' for how content validity had been assessed (Sikkes et al., 2009). This is important given that the Food and Drug Administration (FDA) draft guidance published in 2018, emphasises the need for 'meaningful' assessments of functional ability when identifying early AD patients (Food and Drug Administration, 2018). A recent study by Hartry et al. (2018) concluded that four commonly used dementia assessment measures do not capture concepts deemed important to patients with mild to moderate AD, suggesting that specific effort is needed to ensure that items are considered conceptually relevant by patients and caregivers. Third, people with cognitive complaints may not have someone to act as an informant, and the majority of questionnaires are

informant-report, with only a small number of self-report options available. Even fewer questionnaires offer both options (Jekel et al., 2015).

Another issue with many IADL questionnaires currently in use is that they are out-dated, and do not include modern activities such as using a computer (Sikkes et al., 2012). This is particularly relevant given the growing use and importance of technology and computers in the lives of older adults. For example, adults aged 65 years and over have shown the largest increase in online shopping compared to all other age groups over the past decade, rising from 16% within the age group in 2008 to 48% within the age group in 2018 (Office for National Statistics, 2018). The assessment of everyday technology use has been shown to provide sensitive measures of early change in functional ability (Hedman et al., 2018; Malinowsky et al., 2010; Rosenberg et al., 2009). So, including modern activities such as the use of computers and mobile phones in IADL assessments could potentially improve sensitivity to subtle change at an early stage in cognitive decline (Jekel et al., 2015).

The Amsterdam IADL Questionnaire (A-IADL-Q) was developed with the aim of providing a more up-to-date overview of the IADL used in a technologically advancing society (Sikkes et al., 2012). The A-IADL-Q was originally developed in the Netherlands, and has since been translated and culturally-adapted for use in twelve languages (https://www.alzheimercentrum.nl/professionals/amsterdam-iadl-translations/) (Dubbelman et al., 2019; Facal et al., 2018). However, to date, it has not been culturally adapted and validated for use in the UK. Therefore the content of the questionnaire may not reflect the cultural norms and everyday behaviours of the UK population. In addition, the A-IADL-Q does not currently have a self-report version, which limits its use to people with an informant, or comfortable using an informant.

The aim of this study was therefore to complete a cross-cultural adaptation of the informant-based A-IADL-Q for use in the UK (the A-IADL-UK) and to develop a self-report version. The objectives were to: (1) assess the face and content validity of the translated questionnaire with lay and professional stakeholders and generate candidate new items to represent culturally important IADL; (2) further adapt the questionnaire based on the relevance of all candidate items to older adults in the UK; and (3) pilot the A-IADL-UK in a group of older adults with subjective cognitive decline (SCD) and MCI, to assess the relevance and sensitivity of new items and explore associations with measures of cognition

and function. We hypothesise that higher levels of impairment measured by the A-IADL-UK will be associated with higher levels of cognitive and functional impairment on these existing measures.

Method

Design

This was an iterative mixed method cross-cultural adaptation of the A-IADL-Q undertaken in community settings in England involving a three-step design (Figure 1). In step one, interviews and focus groups were conducted with lay and professional stakeholders to assess the face and content validity of the items. In step two, a questionnaire was administered to older adults to measure the frequency of daily activities. In step three, the questionnaire adapted from the results of steps one and two was piloted.

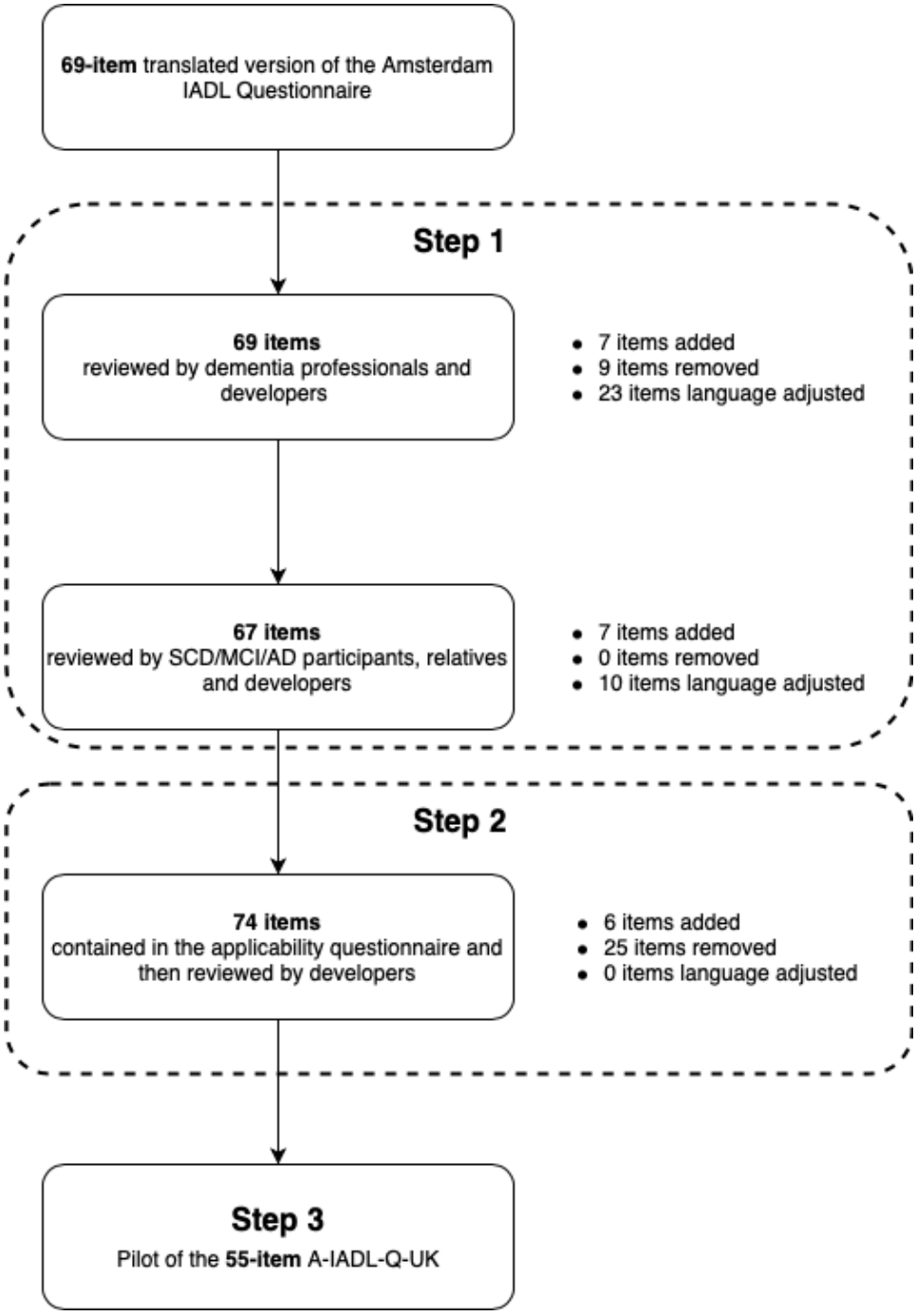

Figure 1. Flowchart detailing the outputs from the three steps of the A-IADL-Q-UK item adaptation process. See Appendix 1 for full details of the changes made to each item at each step.

Participants

Five groups of participants took part in the study, across three steps (Table 1).

Table 1. Overview of all participant demographics across three steps

		Step One		**Step Two**	**Step Three**
	Dementia professionals (n=14)	SCD/MCI/AD participants (n=8)	Relatives (n=6)	Older adults* (n=92)	SCD/MCI participants (n=28)
Age (years)	N/A	78.30 (5.95)	68.87 (13.13)	73.87 (5.53)	72.46 (4.04)
Gender (% women)	11 (79%)	4 (50%)	4 (67%)	62 (71%)	18 (64%)
Ethnicity, white British	N/A	N/A	N/A	87 (95%)	N/A
Years of formal education	N/A	N/A	N/A	Left school before 16 (29%)	13.21 (3.24)
ACE III† Total score	N/A	N/A	N/A	N/A	93.54 (5.49)
ECog‡ Total score	N/A	N/A	N/A	N/A	1.60 (.68)
TMT B§	N/A	N/A	N/A	N/A	77.96 (41.31)
DSB¶	N/A	N/A	N/A	N/A	7.79 (2.41)

Data are presented as mean (SD), or n (%). *Demographic data was not completed by 5 of these participants. †ACE III = Addenbrooke's Cognitive Examination-III (ACE III); ‡ECog = Measurement of Everyday Cognitive Function; §TMT B = Trails Making Test B; DSB = Digit Span Backwards Task.

Dementia professionals were recruited by email and personal contacts. In order to be included, they had to work with older adults and have experience of diagnosing dementia and/or conducting cognitive or functional assessments with people with dementia. The final group of dementia professionals (n = 14) consisted of five consultant old age psychiatrists, four trainee consultant psychiatrists, three dementia research nurses and two later life occupational therapists from the North West of England.

Older people (over the age of 65) with SCD, MCI and mild dementia due to AD were recruited for steps one and three through memory clinics; the UK dementia research

registry ‘Join Dementia Research’ (a national web-based service for participation in dementia studies); step three participants were also part of another study called SAMS (Software Architecture for Mental Health Self-Management) (Stringer et al., 2018). Participants with dementia and MCI diagnoses were referred with a diagnosis already made by qualified memory specialists. Participants with self-reported worries about their memory were identified as SCD if they indicated on a scale of functional capacity - the Everyday Cognition Scale (ECog) (Farias et al., 2008) that they were “concerned they have a memory or other thinking problem” and their total score on this scale was > 1.436. This cut off score corresponds to the upper 95% confidence interval of the mean total ECog scores from a sample of healthy control participants who indicated that they were *not* “concerned they have a memory or other thinking problem” (Stringer et al., 2018). Participants who did not meet this criterion for SCD were not eligible to take part. The SCD/MCI/AD participants and relatives in step one were recruited using the “sampling to redundancy” criterion, that is, interviewing participants until no new themes emerge (Streiner, 2008).

Older adults (over the age of 65) who were cognitively healthy were recruited for step two through Join Dementia Research and local community groups in the Greater Manchester area.

All participants were included if they had the capacity to consent and were able to communicate verbally in English. Individuals with any severe physical or mental difficulties were not eligible for the study.

Description of the parent instrument

The A-IADL-Q consists of 70 items, plus six additional sociodemographic questions that can be added or adapted per study, and is completed by an informant of the patient. IADL are divided into seven categories; household duties, domestic appliances, household budget, work, computer, devices and leisure time/other. Participants are asked if they have completed the activity in the previous four weeks and, if yes, their difficulty performing the activity is rated on a five point Likert scale, ranging from ‘no’ difficulty in performing the task to ‘no longer able to perform this task’. The A-IADL-Q has been shown to have good content validity and test-retest reliability (Sikkes et al., 2012) and good construct validity (Sikkes et

al., 2013a). A recently developed 30 item A-IADL-Q short version (A-IADL-Q-SV) maintained the psychometric quality of the original A-IADL-Q (Jutten et al., 2017).

Items are adapted based on the respondent's answers. For example, further questions about computer use are only asked if the patient answers that they use a computer. The total score on the questionnaire is calculated using an item response theory (IRT) method of scoring, with lower scores indicating poorer performance (Sikkes et al., 2013b). IRT assumes that ordered-categorical item responses represent an underlying construct or 'latent trait' (Embretson and Reise, 2000). This construct for the A-IADL-Q is IADL functioning ranging from ability to disability.

Procedures

The study was approved by the Health Research Authority - National Research Ethics Service England in accordance with the Declaration of Helsinki, and all participants signed informed consent to participate. A 69-item paper-based draft version of the UK informant questionnaire, was created using a combination of items from existing US and Australian culturally validated versions of the A-IADL-Q. The self-report version was created by re-phrasing each item from third person to second person (e.g. '…did <u>they</u> use a computer?' was re-phrased '…did you use a computer?'). The 69-item draft version was then culturally adapted through the following three-step process (Figure 1).

Step 1. Dementia professionals', SCD/MCI/AD and relatives' review

The first step involved reviews by two groups of people: 1) the dementia professionals, and 2) people with SCD, MCI or mild dementia due to AD and relatives of people with MCI and dementia. Participants were presented with the 69 IADL items in the form of a Likert scale questionnaire that asked participants to rate how often they did each activity. The questionnaire included five example questions to illustrate the wording of the final version (e.g. 'In the past four weeks did you use a sat-nav?'). During face-to-face interviews or small focus groups, dementia professionals commented on the clarity and appropriateness of the activity wording and the relevance of the activities to older adults in the UK, they also suggested relevant new activities. Written notes and audio recordings were taken throughout. A summary of the findings were discussed in a developer review with the developer of the original scale (Sietske Sikkes) via video conference, where suggested

changes were considered and decisions were made for each item in preparation for the next stage. This consultation allowed for constructive feedback to ensure the integrity of the scale was maintained. The changes made following the developer review resulted in a 67-item version.

SCD/MCI/AD participants and relatives completed the 67-item version individually and were asked to think aloud throughout. SCD/MCI/AD participants completed the self-report version and relatives completed the informant report version. All participants were also asked to suggest any new activities that were not covered in the questionnaire but were relevant to their daily lives. Comments were audio-recorded and written notes were made. To improve the clarity of items, we made minor iterative changes to the layout and wording of questions in response to feedback from individual participants. More substantial changes to the actual activities, and any deletions or additions, were made following a second developer review.

Step 2. Applicability questionnaire

The two stage review process in step one resulted in a 74-item applicability questionnaire comprising 60 original items; 33 modified original items; and 14 new items. In step two, to assess relevance, the frequency of the activities in the 74-item version was measured using a postal questionnaire. Participants were asked to rate how frequently they completed the activities on a 6-point Likert scale from 'most days' to 'never'. Participants were also able to suggest new activities and provide additional comments. Two follow-up questions ('Did they buy the correct amounts?' and 'Did they buy the correct items?') were excluded from the applicability questionnaire because they were not compatible with a frequency rating. Decisions about changes to the excluded items were based on the developer discussion. Paper copies of the 72-item questionnaire were distributed to 140 older adults over the age of 65, who did not have a diagnosis of dementia. Completed questionnaires were returned by post.

Analysis of the responses to the step two applicability questionnaire considered the mean and median responses for each activity. Activities with a median score of >4 (corresponding to activities not undertaken in the past year or ever) were considered candidates for removal. New activities with a median score <2 (corresponding to activities done every day

or one to three times per week) were considered candidates for inclusion. Items with >6 missing answers, or that were difficult for participants to complete based on observations in the completed versions or notes made by the participants, were also considered candidates for exclusion. In addition, information about item performance from the development of the A-IADL-Q-SV was used to help guide decisions about the inclusion or exclusion of some items. A discussion of the median analysis and decisions about changes were completed in a third developer review, which led to a final 55-item version being created.

Step 3. Pilot of the A-IADL-Q-UK

In step three a 55-item electronic version of the questionnaire was piloted to assess the relevance and perceived difficulty of the new items and to measure overall functional impairment. The UK version (A-IADL-Q-UK) comprising the items developed in steps one and two was administered electronically using Qualtrics software Version New QTrial 2015[1] to 31 older adults with either SCD or a diagnosis of MCI. Participants were sent a link to the questionnaire via email. A reminder telephone call was made if the questionnaire had not been completed after five days. The 55-item version included 9 'new items', 4 items that were completely new and 5 items for which the language or meaning had been adjusted significantly and meant that existing item characteristics could no longer be used e.g. 'using a coffee maker' became 'making a cup of tea or coffee'. As no item characteristics were yet available for the new items and due to sample size it was not possible to use IRT analysis on the step three pilot data, therefore scores for this were calculated using the weighted average. This alternative scoring approach was previously tested for the Amsterdam IADL, and is currently used in clinical practice due to a high concordance with the IRT scoring. Weighted average (WA) was calculated by dividing total IADL score by the number of items endorsed. The following scoring method was then applied 100–(WA*25). Higher scores indicate greater functional impairment.

Step 3: Instruments

Descriptive measures of global cognitive status were obtained using the Addenbrooke's Cognitive Evaluation (ACE) III (Hsieh et al., 2013): a concise neuropsychological assessment

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of cognitive functions commonly used in the UK with validated cut-off scores for MCI and dementia. The battery includes five cognitive subdomains: attention, memory, verbal fluency, language and visuospatial abilities, which provide a cognitive score out of a maximum of 100 (a higher score indicates more intact cognition). The ACE III was selected to investigate the relationship between the A-IADL-UK and global cognitive status.

In order to focus on critical areas of executive functioning we selected the digit span backwards (DSB) test and Trails Making Test (TMT) B (Lezak et al., 2012). TMT B is a measure of executive abilities including set-shifting and mental flexibility, a longer time on this test represents a higher level of impairment. DSB is an executive task particularly dependent on working memory where a higher score represents less impairment. TMT B and DSB are known to be sensitive to age (Lara et al., 2013). Participants' scores on the DSB and TMT B were compared with a larger set of tests administered. Participants' scores on TMT B and DSB appeared to have no ceiling effects and examination of longitudinal data from the SAMS study indicated that participants were not improving on these tests over time.

Subjective ratings of cognitive and functional capacity were obtained using the self-report and informant version of the ECog (Farias et al., 2008). This assessment requires the individual or their informant to rate current functional ability compared to ability 10 years previously. The 39-item questionnaire assesses cognitively-based functional items, across six neurological domains: memory, language, visuospatial abilities, planning, organisation and divided attention. Scores range from 1 ("Better or no change") to 4 ("Consistently much worse"). The A-IADL-UK was compared with the ECog to test whether the two scales were measuring the same construct.

Participants who self-reported (n=7) did so on the A-IADL-UK and the ECog. Participants self-reported if they did not have someone who could act as an informant. For all other participants (n=21) their informant provided responses to these scales. Informants were defined as people who lived with, cared for (if required), or had at least weekly contact with the participant.

Step 3: Statistical analysis

Statistical analyses were performed using SPSS version 22. Since most datasets were not normally distributed (Kolmogorov-Smirnoff goodness of fit test $p<0.05$), non-parametric

tests were used. Correlations were investigated using Kendall's tau-b correlation coefficient because the approximations are better for small sample sizes (Arndt et al., 1999). The significance level was set at $p < 0.05$, unless indicated otherwise. Due to an administrative error in the questionnaire administered to participants in step 3, answers to the question "Did they use technology?" was not included in the weighted average scores. To investigate construct validity, correlations were considered between the A-IADL-UK and a number of other neurological tests selected from a larger set of tests that were administered.

Results

Details of changes to all items in the questionnaire for each step of the cultural adaptation, including reasons for removing and adding items, adjustments to language, decisions from the developer reviews and the final item wording, can be found in Appendix 1 published as supplementary material online attached to the electronic version of this paper at https://www.cambridge.org/core/journals/international-psychogeriatrics. For a summary of the numbers of questions added, removed, and amended, see Figure 1.

Step 1. Dementia professionals', SCD/MCI/AD and relatives' review

Seven items were added and nine items were removed based on suggestions from the dementia professionals and discussion with the developer. Of the seven items added, two were completely new items suggested by the dementia professionals and the other five items were added by the developer based on what was contained in the original Dutch version. Items were removed based on the suggestions from the dementia professionals for a variety of reasons: two were thought to be confusing; four were considered analogous to other activities e.g. 'booking a trip on the internet' was removed as it was considered similar to 'booking holidays' and 'buying on the internet' was already covered in another question; and three were judged as outdated e.g. 'using cheques'. Suggestions of changes in language were undertaken for twenty six items, for example the term 'operating' was changed to 'using' for 10 items as this was thought to be a more common term. Some items that were considered to be confusing or incongruous by dementia professionals were retained to see how the other participants responded to these items.

Following suggestions from the SCD/MCI/AD participants and the relatives, a total of seven new items were added and ten items were adjusted for language. The main reasons for

adjusting the language of items were to add more common terms for example 'electronic banking' was replaced with 'internet banking'; and to clarify the meaning of questions, for example not all participants knew what a smartphone was, so this was changed to 'using a mobile phone to go on the internet'. Items that dementia professionals highlighted as confusing or incongruous were the same ones designated this way by the SCD/MCI/AD participants and relatives. Again, these items were retained at this stage to seek further data on how people engage with them.

Step 2. Applicability questionnaire

Of the 140 questionnaires distributed 92 (65.7%) were returned. Nineteen items were identified as candidates for exclusion and 53 were candidates for inclusion on the basis of the median frequency that each IADL were completed. Following a third developer review six items were added, 24 items were removed and two items were adjusted for language, resulting in a final item count of 55 for use in the pilot.

Step 3. A-IADL-Q-UK pilot

For the pilot, 31 questionnaires were distributed via email link. An email reminder was sent after two weeks. A total of 28 questionnaires (90.3%) were completed. Twenty-one of these participants (75%) had somebody who could act as an informant and seven participants (25%) provided the information themselves in the form of self-report. Although participants with SCD obtained higher mean A-IADL-Q-UK scores[2] (n=17, mean = 98.64, s.d = 2.05) than MCI participants (n= 11, mean = 90.28, s.d = 15.37), this difference was not significant (u = 76.50, p = .430).

Response characteristics of new items

The number of participants endorsing each response to the nine new items and the correlation analyses for the new items in relation to total score are shown in Table 2. The new and revised items performed well: at least half of the participants had completed each activity in the previous 4 weeks and all activities were perceived as either slightly more, more, or much more, difficult by at least one participant per item. When broken down by sub-group (informant report version and self-report version), because of the small numbers

[2] Weighted total including new items

(particularly in the self-report sub-group), for some items there was no variation in the responses given to specific items within one of the sub-groups (e.g. with none of the participants in one sub-group finding the activity more difficult: see supplementary Table 1, published as supplementary material online attached to the electronic version of this paper at https://www.cambridge.org/core/journals/international-psychogeriatrics). Therefore, the analysis was focused on both groups as a whole. 'Making a cup of tea or coffee' and 'using keys' were the most frequently performed activities. 'Reading' was another activity completed by the majority of participants and over 10% (3) of participants found this more difficult to some degree. Despite low numbers of participants completing the activities, 'recording a television program', 'completing household paperwork' and 'maintaining the garden' were each seen as being slightly, more, or much more difficult by three or more participants. Most participants did not find 'making a cup of tea or coffee', 'using the hob', 'using the grill', 'using keys' or 'looking after family', more difficult.

The items ‘using the grill’ and ‘looking after family’ were performed least frequently by participants. Reasons for not using the grill were mixed but most participants reported that they had never used it or had no need to. The majority of participants reported that they did not 'look after family' because they lived too far away, did not have any family to look after, or had never done it.

There was a significant correlation between the weighted average score and four of the new items: 'completing household paperwork', 'recording a television program', 'reading' and 'maintaining the garden'. The remaining five new items were not significantly correlated with the total score.

Table 2. Number (and %) of participants endorsing each response to new items, and correlation coefficients of new items with weighted average score

	Relevance		Difficulty			Kendall's tau-b correlation coefficients of new items and weighted average score (without new items)	
Item	Did not do activity in previous 4 weeks or have never done activity	Completed activity in previous 4 weeks	Did not find the activity more difficult	Found activity slightly more difficult	Found activity more/much more difficult	Correlation with weighted average score without new items	p value
Making a cup of tea or coffee*	0 (0.0)	28 (100.0)	27 (96.4)	1 (3.6)	0 (0.0)	-.25	.12
Using the hob*	2 (7.1)	26 (92.9)	24 (92.3)	2 (7.7)	0 (0.0)	-.08	.63
Using the grill‡	11 (39.3)	17 (60.7)	16 (94.1)	1 (5.9)	0 (0.0)	-.35	.10
Completing household paperwork*	6 (21.4)	22 (78.6)	19 (86.4)	2 (9.1)	1 (4.5)	-.50	.01
Recording a TV program*	10 (35.7)	18 (64.3)	15 (83.3)	2 (11.1)	1 (5.6)	-.57	.01
Using keys*	0 (0.0)	28 (100.0)	27 (96.4)	0 (0.0)	1 (3.6)	-.27	.09
Reading‡	1 (3.6)	27 (96.4)	24 (88.9)	2 (7.4)	1 (3.7)	-.45	.01
Maintaining the garden‡	6 (21.4)	22 (78.6)	18 (81.8)	2 (9.1)	2 (9.1)	-.39	.03
Looking after family‡	13 (46.4)	15 (53.6)	14 (93.3)	1 (6.7)	0 (0.0)	-.37	.10

*classified as new because of significant changes to language and/or meaning

‡completely new item

Exploratory validation analysis of the A-IADL-Q-UK and other neuropsychological tests

Table 3 shows the correlations between the weighted average score of the A-IADL-Q-UK (including the new items) with age and clinical measures. The A-IADL-Q-UK total score did not correlate with age. All correlations with cognitive and functional measures were in the expected directions: these were significant for DSB and ECog and non-significant for ACE III and TMT B. When broken down by sub-group (informant version and self-report version) not all of these patterns held (see supplementary Table 2 published as supplementary material online attached to the electronic version of this paper at https://www.cambridge.org/core/journals/international-psychogeriatrics).

Table 3. Means and Kendall's tau-b correlation coefficients of weighted average scores (including the new items) of the A-IADL-Q-UK with clinical measures and demographics

Measure	N	Mean (SD)	Weighted average score with new items (Kendall's tau-b)	p value
Demographic data				
Age	28†	72.64 (4.40)	-.13 (-.45, .19)	.36
Cognitive functioning				
ACE III‡	28	93.54 (5.49)	.11 (-.28, .44)	.46
DSB§	28	7.79 (2.41)	.38 (.50, .62)	.01
TMT B‖	28	77.96 (41.31)	-.04 (-.37, .28)	.77
Everyday functioning				
ECog¶	28	1.60 (.68)	-.46 (-.67, -.22)	.00

†Demographic data was not completed by 5 of these participants. ‡ACE III = Addenbrooke's Cognitive Examination-III (ACE III); §DSB = Digit Span Backwards Task; ‖TMT B = Trails Making Test B; ¶ECog = Measurement of Everyday Cognitive Function.

Discussion

This development of the A-IADL-Q-UK enhanced the conceptual and cultural relevance of the original version of the questionnaire for an older adult UK population. We assessed face and content validity by utilising the views of people with cognitive impairment, their

relatives, UK older adults and dementia professionals. This essential step improves the clinical meaningfulness of functional assessments for people with SCD and MCI in the UK. The informant version was adapted and a self-report version of the questionnaire was developed. Modifications to the scale included adding 20 items, removing 34 and adjusting the language of 33 items, resulting in a 55-item adapted version. This version of the scale is ready for a full-scale validation.

This cross-cultural validation is important because mere translation of an instrument does not always account for cultural and ethnoracial disparities (Beaton et al., 2000). Frequently used IADL instruments often include culturally specific activities such as balancing a chequebook (Dubbelman et al., 2019). We found that activities such as using a coffee maker and a dishwasher were not common practice amongst current older adults in the UK, and therefore amending or removing these items enhances the validity of the measure for a UK audience.

Four of the nine new items correlated with the total score of the A-IADL-UK. Interestingly, these items were also the ones that most participants felt were more or much more difficult, suggesting that these items are more sensitive to functional impairment in this sample of participants with SCD and MCI. This is in line with research by Marshall et al. (2015), who found that the item “assembling tax records” discriminated between healthy and MCI participants and that lower scores on a “paying bills/balancing checkbook” item predicted progression from healthy to MCI. However, they also found that “heating water and turning off the stove” was sensitive to functional change, whereas in our sample most participants did not find a similar item “using the hob” more difficult. This discrepancy could be due to the smaller sample size in the current study or because the question in the Marshall et al. study asks specifically about remembering to turn off the stove.

Construct validity of the new A-IADL-UK was explored by considering correlations with age and other clinical measures. The exploratory analysis of the weighted average score including the new items found no correlation with age. This is in line with work by Sikkes et al. (2013), who found small but significant correlations with age in the original questionnaire. This is important as it suggests that the questionnaire can be used without normative data for age. Scores on the A-IADL-Q-UK were significantly correlated with another measure of everyday functioning: the ECog. This demonstrates good convergent

validity. Associations with ACE, DSB and TMT B were all in the expected direction. However, the association with ACE and TMT B was non-significant and very weak. Previous literature in this area is mixed. Some studies have found that informant and self-reported measures typically yield small or no associations with executive processes (Aretouli and Brandt, 2010; Jefferson et al., 2006; Plehn et al., 2004). In a more recent study, a longer time spent on TMT B was associated with a lower score on the A-IADL-Q and a model incorporating DSB indicated a satisfactory fit when testing the relationship between change in IADL and change in memory functioning (Koster et al., 2015). There are limited studies exploring the relationship between the ACE III and IADL measures; research that has been done suggests that the ACE III is sensitive to everyday functioning (Giebel and Challis, 2017; Hsieh et al., 2013; Scally, 2016), but this is based on small sample sizes. In a more recent study, the ACE III was related to functional impairment across a number of dementia syndromes (So et al., 2018). However, none of these studies have looked for a relationship between the ACE III and functional ability in people with subjective or mild cognitive decline. Future studies with larger samples, including those with subjective and mild cognitive decline, will enable further investigation of construct validity. What is most important, however, is the predictive validity of the A-IADL-UK and how well it can predict a person's ability to function in the real world. Moore and colleagues argue that predictive validity is more important than comparison to normative data, because it shows whether an instrument can predict competency in actual daily life (Moore et al., 2007). Future validation of the A-IADL-Q-UK should compare scores with observed behaviour of daily activities inside the individual's home.

Although there was no significant difference between the scores of participants with SCD and MCI, it is notable that scores for the MCI group were numerically higher than the SCD group. This is in-line with findings from the Spanish adaptation of the A-IADL-Q by Facal and colleagues (2018), and provides additional tentative evidence for the validity of the scale as a measure of functional impairment. Future research is now needed to compare scores between these groups in studies with larger sample sizes.

Limitations of the current study include the small sample size and low statistical power for the step 3 pilot. The sample size for step 3 was based on pragmatics such as time and budget constraints and was not intended to be fully powered. In addition, because this

sample were part of an on-going study, the inclusion criteria were set by that study and therefore cognitively healthy participants and individuals with dementia were not included, even though they were included in step one and step two. This pilot study was a first step in assessing the reliability and validity of the A-IADL-UK, the results presented are exploratory and further testing is recommended as a next step. The majority of participants in steps one and three were recruited from the Greater Manchester area of the UK, this means that the study has a low geographical reach. The study also has a limited cultural reach as the majority of participants (95%) in the step two applicability questionnaire were white British, which is not reflective of the full ethnic breakdown of the UK (Office for National Statistics, 2011). A further limitation is that ethnicity was not recorded for participants in steps one and three. However, the dementia professionals in step one would have knowledge of a wider and more diverse client base which may mitigate some of these issues.

The assessment of face and content validity is an important psychometric property often lacking in the development of existing IADL scales (Sikkes et al., 2009). A major strength of the current study was that the process for assessing face and content validity was detailed and thorough, this is reflected in the use of a sampling to redundancy criterion in step one meaning all suggestions from participants were considered until no new information emerged. A further strength is the inclusion of a range of stakeholders, including people with cognitive impairment and relatives of people with MCI and dementia. To date relatively few assessments of content validity utilise the knowledge and expertise of patients and caregivers, which often solely relies on the judgements of clinicians (Connell et al., 2018). In addition we compared the instrument to another IADL measure (ECog) administered to the same participant group, enabling a direct comparison between the two IADL instruments.

In summary, in this first UK adaptation of the Amsterdam IADL Questionnaire we developed the informant version and produced the first self-report version, demonstrating the face validity and content validity of the measure. A comprehensive review of the measure was undertaken and included people with cognitive impairment and their relatives, as well as dementia professionals and cognitively healthy older adults. A self-report version of the questionnaire will allow people without an informant to provide information about their ability to complete the IADL. The next step is to determine item characteristics for the new items so that final decisions can be made about which ones to include in the A-IADL-Q-UK.

This will require further data analysis from a larger sample. Further quantitative testing of the A-IADL-UK on a larger sample will enable assessment of reliability and validity and a full examination of internal consistency and measurement bias.

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Conflict of interest

None.

Description of author's roles

GS designed the study, collected the data, carried out the statistical analysis, and led the writing of the paper. LJEB and IL contributed to the design of the study and discussions with the developer. LJEB contributed to the plan and interpretation of data analysis. SAMS is the developer of the original A-IADL-Q and contributed to the design of the study and all the developer discussions. All authors also contributed to the writing of the paper and approved the final draft.

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CHAPTER 4 (Study B): A pilot study to access the feasibility and prospective acceptability of recording computer-use for assessment of cognitive health

4.1. Abstract

Introduction: In order to assess the potential of remotely-monitored computer use behaviours as proxy measures of cognitive and functional ability, it is important to pilot the procedures of a two-phase study by examining the process and resources of a cross-sectional study and evaluating the prospective acceptability of a longitudinal study.

Method: Two older adults (aged 61 and 69) with cognitive impairment and five cognitively healthy older adults (aged 63 to 87) completed a series of semi-directed computer tasks to assess the feasibility of the tasks, hardware, and software of the cross-sectional study. Participants were observed whilst completing the tasks. Semi-structured interviews with a mixture of close- and open-ended questions were completed with participants to assess their prospective acceptability of a longitudinal study which would record daily computer use as a proxy measure of cognitive health. Particular issues explored were privacy and security.

Results: Participants were able to complete all of the tasks, although found it easier to complete tasks that used familiar applications. Difficulties completing tasks were mainly due to them using an unfamiliar operating systems and software applications, resulting in difficulty finding specific functions. Participants were generally positive about the idea of recording daily computer as a proxy measure of cognitive health, and they all said they would be willing to take part in such research. Some participants expressed concerns about the software recording financial transactions or other people's data on their computer, but felt that such concerns could be alleviated by providing sufficient study information.

Discussion: Results from this pilot were used to improve the design and implementation of the subsequent cross-sectional and longitudinal study. For the cross-sectional study, the pilot informed decisions about what operating systems to use and changes to the laptop training to counteract individual differences in experience levels and use of software. For the longitudinal study, feedback was used to ensure the information provided about the study was comprehensive and covered any points of concern relating to security or privacy.

Changes were also made to the recording software to limit what was recorded for websites that involved financial transactions or the use of passwords.

4.2. Introduction

The assessment of instrumental activities of daily living (IADL) is increasingly being recognised as an essential component in the diagnosis of early cognitive impairment (Albert et al., 2011; Lindbergh et al., 2016; Luck et al., 2012; Molinuevo et al., 2017; Petersen et al., 2014). Computer use is a complex IADL (Kaye et al., 2014). Studies have shown that specific computer use behaviours can distinguish between people with and without cognitive impairment (Kaye et al., 2014; Seelye et al., 2015), and have the potential to provide an alternative approach to the assessment of functional ability (Seelye et al., 2018).

There is limited research investigating how computer use could be used to detect change in IADL. To address this, a two-phase study, which included a proof of principle cross-sectional study and an exploratory longitudinal study, was developed to investigate whether measuring a broad range of daily personal computer-use behaviours over time is a pragmatic and sensitive means of detecting early cognitive and functional decline. The aim of the cross-sectional study, was to determine: (1) whether multiple computer-use behaviours can be used to distinguish between cognitively healthy older adults and those in the early stages of cognitive decline; and (2) whether these computer-use behaviours are associated with levels of cognitive and functional ability (Stringer et al., 2018). The aim of the longitudinal study, was to investigate whether everyday computer use behaviours recorded on participants' home computers were associated with cognitive and functional ability over time.

Understanding the performance of older adults in the context of their daily lives requires the development of research protocols that capture relevant real-word tasks and environments while maintaining scientific rigour (Czaja and Sharit, 2003). A pilot study is conducted to identify potential problems with the research design and protocol prior to the larger study (Hassan et al., 2006). They are considered a crucial element of a good study design, and increase the likelihood of success in the main study (van Teijlingen and Hundley, 2002). There are many reasons for undertaking a pilot study, including developing and testing research instruments; assessing whether a research protocol is realistic and

workable; and determining what resources (e.g. staff, equipment) are needed for a planned study (van Teijlingen and Hundley, 2002).

The two-phase study required a pilot study for a number of reasons. First, a series of computer tasks designed for the cross-sectional study needed to be piloted in order to understand participants' experiences when completing them, and to identify any problems associated with participants' interaction with the laptops hardware and software. The tasks would be completed by the participants whilst computer behaviour patterns such as typing speed and mouse clicks were recorded. The tasks were designed to represent normal everyday computer activities that could be completed without too much difficulty. Second, going through the computer activities in the cross-sectional study would allow for checks of all the participant and researcher materials (i.e. instruction sheets) and would provide the opportunity for research staff to train and practice in the administration of the tasks. Third, for the longitudinal study, because the computer behaviours recorded by the software needed to represent normal home computer use, it was important to ask participants if they would feel comfortable having their daily home computer use would be recorded for the assessment of cognitive health.

The aim of this study was therefore to pilot specific aspects of the two-phase study: firstly to examine the process and resources of the cross-sectional study and secondly to evaluate the prospective acceptability of the longitudinal study. The objectives to achieve these aims are described in detail below and summarised in table one. They follow a modified version of Thabane et al's (2010) general reasons for conducting a pilot . The two-phase study did not include a phase III trial, however Thabane's work is still broadly useful and applicable when considering the objectives of this pilot. Thabane et al. (2010) suggests that the reasons for conducting a pilot study can be grouped under four broad headings – process, resources, management and scientific. 'Process' assesses the feasibility of the steps needed for the larger study including determining recruitment rates and checking the understanding of study materials. For this pilot we aimed to assess process by looking at the ability of participants to complete the computer tasks in phase one unaided (with prompts when required). 'Resources' deals with assessing the time and resources required for the main study for example what equipment is required and does the software work as it should. For this pilot we aimed to assess resources by considering the ability of the participants to use

the hardware (laptop) and software (e.g. Microsoft Outlook) in phase one. 'Management' covers any potential human and data management problems such as challenges at participating centres and problems entering data into the computer. 'Management' was not a relevant rational for this pilot because the study did not take place across different centres and the computer data was recording by the software. Finally, 'scientific' deals with the assessment of treatment safety, determination of dose levels and the estimation of treatment effect. This rationale is quite specific to phase III trials. Therefore, instead of looking at the effect of a treatment, we aimed to evaluate prospective acceptability of the phase two longitudinal study which would record participant's home computer use.

Table 1. Pilot objectives adapted from Thabane et al's rationale for pilot studies

Thabane et al's reasons for conducting a pilot	Objectives for the pilot	Study
Process: Assesses the feasibility of the steps needed for the larger study e.g. recruitment and study materials.	Objective one: Examine participants' range of experiences when completing the tasks.	Phase one: Cross-sectional study
Resources: Assesses the time and resources required for the main study e.g. required equipment and software.	Objective two: Examine participants' range of experiences while using the hardware (laptop) and software (e.g. Microsoft Office).	Phase one: Cross-sectional study
Scientific: Deals with assessment of treatment safety, dose, effect and variance of effect.	Objective three: Evaluate older adults prospective acceptability of recording home computer use	Phase two: Longitudinal study

4.2.2. Feasibility and acceptability evaluation framework

'Feasibility' was operationalised through the question 'can it work?' (Orsmond and Cohn, 2015). For this pilot this was operationalised as establishing whether participants could complete the tasks in phase one with minimal difficulty, assistance and worry. This was

assessed by observing participants completing the tasks, and afterwards asking participants how they felt about the tasks; what they found easy or difficult; and why.

'Prospective acceptability' is defined by Saracutu et al. (2018) as how an individual feels about an intervention prior to participating. In this study prospective acceptability was operationalised as participant willingness to take part in a longitudinal study which would record home computer use. This was assessed by asking participants how they would feel about having their home computer use recorded and what worries or concerns they may have.

4.3. Method

This was a, mixed-methods, cross-sectional pilot study undertaken in community settings in Greater Manchester. The study was approved by The University of Manchester Ethics Committee in accordance with the Declaration of Helsinki, and all participants provided written informed consent prior to participating.

4.3.1 Participants

The demographic, cognitive and functional details for the participants are detailed in table two. All participants were above 60 (range = 61 to 87 years), 57% were female and total scores on the ACE III ranged from 69 to 99.

Table 2. Demographic, cognitive and functional variables

Participant	Age	Gender	Group (AD, MCI or HD)	Total ACE III score
1	71	m	HC	96
2	86	f	HC	95
3	87	f	HC	98
4	73	f	HC	95
5	63	m	HC	99
6	69	f	AD	69
7	61	m	MCI	90

*ACE III = Addenbrooke's Cognitive Examination-III (ACE III)

In order to be included in the study participants had to be: living in their own homes; have the capacity to consent; 60 years of age or older; regular computer users (defined as using a laptop or desktop computer at least once a week); current users of a Microsoft Windows operating system; and able to communicate verbally in English. Individuals with any acute physical or mental difficulties were excluded from the study. For participants in the 'cognitively impaired' group, the diagnosis was made by qualified memory specialists and verified through the patients' clinical records. The final sample comprised two participants with clinically significant cognitive impairment (mean age = 65; female n=1) and five cognitively healthy control participants (mean age = 76 years; female n=3). Clinically significant cognitive impairment was defined as either: 1) MCI, as per Petersen's criteria (Petersen, 2004); or 2) early dementia due to probable AD, as per standard NINCDS-ADRDA criteria (McKhann et al., 2011). Participants were recruited through memory clinics and local community groups in Greater Manchester and Holland.

4.3.2. Procedure

Participants were invited to take part in a single testing session conducted either in their own homes (n=5) or at The University of Manchester (n=2).

4.3.2.1 Tasks of computer performance

All tasks assessing computer-use performance were completed on the same 14.1 inch laptop computer (Dell Latitude E6410) running Windows 7. Participants were provided with a separate keyboard and mouse if they preferred. Participants initially completed a practice session on the laptop, involving shortened versions of the experimental computer tasks (Table 2). The practice session was divided into four sections: desktop (i.e. main user interface), Word, email and Internet Explorer.

Table 2. Details of the practice computer tasks

Practice task	Details of practice task
Desktop	This task was completed on the Windows 7 desktop: click on the time/date display and scroll to the next month.

Word	This task was completed in Microsoft Word: open a specific Word document on the desktop, scroll, highlight, format, minimise, maximise, and close Word.
Email	This task was completed in Microsoft Outlook: start the email program, open new email, type and close the email program.
Internet Explorer	All of these tasks were completed in Internet Explorer (IE): open IE, specific search in Google, click on a specific link, scroll to a specific section of a website, return to previous page, scroll and close IE.

Following the practice session, participants were asked to follow a set of written instructions (Appendix H) in order to complete five experimental computer tasks (Table 3) which lasted approximately 45 minutes: a desktop navigation task; an email account management task; a word processing task; a diary entry task and an internet search task. Participants could follow the instructions verbatim or adopt their own methods to complete the tasks if they preferred.

Table 3. Details of the main computer tasks

Main task	Details of main task
General computer operations	This task was completed on the Windows 7 desktop: open a specific Word document, scroll, minimise, maximise, close Word document, delete a folder, move a document into a folder, click on the time/date display, click on a specific date.
Email	This task was completed in Microsoft Outlook: start the email program, find an email with a specific subject, open the email in a new window, close email, delete email, reply to email, send email, move email to folder, close the email program.
Word processing	This task was completed in Microsoft Word: open a specific Word document, cut and paste, edit text, delete text, format text, save and close.

Diary entry	This task was completed in Microsoft Word: open a blank Word document, type a title, underline, type a diary entry for 3 minutes, save the document with a specific name, close.
Web search	All of these tasks were completed in Internet Explorer (IE): open IE, specific search in Google, click on a specific link, scroll to a specific section of a website, return to previous page, scroll, and close.

Participants were told that they should try to complete the tasks by themselves and that if they were unsure to try and work it out on their own based on what they thought was right. This was required to ensure the software was, on the whole, recording the participants' own actions and was therefore representative of their computer use behaviour. However, we also wanted participants to be able to move through the tasks and complete them all if possible. Therefore, if participants were having difficulty with a task, and could not work it out on their own, then prompts were provided by the investigator.

A four-level prompt system was utilised with increased levels of support offered at each level (Figure 1). The investigator would only provide an increased level of support if the previous level of support had not worked. Indications of requiring further support included, but were not limited to: getting frustrated; saying they do not know what they are doing; or asking for help. The first level (level one) was no prompts. This included giving the participant time to work things out, make mistakes and try different options. Level two was general encouragement and included prompts such as 'keep going' and 'check the instruction sheet'. Level three was non-specific guidance: a prompt that helps to direct them but does not direct them to the specific action required e.g. 'you're in the right place'. Specific guidance explaining to participants exactly how to complete the task was provided at level four. This included telling participants specifically where to look or what they needed to do e.g. 'you need to double click' or 'I'll point to it on the screen'.

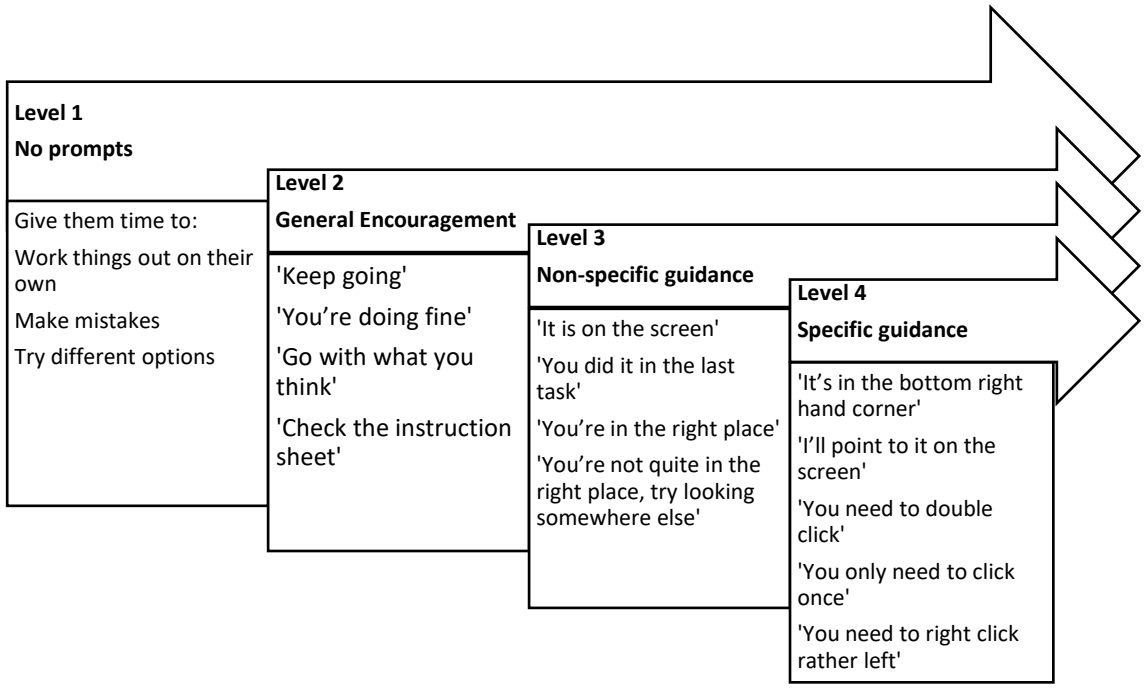

Figure one. Four-level prompt system for supporting participants when completing the computer tasks

4.3.2.2. Interview

The computer tasks were followed by a short semi-structured interview (lasting approximately 15 minutes) administered face-to-face by the investigator. Participants were asked how they felt about the tasks they had been asked to complete, what they found easiest and most difficult, any general worries or concerns they had when completing the tasks, how they felt about having their computer use recorded, and any concerns they might have about security or privacy. These questions were asked to ascertain their experiences of completing the computer-based tasks and their thoughts regarding the recording of their daily computer use. This was audio recoded and used to make notes of key points arising from each question.

A screening questionnaire covering demographic details, health status and computer usage, and a battery of cognitive and functional tests, were also administered. These were not part of this pilot of the computer tasks, and so are not reported here.

4.3.3. Analysis

Notes from the interview audio recordings were recorded in an Excel spreadsheet and a summary of each answer was produced containing the key points. The research team discussed the outcomes from the pilot, and considered how the results could inform and improve the design of the main study. Pragmatic changes were made to documents (such as the computer activities instruction sheet for participants and the participant information sheet) and a record was made in the form of handwritten notes of these changes.

4.4. Results

The audio from the interview with the MCI participant was damaged therefore audio recordings from six participants, and observations from seven participants were used in the analysis.

4.4.1. Objective one: Examine participants' range of experiences when completing the tasks.

All participants were able to complete all the tasks (with prompts when necessary). Overall, participants said they felt comfortable completing the tasks. When asked how they felt about the tasks, one participant felt they did not do as well as they would have liked because the computer was different to the one they use at home, suggesting that familiarity with the equipment is an important factor in successful completion of computer based tasks.

Participants had different views on which tasks were the easiest. Two participants found it easier to complete the general computer operations, two participants found the word task easiest, and one participant said both the google search and the email tasks were easiest. The reasons for participants having different responses to what they found easiest was based on what the participant was used to using. For example one participant stated that Word was easiest because they had been using Word for many years and used it in their job before they retired. Two participants said they found particular tasks easy because they did them every day, this included general computer operations, email and Google. This suggests that level of experience with specific types of software is a determining factor in how well tasks are completed.

4.4.2. Objective two: Examine participants' range of experiences when using the hardware and software.

A number of issues were identified relating to participants' familiarity with the computer software. Some participants who were used to using Windows 7 found it difficult to use the Windows 8 laptop. Also, some participants were either not regular users of, or were not familiar with, the version of certain programs used in the experimental tasks (e.g. Word). Three participants were concerned about the differences in hardware and software between their own computers and the study computers. For example one participant used Microsoft Works rather than Microsoft Word, and commented that there were more options in Word and therefore it took them longer to search for specific functions. Some participants had specific difficulties with tasks that they either had never done before or because they were used to using a different type of application or software. Three participants said Word was the most difficult task, either because they use a different version, they do not do it very often, or they never use it. The email task was difficult for two participants because they were not used to using outlook and used different email applications e.g. Sky. One participant stated that if they were using their own email they would have been much quicker. Again, this suggests that familiarity with the type of hardware and software is an important factor in participants feeling comfortable with and successfully completing the tasks.

It was observed that participants often used keyboard shortcuts rather than mouse clicks. This highlights that people use the mouse and keyboard in different ways to approach specific computer tasks, which could impact on the recorded patterns of keystroke and mouse behaviour.

4.4.3. Objective three: Evaluate older adults' prospective acceptability of recording home computer use.

All of the participants expressed that they would not mind if their daily computer use were recorded. Three participants said they would feel good about it, and another explained that it could be good because it might pick up on something they are not aware of. This suggests that participants would be willing to take part in the longitudinal study and have their computer use recorded.

There were two main concerns relating to security and privacy expressed by four participants. There were concerns about financial transactions and the recording of other people's data. Two participants explained that they may worry about the computer recording their financial transactions and online banking. They went on to suggest that restrictions would need to be in place to protect their privacy with such matters and a facility to switch off the recording would be required. Concerns were also raised by two participants about the computer recording other people's information that may be on their computer for example in an email or word document. This suggests that security and privacy are of central concern to participants.

To alleviate any potential concerns, three participants stressed that they would require guidance and sufficient information about a future study of their computer use behaviour, when deciding whether to take part. They stated it would be necessary to include information about how the data would be used and how it will be protected to establish trust and put their mind at ease. Therefore, in order for participant to feel comfortable with having their computer use recorded, concerns about security and privacy should be addressed in the study information and study design.

Two participants explained that, despite potential concerns, they would take part in a research study that involved recording their computer behaviour for altruistic reasons. One participant said they would not like to have their computer behaviour recorded, but would participate if it was to help others. Another participate had concerns about the software recording financial transactions and other peoples' information on her computer, her family had also expressed concerns, however she said she was generally not worried and felt it was her duty to contribute to medical research. This raises the concern that some participants might take part even if they did not want to, this emphasises the importance of giving participants the opportunity to voice any worries or concerns and to make sure these are appropriately addressed.

4.5. Discussion

This study had three objectives: 1) To examine participants' range of experiences when completing the tasks; 2) to examine participants' range of experiences when using the hardware and software; 3) to evaluate older adults' prospective acceptability of recording

home computer use. The results of the pilot study suggested that the computer-based tasks could be completed (with prompts when necessary) and that participants felt they would accept and tolerate having their home computer use recorded for an extended period. Specifically, the pilot improved the design of the larger studies in two ways. For the cross-sectional study, it informed decisions about resources and changes to the protocol to counteract individual differences in participants' experience levels and their use of hardware, software. For the longitudinal study, we used the feedback from participants to improve the information provided to participants about the study. Moreover, to alleviate concerns about privacy and security, changes were made to what was recorded by the software. These changes are discussed below.

Familiarity with the operating system was found to be an important factor for participants in feeling comfortable with and successfully completing the tasks. A number of participants were not comfortable completing the tasks on a Windows 7 computer because they were used to using a Windows 8 machine. The reason that we had planned to only use one operating system (Windows 7) was because this would mean higher experimental control. One challenge of recording semi-structured computer-use behaviour is the trade-off between higher experimental control (i.e. from having everyone use the same laptop) versus ensuring that everyone was using a system they were familiar with and also versus only recruiting participants who were familiar with the selected operating system and so halving the number of participants who could take part. The findings from this pilot study showed that if participants use an operating system they are not used to, this leads to difficulty searching for specific functions, increasing the time taken to complete the tasks and the chance of making mistakes. In order to eliminate the potentially confounding effect of system familiarity, we decided to use two operating systems Windows 7 and Windows 8 for the cross-sectional study. Six laptops were purchased, three were installed with Windows 7 and three with Windows 8. This meant that users of both types of operating system could be recruited, and participants could complete the tasks on a system they felt more comfortable with.

Participants found it difficult to complete tasks using software they were not familiar with. In order to alleviate difficulty when using unfamiliar software the study design was amended and changed in two ways. Firstly, the participant instructions were amended for

some of the tasks to ensure that the details of each task were as clear as possible. The wording was shortened and simplified and any unnecessary information or instructions were removed. Where it had not already been done the wording was changed to emphasise the action that needed to be done for each step, the action (verb) for each task was put at the start of each sentence and was underlined. For example task 2 step 2 was changed from "Somebody has sent you an e-mail with the subject 'Important-study'. Locate this message in the inbox" to "Find the email somebody has sent you, with the subject 'Important-study'". Secondly, the laptop practice activities would be repeated until the participant felt confident with each of the tasks. Participants who were not used to using Word and Outlook had expressed difficulty with these tasks. By repeating the practice activities participants could use these applications until they felt comfortable to move on to the main tasks. This change is in line with work by Czaja et al. (2001), in their study investigating age differences in the performance of a complex information search they concluded that older adults may require extended practice and training to ensure they are comfortable with computer equipment.

Even though it was observed that people approached tasks in different ways (i.e. used keyboard shortcuts instead of the mouse), no changes were made to the design of the subsequent cross-sectional and longitudinal studies. The reason for this is that it did not make sense to restrict the ways that the mouse and keyboard were used in either study. In the cross-sectional study it could make the tasks harder for some participants, which would bias the results and in the longitudinal study the purpose was to record non-directed behaviours. Whilst these different approaches to using the keyboard and mouse might make it more difficult to detect group differences, this would be less relevant for change over time.

The main concerns expressed by the participants about the longitudinal study emphasised the importance of providing comprehensive information and guidance about the purpose of the research, the use of data, and the protection of data. We addressed these concerns in two ways: by improving the information provided to participants and by refining the software. A number of modifications were made to the participant information sheets, including an explanation of what data would be recorded and how it would be protected. Participant had concerns about the recording of information, for example in an email or

word document, which may contain other people's details. To alleviate these concerns participants were provided with information explaining that the content of word documents and emails would be recorded but all data would be encrypted at a high level. To address participants concerns about information on secure websites (e.g. financial interactions) being recorded, changes were made to the design of the software to limit what was recorded for certain websites. For all secure websites the data capture was reduced to no longer include alpha-numeric content and to just record keystroke count and timestamp. Details about what data was captured on secure websites was fully articulated to participants during the recruitment and consent process. These changes are in line with the work of Innes and colleagues (2018) who found that potential randomised controlled trial (RCT) participants prioritised information about the consequences of taking part, specifically the advantages and disadvantages. They conclude that researchers should work with potential participants to identify what information is considered critical to support informed choices. In this pilot the views of the target audience was utilised to improve the information in participant information sheets and the study design.

4.6. Conclusion

This pilot was important as it informed the design and implementation of two consequent studies of the PhD. For the cross sectional study participants were provided with equipment and software for which they were most familiar, controlling for potential confounders; description of the tasks were made more clear and concise to help participants complete the tasks with greater ease; and the practise task was extended to counteract individual differences. For the longitudinal study changes were made to the participant information, and to what was recorded by the software to address and alleviate participant concerns, minimise risk and ensure valid informed consent.

CHAPTER 5 (Study C): Can you detect early dementia from an email? A proof of principle study of daily computer use to detect cognitive and functional decline

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Author contributions:

Gemma Stringer conceived the original idea for the paper; edited the ethics application; edited the study documents; obtained ethical approval; recruited study participants; collected the data; carried out the statistical analysis; interpreted the data and led the writing of the paper. Professor Iracema Leroi, Professor Peter Sawyer, Professor Alistair Sutcliffe, Professor John Keane, Professor Xiaojun Zeng and Dr Paul Payson designed and obtained funding for the original SAMS study. Gemma Stringer joined the SAMS study as a Research Associate and registered for the PhD after the ethics application for study two had been drafted and submitted for the first internal check at the university. Dr Laura Brown was an informal advisor for the SAMS project in her position as the candidate's supervisor. Professor Iracema Leroi wrote the first draft of the ethics application. The joint author Dr Sam Couth joined the project during the data collection and was involved in carrying out the statistical analysis, interpreting the data and writing the paper. Dr Laura Brown, Professor Iracema Leroi and Professor Daniela Montaldi provided methodological guidance, statistical guidance and supervisory input. All authors critically reviewed and agreed on the submitted manuscript for publication.

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RESEARCH ARTICLE

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Can you detect early dementia from an email? A proof of principle study of daily computer use to detect cognitive and functional decline

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Objective: To determine whether multiple computer use behaviours can distinguish between cognitively healthy older adults and those in the early stages of cognitive decline, and to investigate whether these behaviours are associated with cognitive and functional ability.

Methods: Older adults with cognitive impairment (n = 20) and healthy controls (n = 24) completed assessments of cognitive and functional abilities and a series of semi-directed computer tasks. Computer use behaviours were captured passively using bespoke software.

Results: The profile of computer use behaviours was significantly different in cognitively impaired compared with cognitively healthy control participants including more frequent pauses, slower typing, and a higher proportion of mouse clicks. These behaviours were significantly associated with performance on cognitive and functional assessments, in particular, those related to memory.

Conclusion: Unobtrusively capturing computer use behaviours offers the potential for early detection of neurodegeneration in non-clinical settings, which could enable timely interventions to ultimately improve long-term outcomes.

KEYWORDS

Alzheimer's disease, cognitive decline, computer use, dementia, functional ability, mild cognitive impairment

1 | INTRODUCTION

Impairments in cognitive and functional abilities can be detected in the prodromal or "mild cognitive impairment (MCI)" stage of dementia.[1] Identifying the earliest symptoms of MCI is important for predicting progression to dementia and in providing a target for potential therapeutic interventions which act in the earlist stages of neurodegenerative diseases such as Alzheimer disease (AD).[2] Current clinical diagnostic criteria for MCI include problems in performing instrumental activities of daily living (IADL) as a part of the clinical syndrome.[1] IADL are activities beyond basic self-care that are necessary for living independently, eg, cooking.[3] Subtle impairments in IADL may also be evident in the pre-clinical (ie, pre-MCI) stage of dementia[4,5] and may be predictive of future cognitive decline.[6] Moreover, higher-level IADL, such as driving, managing finances, and using a computer, require complex cognitive processing and therefore may be more prone to deterioration in the early course of cognitive decline.[5]

To date, IADL assessments have generally been paper-based tools which are intermittently administered in clinic settings, and which rely on the recall of past behaviour, either by the affected person or their

ABBREVIATIONS: ACE, Addenbrooke's cognitive examination; AD, Alzheimer's disease; ECog, Measurement of Everyday Cognition; IADL, Instrumental activities of daily living; MCI, Mild cognitive impairment

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informant. Such tools are not ideally suited to detecting subtle changes in an individual's functional ability in everyday settings, over a prolonged period of time.[7,8] The challenge, therefore, is to detect objective and meaningful functional changes in higher-level IADL as early as possible and in ecologically meaningful settings, such as in the person's own home.

Capturing information about daily personal computer use activities may provide an opportunity to assess subtle changes in functional ability in elderly people over time. While personal computer use is an IADL in its own right, it also enables the user to complete a range of other complex IADLs, such as shopping, managing finances, and communicating.[9] The number of adults aged over 65 years using technology in the UK is increasing. Daily computer use in this age-group rose from 9% in 2006 to 45% in 2015,[10] accessing the internet on a mobile phone grew from 3% in 2011 to 21% in 2016,[11] and shopping online increased from 16% in 2008 to 45% in 2016.[11] Furthermore, as competent computer use relies on intact cognitive functioning across several domains (eg, attention, working memory, and executive function), changes in patterns of computer use (ie, functional change) may be a particularly sensitive indicator of cognitive decline.[12]

Previous studies have demonstrated the feasibility of measuring computer use behaviours in older adults to distinguish between those with and without cognitive impairment. For example, it has been shown that people with MCI have reduced frequency and duration of daily computer use,[13] and take longer to complete an online questionnaire.[14] Seelye and colleagues[7] have also demonstrated that people with MCI make significantly fewer mouse movements, take longer pauses between movements, and have a higher variability in the trajectory of mouse movements. These behaviours were significantly correlated with cognitive test scores. Vizer and Sears[15] also demonstrated that keystroke speed and linguistic content is associated with cognitive impairment in older adults. In spite of these promising findings, it remains uncertain whether these individual computer use behaviours (eg, speed of use, typing abilities, and mouse operations) could be used as a composite marker of cognitive impairment in a single participant group. This is particularly important because a range of different behaviours are required to correctly operate a computer, and any one of these could be affected by cognitive decline. Another uncertainty in the field arises from the inclusion of novice or non-computer users in the participant sample of previous studies (eg, Kaye et al[13]), which may limit the interpretation of findings due to the additional cognitive burden of learning to use a computer for the purposes of the study. Finally, the relationship between functional ability reflected by personal computer use and paper-based IADL measures has yet to be explored.

The study presented here is a cross-sectional proof of principle study designed to determine (1) whether multiple computer use behaviours, displayed by a sample of experienced older computer users on commonly undertaken computer tasks, can be used to distinguish between cognitively healthy older adults and those in the early stages of cognitive decline; and (2) whether these computer use behaviours are associated with cognitive and functional ability.

Key points

- This is one of the first investigations to explore a link between combined computer use behaviours and paper-based instrumental activities of daily living.
- A profile of computer-use behaviours can be used to differentiate between older adults with cognitive impairment and cognitively healthy older adults.
- Unobtrusively capturing data about various personal computer use behaviours could in the future be used to detect subtle, yet significant changes in cognitive and functional abilities.

2 | METHODS

2.1 | Participants

Twenty participants with cognitive impairment (MCI, $n = 17$; mild dementia due to AD, $n = 3$) were recruited through the UK dementia research registry "Join Dementia Research", as well as through local memory clinics and community groups. Participants referred from memory clinics had all received a clinical diagnosis from a qualified memory specialist based on Peterson's criteria[16] for MCI or NINCDS-ADRDA criteria[17] for AD. Participants who self-referred to the study all reported a diagnosis of MCI or mild dementia due to AD, given by a specialist memory clinic. Specific clinical subtypes of MCI (ie, amnestic vs non-amnestic; single vs multiple domain) could not be ascertained. All participants had high functional ability, according to Katz criteria (all ≥5).[18]

Twenty-four healthy control participants who had no prior history of cognitive impairment also participated in the study and were recruited through Join Dementia Research and local community groups (see Table 1 for demographic details).

Additionally, to be included in the study, all participants were required to have the capacity to provide informed consent, were 65 years of age or older, were regular computer users (defined as using a laptop or desktop computer at least once a week), used Microsoft Windows versions 7, 8, or 10, were able to communicate verbally in English, and had no acute physical or mental problems severe enough to interfere with the conduct of the study.

Duration (in years) and current frequency (days per week) of computer use was recorded for each participant as a measure of computer use experience (Table 1).

The study was approved by the Health Research Authority—National Research Ethics Service England in accordance with the Declaration of Helsinki, and all participants provided informed consent to participate.

2.2 | Procedure

Participants were invited to take part in a single testing session lasting approximately 2 hours conducted either in their own homes or at The University of Manchester.

TABLE 1 Demographic, computer use, cognitive, and functional variables

	Cognitively Healthy Control Participants, Mean (SD) *n* = 24	Cognitively Impaired Participants, Mean (SD) *n* = 20	Test Statistic	df	*P* value
Age (years)	71.09 (5.38)	75.60 (5.78)	−2.67	42	.011
Gender (% women)	58	30	3.532	1	.060[a]
Years of formal education	14.42 (3.88)	12.80 (3.74)	1.40	42	.169
15+ years computer use experience	19 (79.2%)	9 (45%)			.058[b]
Uses computer everyday	21 (87.5%)	11 (55%)			.015[b]
Trails B	81.17 (19.95)	145.45 (73.55)	−4.26	28.41[d]	.000
ACE-III[c] Total score	93.29 (4.05)	85.35 (6.92)	4.74	42	.000
ACE-III[c] Memory	23.96 (2.37)	20.30 (3.64)	3.86	31.51[d]	.001
ACE-III[c] Attention	17.42 (1.02)	16.6 (2.23)	1.51	25.51[d]	.116
ACE-III[c] Fluency	11.0 (1.84)	9.40 (2.04)	2.74	42	.009
ACE-III[c] Language	25.58 (.78)	24.50 (1.19)	3.49	31.53	.001
ACE-III[c] Visuospatial	15.33 (.91)	14.55 (1.79)	1.77	27.14	.088
ECog[e] Total score	1.40 (.38)	2.06 (.72)	−3.75	27.72[d]	.001
ECog[e] Memory	1.74 (.52)	2.71 (.81)	−4.66	31.12[d]	.000
ECog[e] Language score	1.45 (.46)	2.11 (.90)	−2.97	27.18[d]	.006
ECog[e] Visual-spatial	1.24 (.37)	1.58 (.644)	−2.20	42	.003
ECog[e]: Planning	1.23 (.46)	1.92 (1.03)	−2.75	25.37[d]	.011
ECog[e] Organization	1.20 (.37)	1.69 (.80)	−2.48	25.68[d]	.020
ECog[e] Divided attention	1.38 (.63)	2.29 (.99)	−3.58	31.06	.001

[a]Chi square test.

[b]Mann Whitney test.

[c]ACE-III, Addenbrooke's Cognitive Examination-III.

[d]Equal variances not assumed.

[e]ECog, Measurement of Everyday Cognitive Function.

Bonferroni corrected *P* value (α = .003).

2.2.1 | Cognitive and functional measures

Descriptive measures of global cognitive status were obtained using the Addenbrooke's Cognitive Examination (ACE)-III.[19] This test assesses 5 cognitive subdomains: attention, memory, verbal fluency, language, and visuospatial abilities, which provide a cognitive score out of a maximum of 100. Given that the only performance-based measure of executive function on the ACE-III is verbal fluency, we also incuded Part B of the Trail Making Test in the test battery as a measure of visual attention and task switching abilities.[20]

Subjective ratings of cognitive and functional capacity were obtained using the Everyday Cognition (ECog) scale.[21] This assessment requires participants to rate their current functional abilities compared with 10 years previously. The 39-item questionnaire assesses cognitively based functional items, across 6 domains: memory, language, visuospatial abilities, planning (executive functioning), organisation (executive functioning), and divided attention (executive functioning). Scores range from 1 ("Better or no change") to 4 ("Consistently much worse"). To ensure high accuracy and detail of ECog ratings for cognitively impaired individuals, this test was completed by an informant (for 17 of the 20 participants) who knew the participant well, either as co-habitants or seeing the participant in-person at least 3 times per week.

Each group's mean total ACE-III and ECog scores and mean scores for each cognitive domain (including Trail Making Test Part B) can be seen in Table 1.

2.2.2 | Tasks of computer performance

All tasks assessing computer use performance were completed on a laptop (Lenovo Think Pad T540P) running Windows 7, 8, or 10, depending on which operating system the participant was familiar with from their own personal computer. Participants were provided with a separate keyboard and mouse if they preferred.

Participants were asked to follow a set of written instructions in order to complete 4 experimental computer tasks: (1) a basic Desktop navigation task, which included using the date and time function, use of folders, and the recycle bin; (2) a Word processing task that involved editing a Word document and writing a diary entry; (3) an email (Outlook) task that included opening, writing, sending, and deleting emails; and (4) an internet browsing (Internet Explorer) task that included performing a Google search and navigation of a webpage. Participants could follow the instructions verbatim or adopt their own methods to complete the tasks, if they preferred.

Participants initially completed a practice session that involved shorter versions of the experimental computer tasks. The practice activity was repeated until the participant was confident in completing the tasks (approximately 2 repeats).

2.2.3 | Computer use behaviour data capture

Specially developed recording software (for further details, see Gledson et al[22] and Bull et al[23]) captured computer use behaviours

as a list of time-stamped events. In-line with previous research, the current study focussed on behaviours relating to mouse operations,[7] keystrokes,[15] and speed of use.[13]

Pauses were recorded as any period of inactivity greater than 10 seconds. To calculate event frequencies (eg, number of pauses per minute), computer use variables were divided by the total time to complete all 4 computer activities. Keyboard presses, and the key type and duration were recorded. Keystrokes included text-based entries whilst completing the diary entry during the Microsoft Word task (based on Vizer and Sears[15]), as well as all other key-presses for general computer operations. To distinguish keyboard presses relating to higher-level linguistic and semantic features from more general operations, we analysed these separately and termed these "Text" and "Operational" keystrokes, respectively. Mouse operations included information such as total mouse clicks and the time, distance, and screen areas crossed.

2.3 | Statistical analysis

Outliers for each computer use variable were removed using the non-recursive procedure[24] for each group of participants. This equated to 3.5% and 4.5% of data removed for the cognitively healthy control and the cognitively impaired groups, respectively. The distribution of the data was assessed using skewness and kurtosis. For non-normally distributed variables, the data were log transformed.

Cross-sectional group comparisons of demographic details, cognitive and functional test scores, and computer use variables were undertaken using independent samples t-tests for continuous variables, Chi-square tests for categorical variables, and Mann-Whitney U tests for ordinal data. Kendall's Tau correlations were used to examine the relationship between selected computer use variables and each of the cognitive domains and total scores from the cognitive and functional paper-based tests. To determine whether age and computer use experience could account for any associations observed between ECog and ACE-III scores and selected computer use variables, separate hierarchical regression analyses were conducted for each of the computer use variables. In step one of each model, years and frequency of computer use were added to the regression. In step two, age was added. In step three, ECog and ACE-III scores were added.

The selected computer use variables and the cognitive and functional test scores were then used to determine their probability distribution with respect to their sensitivity and specificity at classifying cognitive impairment using receiver operating characteristic (ROC) curve analyses. Predictive probability scores were calculated for the combined computer use variables and for the combined ACE-III, ECog, and Trail Making Test B scores, and then also subject to ROC curve analyses. Comparisons between ROC curves were conducted according to the method described by DeLong et al.[25]

Analyses were performed using SPSS version 22 and MedCalc version 17.8.

3 | RESULTS

3.1 | Selection of candidate variables: Performance on computer tasks

Participants in the cognitively impaired group differed significantly from those in the control group on several computer use behaviours (Table 2).

3.1.1 | Overall performance time variables

Compared with participants in the control group, cognitively impaired participants took longer to complete the computer tasks, paused more frequently overall and per minute, and had a longer total pause length per minute. By contrast, the mean duration for each pause did not differ significantly between the 2 groups. Therefore, the number of

TABLE 2 Comparison of selected computer use behaviours in cognitively healthy control participants compared with those with cognitive impairment, using independent samples t-tests

		Cognitvely Healthy Control Participants			Cognitively Impaired Participants					
		N	Mean	SD	*N*	Mean	SD	*t* Value	df	*P* Value
Overall performance time	Total duration (min)	24	18.62	4.70	19	27.02	7.33	−4.56	41	<.001
	Total number of pauses	24	20.00	8.24	19	35.68	13.55	−4.69	41	<.001
	Number of pauses per min[a]	24	1.04	.24	19	1.35	.25	−4.08	41	<.001
	Pause length per pause	23	17.53	2.95	19	19.17	2.98	−1.78	40	.082
	Pause length per min	23	18.81	6.11	19	27.16	6.41	−4.32	40	<.001
Keyboard	Total "text" keystrokes	23	384.48	128.78	19	203.05	122.93	4.64	40	<.001
	"Text" keystrokes per min[a]	23	128.48	35.03	19	63.65	32.64	6.16	40	<.001
	Total "operational" keystrokes	23	122.26	20.98	18	133.11	31.31	−1.33	39	.192
	"Operational" keystrokes per min	23	8.30	2.14	18	5.43	1.86	4.50	39	<.001
Mouse	Total mouse clicks[a]	22	103.41	21.56	20	174.65	79.34	−3.88	21.55[b]	.001
	Mouse clicks per min	23	5.95	1.52	19	5.89	2.41	.095	29.21[b]	.925
	Inter-click interval (secs)	23	10.7	2.49	20	11.3	4.43	−.595	29.0[b]	.557
	Total pixel count	24	21.5 k	8.77 k	17	22.2 k	9.32 k	−.253	39	.802
	Pixels per sec per inter-click interval	23	20.1	5.78	20	15.2	6.39	2.60	41	.013

[a]Variables selected for further analysis.

[b]Equal variances not assumed.

Bonferroni corrected *P* value (α = .004).

pauses per minute was chosen as the focus of further analysis based on the assumption that the greater total pause length per minute for the cognitively impaired group is due to them taking more pauses (of similar duration to control participants) per minute.

3.1.2 | Keyboard-use variables

Cognitively impaired participants made fewer "Text" keystrokes in total and per minute than the cognitively healthy participants. Because all participants took approximately the same length of time to complete the task involving "Text" keystrokes (approximately 3 minutes per participant), so total Text keystrokes and Text keystrokes per minute are a similar measure. Therefore, we focussed our analysis on Text Keystrokes per minute (ie, speed of typing). The cognitively impaired group did not differ significantly from the control group on total "Operational" keystrokes, but produced significantly fewer "Operational" keystrokes per minute. This difference was due to the different speeds the participants took to complete the tasks overall (see Section 3.1.1), and thus no further analysis was conducted on "Operational" keystrokes.

3.1.3 | Mouse-based variables

The cognitively impaired group executed a significantly greater number of mouse clicks compared with the control group, but there were no group differences on the number of clicks per minute. We selected total mouse clicks for further analysis based on the assumption that this indicated cognitively impaired older adults made more mistakes and then had to perform more clicks to correct these errors and therefore also contributing to the longer total duration to complete the tasks (see Section 3.1.1). The time between clicks (ie, inter-click interval) did not differ between the 2 groups. Mouse movements did not differ between the groups, as ascertained by the total number of pixels (ie, screen area covered) and the screen pixels within inter-click intervals (ie, speed of mouse movements).

3.2 | Correlations between computer use variables

Separate Kendall's Tau correlation analyses were conducted between the computer use variables selected from the group comparisons and each of the cognitive (ACE-III and Trail Making Test Part B; Table 3) and functional (ECog; Table 4) measures. A number of significant

TABLE 3 Correlation matrix for Trails B, ACE-III, and computer use variables

Measure	1	2	3	4	5	6	7	8	9	10
1. Trails B	-									
2. ACE Total	−.425[c]	-								
3. ACE Attention	−.257[a]	.447[c]	-							
4. ACE Memory	−.234[a]	.694[c]	.319[a]	-						
5. ACE Fluency	−.370[b]	.481[c]	.118	.258[a]	-					
6. ACE Language	−.326[b]	.559[c]	.236	.522[c]	.223	-				
7. ACE Visuospatial	−.354[b]	.390[b]	.416[b]	.167	.149	.168	-			
8. Number of pauses per min	.331[b]	−.376[c]	−.110	−.362[b]	−.298[b]	−.248[a]	−.154	-		
9. "Text" keystrokes per min	−.474[c]	.519[c]	.153	.384[c]	.428[c]	.271[a]	.310[a]	−.358[c]	-	
10. Total mouse clicks	.211	−.213	−.088	−.251[a]	−.148	−.198	−.024	.070	−.296[b]	-

[a]$P < .05$.

[b]$P < .01$.

[c]$P < .001$.

TABLE 4 Correlation matrix for ECog and computer use variables

Measure	1	2	3	4	5	6	7	8	9	10
1. ECog Total	-									
2. ECog Memory	.791[c]	-								
3. ECog Language	.692[c]	.517[c]	-							
4. ECog Visual–spatial	.722[c]	.624[c]	.612[c]	-						
5. ECog Planning	.671[c]	.586[c]	.520[c]	.640[c]	-					
6. ECog Organization	.582[c]	.476[c]	.444[c]	.512[c]	.540[c]	-				
7. ECog Divided attention	.673[c]	.599[c]	.499[c]	.542[c]	.594[c]	.522[c]	-			
8. Number of pauses per min	.175	.269[a]	.095	.094	.072	.184	.097	-		
9. "Text" keystrokes per min	−.134	−.251[a]	−.051	−.121	−.081	−.120	−.128	−.358[e]	-	
10. Total mouse clicks	.317[b]	.360[c]	.179	.158	.202	.208	.347[b]	.070	−.296[b]	-

[a]$P < .05$.

[b]$P < .01$.

[c]$P < .001$.

correlations were found (all $P < .05$), but only the Memory domain of the ACE-III and the ECog tests were significantly correlated with all 3 of the computer use variables.

Given that only the Memory domains were significantly correlated with all 3 computer use behaviours, we only included this cognitive domain within the regression models (Table 5). For mouse clicks and pauses per minute, neither age nor computer use experience could account for performance on these measures (all $P > .05$); however, the addition of ACE-III and ECog Memory scores led to a significant increase in the explained variance (R^2 change values both $P < .05$), and this model showed significant predictions of number of pauses per minute and number of mouse clicks (both $P < .05$). For "Text" keystrokes per minute, computer use experience was a significant predictor of performance accounting for 36.8% of the variability, which increased significantly with the addition of age (R^2 change = .101, $P = .011$) and increased significantly again with the addition of ACE-III and ECog Memory scores (R^2 change = .103, $P = .020$). Therefore, ACE-III and ECog Memory scores are significant predictors of keyboard typing speed ($R^2 = .260$, $P = .003$), but age and computer use experience may also account for variability in this behaviour.

3.3 | Accounting for within-group differences

To account for the possibility that the between-group differences were driven by those with mild dementia due to AD, all statistical analyses were repeated comparing only MCI participants to control participants. The results were unaffected, with the exception of ACE-III Memory score, which was no longer significantly related to number of mouse clicks.

3.4 | Receiver operating characteristic curve (ROC) analysis

The ROC analyses (Table 6) for the computer use variables all showed "good" (AUC = .8–.9) or "excellent" (AUC = .9–1.0) correct classification of cognitive impairment. In comparison, ACE-III and ECog total scores and memory domain scores, as well Trail Making Test B scores, all showed "moderate" (AUC = .7–.8) or "good" correct classification of cognitive impairment. Sensitivity and specificity values for each measure, as determined from the Youden index (*J*), are included in Table 6. When all the selected computer use variables were combined into a single predictive probability and compared with combined ACE-III Memory score, ECog Memory score, and Trail Making Test B predictive probability, correct classification was significantly higher for the combined computer use variables ($z = 2.002$, $P = .045$).

4 | DISCUSSION

In this proof of principle study, we examined whether computer use behaviours recorded from semi-structured tasks could discriminate

TABLE 5 Hierarchical linear regression analysis to account for age and computer use experience in the variability of computer use performance

					Change Statistics		
Dependent Variable	Model	*R* Square	*F*	*P*	*R* Square Change	*F* Change	*P*
Number of pauses per min	Step 1	0.045	0.948	0.396	-	-	-
	Step 2	0.152	2.321	0.090	0.106	4.885	0.033*
	Step 3	0.356	4.089	0.005*	0.204	5.870	0.006*
"Text" keystrokes per min	Step 1	0.368	11.430	<.001*	-	-	-
	Step 2	0.469	11.179	<.001*	0.101	7.233	.011*
	Step 3	0.572	9.629	<.001*	0.103	4.348	.020*
Total mouse clicks	Step 1	0.124	2.767	0.075	-	-	-
	Step 2	0.130	1.901	0.146	0.006	0.271	0.605
	Step 3	0.319	3.379	0.013*	0.189	4.997	.012*

Step 1, years and frequency of computer use; Step 2, + age; Step 3, + ACE-III and ECog Memory scores.

*$P < .05$

TABLE 6 ROC curve analyses

	Area under the ROC Curve			Youden Index				
Variable	AUC	SE	*z*	*P*	*J*	Cut-off criteria	Sensitivity (%)	Specificity (%)
Number of pauses per min	0.80	0.07	4.47	<.001	0.509	>1.09	84.21	66.67
"Text" keystrokes per min	0.91	0.04	9.98	<.001	0.677	≤104	89.47	78.26
Total mouse clicks	0.80	0.08	3.86	<.001	0.550	>146	55.00	100.00
ACE-III Total	0.85	0.06	5.62	<.001	0.675	≤89	80.00	87.50
ACE-III Memory	0.80	0.07	4.47	<.001	0.558	≤23	85.00	70.83
ECog Total	0.82	0.07	4.74	<.001	0.575	>1.26	95.00	62.50
ECog Memory	0.84	0.06	5.26	<.001	0.600	>2.00	85.00	75.00
Trail making test B (seconds)	0.83	0.06	5.35	<.001	0.525	>82	90.00	62.50
Computer use behaviours combined	0.98	0.02	26.13	<.001	0.889	>.72	88.89	100.00
Memory (ACE-III and ECog) and trails B combined	0.92	0.04	9.89	<.001	0.717	>.41	80.00	91.67

between people with cognitive impairment and cognitively healthy control participants, and whether measures of functional ability and cognition were related to these computer use behaviours. Consistent with previous findings, the 2 groups performed differently on computer activity measures of time,[13] keystrokes,[15] and mouse operations.[7] In contrast to previous studies which have focused on individual examples of computer use behaviour, here we have demonstrated that a *combined* profile of behaviours has potential to provide information about cognitive and functional decline in the early stages of neurodegeneration. We have also demonstrated the potential influence that age and computer use experience can have on computer use abilities and therefore need to be accounted for when determining how cognitive ability affects computer use performance.

Decline in performance of computer-based activities is likely to vary among individuals; therefore, capturing a range of behaviours will significantly increase the likelihood of early detection. Nonetheless, when capturing data reflecting multiple behaviours, it is imperative that the measures are highly sensitive and specific to acknowledged thresholds for recognised clinical syndromes such as MCI or dementia, thus guarding against a high false positive rate. In the current study, all of the computer use measures showed "good" or "excellent" correct classification of cognitive impairment with high sensitivity and specificity. Indeed, when these measures were combined into a single predictive probability measure, they showed a significantly greater correct classification of cognitive impairment compared with a combination of paper-based measures typically used in a clinical setting. Additionally, certain participants within the cognitively impaired group scored within the normal range on the ACE-III (>88/100), which could explain why the specificity and sensitivity of ACE-III scores were lower than reported previously (ie, a cut-off score of <88 giving 100% sensitivity and 96% specificity[19]). This could be due to numerous reasons, including a practice effect from completing the test previously in clinic, the home setting being a less stressful environment compared with a clinic setting, and/or the day-to-day variability in cognitive functioning as a result of changes in mood or fatigue. Therefore, this emphasises the utility of these computer-based monitoring measures to provide a potentially sensitive identification of cognitive impairment in a home-based setting in the first instance, which could then be used to supplement follow-up clinic-based measures to ascertain the degree and type of impairment.

One limitation of this exploratory study is that sub-type of MCI (ie, amnestic vs non-amnsetic) of each participant was unknown. We acknowledge, therefore, that there may have been some variability in cognitive profiles between participants. From the ACE-III and ECog results, there are clear group differences on numerous cognitive domains, but only memory scores were significantly correlated with all 3 of the selected computer use variables. It remains unclear why episodic and semantic memory abilities (which are included in the ACE-III and ECog tests) may be related to such functional tasks as keyboard typing speed. It could be that the majority of participants were of amnestic MCI type, and so memory was the strongest measure of overall cognitive function (as assessed by the ACE-III). Similarly, because the ECog was completed mostly by participants' informants, perhaps memory decline is the most noticeable impairment compared with other cognitive domains and is therefore rated as the most impaired domain. To address this issue, it would be beneficial to use a cognitive test battery which covers a broader range of cognitive domains, such as procedural memory and processing speed. Nevertheless, it remains uncertain which computer use behaviour changes (eg, slower typing speed) are most likely to be associated with declines in particular cognitive functions (eg, divided attention, language production, procedural memory, etc.). We have recently attempted to address this issue by convening a group of experts in clinical and cognitive neuroscience to determine which cognitive domains may be related to a range of different computer use behaviours, and how decline in specific domains might affect performance on different computer use activities (see Couth et al[26]).

5 | CONCLUSION

This proof of principle study has demonstrated that a computer-based monitoring system can differentiate between cognitive impairment (ie, MCI and early AD) and healthy cognitive ageing using semi-directed computer tasks and several objective measures of computer use performance. The next phase will be to determine whether we can passively detect early changes over time in these same computer use behaviours, using unobtrusive recording of the behaviours through software embedded in participants' personal computers. The ultimate aim is to ascertain whether behaviour changes associated with cognitive and functional decline could provide a sensitive and efficient way to detect very early signs of dementia.

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CONFLICT OF INTEREST

None declared.

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CHAPTER 6 (Study D): Passive assessment of computer use behaviours in the home can indicate early cognitive impairment: An exploratory longitudinal study.

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Authors contributions:

Gemma Stringer conceived the original idea for the paper, wrote the clinical protocol and ethics application, created the study documents, obtained ethical approval, recruited study participants, collected the data, carried out the statistical analysis and interpreted the data. Gemma Stringer wrote the first draft of the manuscript and completed all revisions following review by the co-authors. Professor Iracema Leroi, Professor Peter Sawyer, Professor Alistair Sutcliffe, Professor John Keane, Professor Xiaojun Zeng and Dr Paul Payson designed and obtained funding for the original study. Dr Laura Brown was an informal advisor for the original study in her position as the candidate's supervisor. Dr Sam Couth was involved in obtaining ethical approval, recruited study participants and collected data. Dr Laura Brown, Professor Iracema Leroi and Professor Daniela Montaldi provided methodological guidance, statistical guidance and supervisory input. All authors critically reviewed and agreed on the submitted manuscript for publication.

The ***submitted version*** of the manuscript is presented.

Passive assessment of computer use behaviours in the home can indicate early cognitive impairment: An exploratory longitudinal study.

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Abstract

Introduction: Computer use behaviours have the potential to provide useful information about an individual's daily cognitive and functional abilities. However, little research has been based on evaluations of unaided and undirected personal computer use in the home. Here, we explored whether patterns of time spent on the computer, mouse clicks, and keystroke speed obtained from continuously-assessed routine home computer-use i) could discriminate between individuals with subjective cognitive decline (SCD) and individuals with mild cognitive impairment (MCI); ii) were associated cross-sectionally with cognitive or functional ability; and iii) changed over time.

Method: Thirty-two participants with SCD (n=18) or MCI (n=14) (mean age = 72.53 years; female n = 19) participated in a longitudinal study (mean duration = 225 days, SD = 31.22), in which their in-home computer use behaviour was continuously and unobtrusively recorded using custom-made software. Cognitive and functional assessments were completed at three time points: 1) baseline: 2) mid-point (4.5 months); and 3) end point (month 7 to 9).

Results: Individuals with MCI had significantly slower keystroke speed (95% CI .55, 1.22) and spent less time on the computer (95% CI 5.41, 86.20) than individuals with SCD. More time spent on the computer was associated with better task switching abilities (95% CI .008, .076). Faster keystroke speed was associated with better visual attention (95% CI .040, .701), recall (95% CI .298, .788), recognition (95% CI .282, .793), task inhibition (95% CI .009, .425) and task switching (95% CI .096, .592). There was a decline in recall scores (95% CI -.110, -.028) over the study period. No change in computer use behaviour was detected.

Conclusion: Passive monitoring of keystroke speed shows potential as an indicator of a person's cognitive status, and time spent on the computer and keystroke speed can differentiate between groups with SCD and MCI.

Introduction

Subtle changes in instrumental activities of daily living (IADL) may be a marker of the development of a neurodegenerative condition leading to dementia. Difficulty with IADL, such as managing finances and taking medication, may manifest in the prodromal and preclinical stages [1-4] and can discriminate between cognitively healthy individuals and individuals with mild cognitive impairment (MCI) [5, 6], as well as being able to predict whether a healthy person will go on to develop MCI [7]. Furthermore, difficulties in performing IADL may occur many years before the onset of the clinical syndrome of dementia [8], and may emerge in the subjective cognitive decline (SCD) stage [9]. However, clinic-based assessments of IADL can only provide episodic information; are highly subjective; and lack temporal precision, intraindividual specificity and ecological validity [10, 11].

Advances in ubiquitous computer software and "smart home" technologies have made it possible to unobtrusively monitor IADL, providing continuous real-time information about a person's cognitive and functional ability from within their own homes [12, 13]. These technologies range from sensors distributed around the home [14-16]; wearable sensors [17, 18]; and software for monitoring computer activities [11, 19-21]. Being able to monitor daily activity in a home-based setting has the potential to provide information about subtle within-person change over time, even at the pre-symptomatic stage, and may provide valuable information to support clinic-based assessments. One advantage of this new assessment paradigm is that it can be embedded into commonly used devices, and therefore requires minimal or no extra effort or action on the part of the individual outside of their normal routine. It also offers increased opportunity for older adults to self-monitor and self-manage, which has the potential to increase feelings of self-efficacy [22] and foster independence [23].

Personal computer use is increasingly common in older adults. For instance, in the UK, internet use in retired older adults aged 65 to 74 has increased from 52% in 2011 to 83.2% in 2019 [24]. Similarly, in the US, internet use in adults aged 65 and over increased from 46% in 2011 to 73% in 2019 [25]. As such, monitoring older adults' personal computer use is a particularly viable option for continuously and unobtrusively monitoring functional and

cognitive ability. Previous studies have shown that three main aspects of computer use differ between individuals with cognitive impairment and cognitively healthy controls: time spent on the computer [20, 21], frequency, variability and efficiency of mouse movements [19], and keystroke speed [26]. Previous studies have primarily involved participants who were novice computer users, and therefore required a period of computer training prior to the start of the study. As individuals with cognitive impairment may have difficulty retaining new training information over time, this makes it difficult to evaluate whether any observed changes in computer use are due to a decline in existing skills or difficulty in acquiring new ones. To address this potential issue, we have recently tested a cohort of experienced computer users on a series of directed computer tasks [27]. In this study, computer use behaviours were recorded using custom-made software developed by the SAMS (Software Architecture for Mental Health Self-Management) technical team (for further details of SAMS software see [28, 29]). We demonstrated that measuring performance on a specific set of computer use behaviours (including pauses, mouse clicks and typing) could discriminate between individuals with cognitive impairment and cognitively healthy controls, and that these behaviours were associated with performance on cognitive and functional assessments, in particular, those related to memory. What remains to be explored is the predictive utility of non-directed computer tasks, as well as longitudinal change in computer use behaviours and whether this corresponds to changes in cognitive and functional ability at both the group and individual level.

In the present study, we evaluated the potential of using continuously recorded home computer-use as a marker of the level of, or change in, cognitive and functional ability. There were three aims: 1) to investigate whether passive computer use behaviour could differentiate between individuals with MCI and individuals with SCD; 2) to examine cross-sectional associations between passive computer use behaviour and cognitive and functional test scores; 3) to determine whether any change over time in passive computer use was associated with change in cognitive and functional test scores.

Materials and Methods

Study design

This was an exploratory longitudinal study of in-home computer use behaviours using custom-made monitoring technologies. Participants were recruited to the study on a rolling basis over a period of 2 months. The length of time participants were in the study ranged from 7 to 9 months (mean = 31.94 weeks, SD = 4.47). Participants completed a battery of cognitive and functional assessments at three testing time points: 1) baseline: 2) mid-point (4.5 months); and 3) end point (month 7 to 9). Cognitive and functional assessments, combined with continuous recording of specific computer activities for the entire study period, was completed in participants' own homes.

Participants

Thirty-two participants with subjective cognitive impairment (n=18) or mild cognitive impairment (n=14) (age range = 65 to 84 years) participated in the study (Table 1).

Table 1. Demographic, cognitive and functional variables at baseline

	All participants (MCI and SCI: N=32)	MCI participants (n=14)	SCD participants (n=18)
Mean (SD) age in years	72.53 (4.29)	74.34 (4.76)	71.13 (3.39)
No. (%) of females	19 (59.38)	6 (42.86)	13 (72.22)
Mean (SD) years of formal education	13.08 (3.35)	12.86 (3.21)	13.44 (3.52)
Modal years of computer use	15 years and over	15 years and over	15 years and over
Mean (SD) Geriatric Depression scale total score	2.09 (1.94)	2.39 (2.09)	1.71 (1.73)
Mean (SD) Starkstein Apathy scale total score	30.94 (4.54)	32.64 (4.43)	29.61 (4.29)

Data are presented as mean (SD), mode or number (%). †ACE III = Addenbrooke's Cognitive Examination-III (ACE III); ‡ECog = Measurement of Everyday Cognitive Function.

Participants were recruited through the UK dementia research registry 'Join Dementia Research' (a national web-based service that allows individuals to register their interest in

participating in dementia research and be matched to suitable studies), as well as memory clinics and local community groups in the Greater Manchester area. Participants who had taken part in a previous study on assessing computer use behaviour in controlled settings [27] were also invited to take part. Participants were eligible to take part in the study if they: had the capacity to consent; were 65 years of age or older; were regular computer users (defined as using a laptop or desktop computer at least once a week); owned a personal computer or laptop that used Microsoft Windows versions 7, 8 or 10; had a home internet connection; and were able to communicate verbally in English.

Participants with MCI referred from memory clinics had all received a clinical diagnosis from a qualified memory specialist based on Peterson's criteria for MCI [30]. Participants who self-referred to the study all reported a diagnosis of MCI given by a specialist memory clinic. Specific clinical subtypes of MCI (i.e. amnestic vs non-amnestic; single vs multiple domain) were not ascertained. SCD participants were identified if they indicated on the ECog [31] that they were “concerned they have a memory or other thinking problem” and their total score was greater than 1.43. This cut-off score corresponds to the upper 95% confidence interval of the mean total ECog scores from a sample of healthy control participants [27], who indicated that they were not “concerned they have a memory or other thinking problem”.

The study was approved by the Health Research Authority - National Research Ethics Service England in accordance with the Declaration of Helsinki, and all participants provided written informed consent to participate.

Cognitive and functional measures

Where possible, different versions of tests containing visual and verbal memory elements (i.e. Addenbrooke’s Cognitive Evaluation (ACE) III, Free and Cued Selective Reminding Test (FCSRT) and the Doors and People Test) were used at each time point to counteract practice effects. Where different versions were not available, the research team produced its own adapted versions i.e. different people and shapes used in the Doors and People Recall test. All cognitive and functional scores were positively coded for ease of interpretation, with a higher score indicating better cognition or function.

Global functional status

Descriptive measures of global cognitive status were obtained using the ACE III [32]: a concise neuropsychological assessment of cognitive functions commonly used in the UK with validated cut-off scores for MCI and dementia. The test includes five cognitive subdomains: attention, memory, verbal fluency, language and visuospatial abilities, which provide a cognitive score out of a maximum of 100 (a higher score indicates better cognitive function).

Functional ability

Subjective ratings of cognitive and functional capacity were obtained using the self and informant versions of the ECog [31]. This assessment requires informants or the participant to rate the current functional abilities of the participant compared to 10 years previously. The 39-item questionnaire assesses cognitively based functional items across six neurological domains: memory, language, visuospatial abilities, planning, organisation and divided attention. Scores range from 1 ("Better or no change") to 4 ("Consistently much worse"). The informant version was used for the 27 of the 31 participants who had an informant (i.e. someone who knew the participant well, either as co-habitants or seeing the participant in-person at least three times per week). The self-report version was used for the other five participants who did not have an informant.

Processing speed

Trails Making Test A (TMT A) [33], simple reaction time (SRT) and four-choice reaction time (CRT) [34] were used to assess cognitive processing speed. Participants completing TMT A are required to draw lines to connect circled numbers in a numerical sequence (i.e., 1-2-3, etc.) as rapidly as possible. Simple reaction time (SRT) and four-choice reaction time (CRT) means and standard deviations were measured for each participant on the Deary-Liewald reaction time task [34]. The SRT involved eight practice trials and twenty test trials. The CRT involved eight practice trials and forty test trials.

Episodic memory

Episodic memory was measured using the FCSRT [35]. The FCSRT begins with a study phase in which subjects are asked to search a card containing four pictures (e.g., grapes) for an item that goes with a unique category cue (e.g., fruit). After all four items are identified, immediate cued recall of just those four items is tested, providing retrieval practice while the items are still in working memory. The search is performed again for items not retrieved by cued recall. The search procedure is continued for the next group of four items until all 16 items have been identified and retrieved in immediate recall. The study procedure is followed by three trials of recall, each consisting of free recall, followed by cued recall for items not retrieved by free recall, for a maximum score of 48 (a higher score indicates better performance). Items not retrieved by cued recall are presented again. Each separate trial is followed by 20 seconds of interference. The FCRST produces three scores: free recall, total recall and cue efficiency. Free recall (the cumulative sum of free recall from the three trials; range 0-48) was evaluated for the current analysis because it has been shown to be more sensitive to dementia than the other two measures [36].

Recall and recognition

The Doors and People Test was administered to assess verbal and visual recall and recognition [37]. The subtests were administered in the following order: verbal recall (people subtest); visual recall (shapes subtest); verbal recognition (names subtest); visual recognition (doors subtest). Both recognition memory tasks adopt a multiple-alternative forced-choice design. A higher score indicates better performance. New stimuli were produced for the recall tasks at time points two and three: new pictures and names for the people subtest and new shapes for the shapes subtest. Total age-scaled recall score, total age-scaled recognition score and overall forgetting score (verbal age scaled forgetting score + visual age scaled forgetting score) were assessed for the current analysis.

Executive function

Executive function was captured using the Trails Making Test B (TMT B) and Digit Span Backwards (DSB) test [33]. Participants completing TMT B are required to draw lines to connect circled numbers and letters in an alternating numeric and alphabetic sequence (i.e., 1-A-2-B, etc.) as rapidly as possible.

Participants completing DSB are asked to report digit sequences backwards, beginning with a length of two digits up to eight digits, with two trials at each increasing list length. The test is discontinued after a score of 0 on both trials of any item.

Executive function was also captured using the Color-Word Interference Test (CWIT)[38]; a recently developed modification of the Stroop test [39] that includes four conditions (colour naming, word reading, inhibition and task switching). Completion time (seconds) for each condition was used to calculate an interference and task switching score (for details on scoring the Stroop test see [40]).

Depression and apathy

Baseline measures of depression and apathy were captured using the Geriatric Depression Scale [short form] (GDS) [41] and the Starkstein Apathy Scale [42]. A higher score on the GDS indicates a greater level of depression. Participants scoring more than 5 were signposted to their GP but not excluded from the study. A higher score on the SAS indicates a greater level of apathy.

Computer use behaviours

SAMS system architecture

The SAMS recording software captures computer-use activities as a list of time-stamped events using recording software specifically developed by the project's software development team. The SAMS desktop logger records all computer activities including mouse clicks and keystrokes. All alpha numeric keystrokes typed in secure browsers such as banking or email passwords are suppressed, but keystroke count and timestamp are captured. All computer use data captured by SAMS is immediately encrypted. The software and user interface was developed with input from clinical domain experts and potential end-users, including study participants from initial pilot studies.

SAMS installation and setup

All participants had the SAMS software installed on their home computer. If the computer was used by others in the household, either separate user accounts were set up for each user, or an identity checker was installed which asked the user to respond to an on-screen

prompt asking if they were the participant, so that data relating to the participants' behaviour could be distinguished from others. This pop-up would occur following a 10-minute period of computer inactivity, with the participant given the option to extend the time between pop-ups to up to 4 hours.

Following the SAMS software set-up, a short training session was undertaken to introduce the participant to the software. It was explained that the SAMS software would always run in the background of the computer unless they paused it and a link to the software was available on the desktop and in the windows notification tray (shown in Fig. 1. a and b). If the participant wished to work privately, they could click on the software icon link and a pop-up window would allow them to pause and resume monitoring (shown in Fig. 1. c).

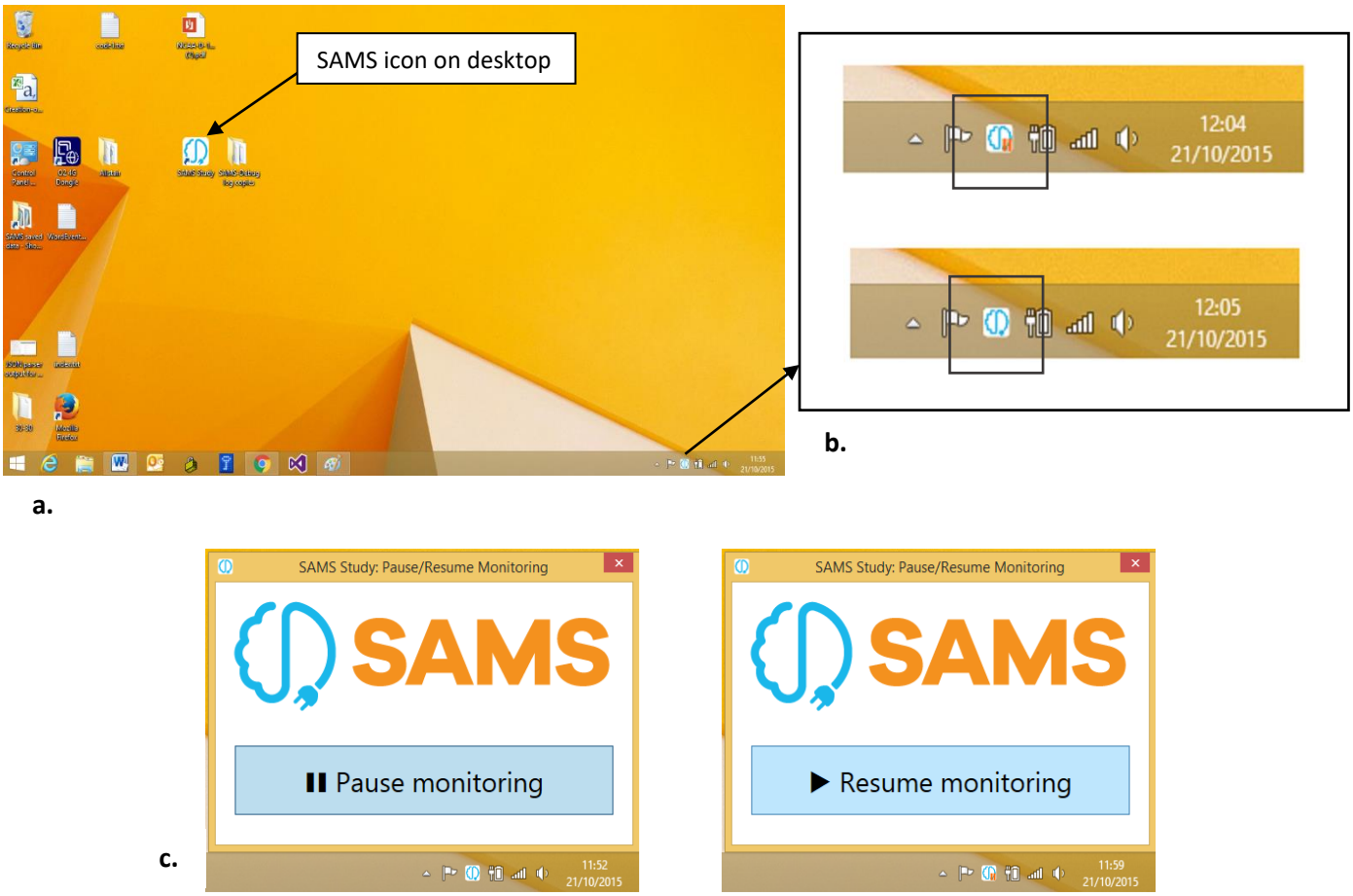

Fig. 1. Examples of SAMS software visible to participants on their computers. a. Example screen showing the SAMS icon on the desktop and in the Windows notification tray. b. Enlarged notification tray icons, the top image is the icon when SAMS is paused (top) and the bottom image is the icon when SAMS is monitoring. c. The pop-ups that appear when the SAMS icon is pressed, the option to pause (left) when SAMS is monitoring and the option to resume when SAMS is paused (right).

The participants were oriented to the technical helpline procedures, which they could call if there was a problem with their computer related to the SAMS software. All participants received a monthly check-up phone call to discuss any computer issues and to report any days the computer was 'inaccessible' (i.e. planned holiday, no access to computer or computer not working).

Computer use variables

Although the SAMS recording software is capable of capturing a variety of computer-use behaviours, the current study focussed on mouse clicks, keystroke speed, and computer use duration, all of which have been previously shown to be associated with cognitive ability (Kaye, 2014; Seelye, 2015; Vizer and Sears, 2015; Stringer, 2018).

The data collected by the SAMS software on day one were not included in the analysis because this included activity from the SAMS technical team when installing the software.

Computer use duration was recorded across each computer use 'session': defined as a period of activity on the computer (i.e. mouse moves, clicks, and keystrokes) with a pause of no longer than 15 minutes. Daily computer use was calculated as the sum of the duration of all 'sessions' per day. The pattern of daily computer use was analysed in three ways: 1) for every single day in the study, irrespective of whether the computer was accessible or used; 2) only the days that participants reported that the computer was accessible (i.e. not on holiday), irrespective of whether the computer was used or not; and 3) only the days when the computer was accessible and used.

For the longitudinal analysis of change in computer use over time and the cross-sectional analysis of differences between individuals with MCI and SCD, daily computer use was analysed for every day in the study (method 1), and every day in the study when the computer was accessible, irrespective of use (method 2). The pattern of results was broadly similar for both analysis methods (see supplementary tables 1 and 3). As all the effects were in the same direction and all patterns of significance were the same, for simplicity, we present computer use data from all days where the participant was in the study, including days when the computer was not accessible or used (method 1). This measure represents the most feasible, least labour intensive and most natural form of the data as it does not require additional information from the participants about when the computer was inaccessible. Additionally, this measure is not subject to bias as it does not require participants to report information that relies on memory and executive functioning.

The cross-sectional analysis of associations between computer use behaviours and cognitive and functional test scores uses computer use variables measured over temporal bins

corresponding to the dates of the cognitive tests for each participant (see page 15 for details of temporal bins). To account for the inconsistent and varied daily computer use across these shorter temporal bin periods, this analysis focused on daily computer use for every day that the computer was accessible (method 2) and every day that the computer was accessible and used (method 3), within these temporal bins. The pattern of results was broadly similar, with all associations in the same direction (see supplementary table 2). For simplicity, we present computer use data based on days of actual computer use (method 3), since the data is less skewed by days when there were 0 minutes of computer use.

Mouse click frequency was calculated by dividing total mouse clicks (left and right) per day by the total duration of computer use per day.

Keystroke speed was calculated first by identifying distinct bursts of keystroke activity. This was done to isolate sequences of keystroke activity rather than instances of sporadic keypresses (i.e. navigating an application or pressing the keyboard in error). A burst was defined as a series of at least five consecutive keystrokes with a pause between keystrokes (keystroke up to keystroke down) of no longer than 1.957 seconds. The 1.957 second pause duration was the upper limit gap (mean gap + 2*SD) between keystrokes on a Word task used in Stringer et al (2018). Bursts were based on a minimum of 5 consecutive keystrokes to ensure that short bursts with very high keystroke speeds were not included because these typing speeds would not be sustainable for long periods. Any keystroke over the 1.957 second limit signified the end of a burst. A burst was also defined as ended if the mouse was used. Keystroke bursts did not include modifier keys (CTRL, ALT and Shift), because they are used at the same time as other keystrokes and skew the keystroke speed. As the removal of specific keys could only be applied to known keystrokes, and the key code of keys typed in secure browsers was suppressed, all keystrokes occurring in suppressed browsers were removed. Daily keystroke speed was calculated by dividing the total number of keystrokes in bursts per day by the total duration of bursts per day.

To encourage participants to type more, and thus collect more data relating to keystroke speed, participants were asked to complete a weekly diary entry. This involved asking them to write about general feelings during the week (highpoints, low points) and report key life events (positive and negative). Completion of the diary entry was explained during the

training process and participants were sent monthly reminders to encourage them to continue to complete their weekly diary entry.

Statistical analysis

Statistical analyses were performed using SPSS version 22 and Stata/SE version 12.1. Outliers were calculated for the cognitive data using the non-recursive procedure described by Van Selst and Jolicouer (1994). Two participants' reaction time data were omitted because at least one of the data points from the three testing sessions were missing due to technical problems with the reaction time recording software. One participant's Stroop data was excluded because they were colour blind.

A conventional *p* value of 0.05 was used because of the small sample size and low power. However, given the exploratory nature of this study we also considered the results in light of a false discovery rate (FDR) correction (q = 0.2), as described by Benjamini and Hochberg (1995), to account for increased risk of false positives [43].

Cross-sectional data analysis

To investigate cross-sectional differences between individuals with MCI and SCD, we used multilevel modelling (MLM) to allow for the statistical dependency between multiple observations for the same individuals. We regressed the computer use and cognitive variables on a variable capturing membership to the SCD vs MCI group. This analysis was based on all available data for the full time period of the study.

In order to examine cross-sectional correlations between computer use data and cognitive and functional test scores, computer use variables were first measured over temporal bins that corresponded to the dates of the cognitive tests for each participant: the first three weeks after the baseline assessment (T1); the week of the midpoint assessment (T2) and the two weeks either side; and the three weeks prior to the end point assessment (T3). We then used MLM to examine cross-sectional associations between computer use behaviours and cognitive and functional test scores across the entire study period, again allowing for the statistical dependency between multiple observations for the same individuals, and statistically adjusted for age, educational attainment and years of computer use.

Change over time analysis

To analyse whether there was any change in computer behaviour and/or cognitive scores over time, we used MLM for repeated measures, treating time from inclusion in the study as a continuous predictor variable and allowing for the statistical dependency between multiple observations per individual. We then adjusted associations for variations in age, educational attainment, and years of computer use. We considered statistical significance of the adjusted regression coefficient of the time variable ($p < 0.05$) as evidence for a change over time between baseline and follow-up measurements, with a positive or negative coefficient signalling improvement or deterioration, respectively. The computer use behaviour data (total computer use duration, mouse click frequency and keystroke speed) were regressed on the number of days each participant was in the study. The cognitive and functional scores were regressed on the time variables for each participant. The time variable represented the amount of time (in weeks) that passed at each assessment since the baseline assessment. For baseline this was 0 weeks for all participants, for midpoint assessment this ranged between 16 and 21 weeks (mean = 17, SD = 1.54), and for end point this ranged between 20 and 40 weeks (mean = 34, SD = 3.59).

Results

Participants were in the study for between 139 and 274 days (median = 227, IQR = 202.75 - 247). The total number of days of use ranged between 39 and 238 days for the study period (median = 162.5, IQR = 106.75 – 182.25). There was variability in number of days participants did not use the computer, ranging from 5 to 208 days (median = 72, IQR = 48.25 – 113.5). Participants reported between 2 and 101 days (median = 201, IQR = 182.75 – 227.5) where their computer was inaccessible. In total participants did not use the computer for 36% (2590 days) of the total days all participants were in the study (7200 days). Seventy two percent of participants (n=23) used the computer for 50% or more of their days in the study, 31% (n=10) used the computer for 75% or more of the days, and just 12% (n=4) had 90% or more daily use. The lowest percentage days of computer use was 23%. No observations (days) were dropped from the analysis due to the computer not being used.

Average daily computer use based on all days was 68.73 minutes (SD = 97.64) (shown in Fig. 2. a) and 74.21 minutes (SD = 99.44) based on all days minus days where the participant reported the computer was inaccessible. Average daily mouse click frequency was 7.86 clicks per minute (SD = 6.46) (shown in Fig. 2. b). Average daily keystroke speed was 2.59 keystrokes per second (SD = .80) (shown in Fig 2. c).

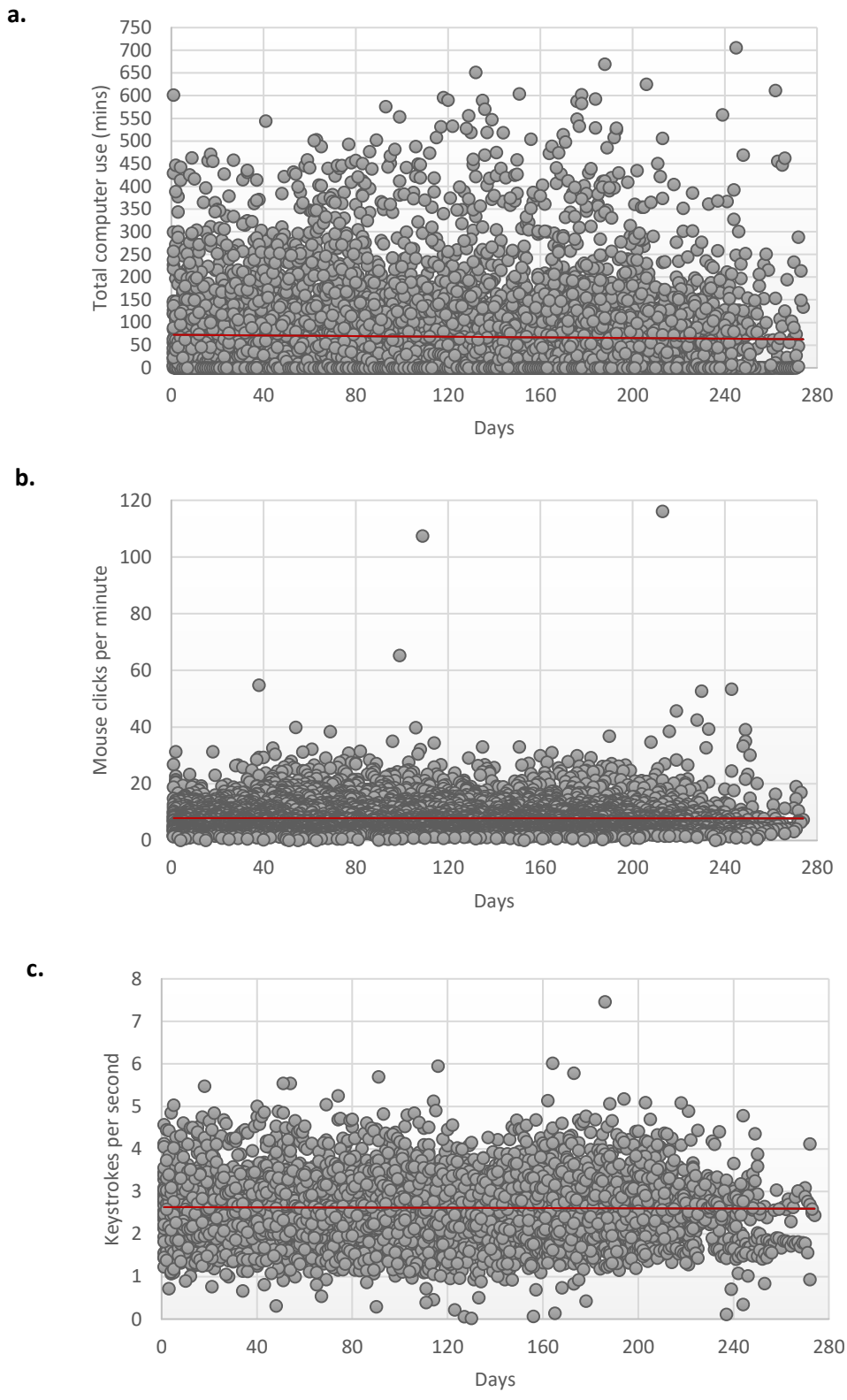

Fig. 2. Variability in computer use behaviours over time (days). a. Variability in computer use duration in minutes. b. Variability in mouse clicks per minute. c. Variability in keystrokes per second.

Cross-sectional analysis of differences between groups

In line with group categorisation, MCI participants had greater impairment on all of the cognitive and functional assessments compared to the SCD participants, and the majority of these differences were significant (Table 2). Participants with MCI also differed significantly to participants with SCD on two out of three computer behaviours. Participants with MCI spent significantly less time on the computer ($p = .026$) and had slower keystroke speed ($p < .001$) compared to individuals with SCD. These effects held significance after applying the false discovery rate.

Table 2. Multi-level models for the comparison of MCI participants to SCD participants on computer-use behaviours and cognition

Variables		MCI (N=14)	SCD (18)	β	95% CI	*p* value
		Mean (SD)	Mean (SD)			
Computer use behaviours	Daily computer use – every day in the study[§] (mins)	43.95 (66.46)	87.14 (112.01)	45.81	[5.41, 86.20]	.026
	Mouse click frequency per minute	7.47 (5.94)	8.08 (6.73)	.83	[-1.68, 3.35]	.516
	Keystroke speed (secs)	2.05 (.64)	2.92 (.71)	.89	[.55, 1.22]	.000
Cognitive variables	ACE III	88.36 (4.73)	96.28 (3.49)	7.92	[5.35, 10.49]	.000
	ECog[†]	-1.93 (.75)	-1.46 (.42)	.47	[.07, .87]	.021
	TMT A[†]	-44.81 (23.49)	-33.33 (10.42)	11.48	[-.86, 23.81]	.068
	TMT B[†]	-108.93 (65.12)	-66.35 (29.73)	42.58	[8.33, 76.83]	.015
	DSB	6.62 (1.89)	8.85 (1.75)	2.23	[1.16, 3.31]	.000
	FCRST	27.33 (8.98)	36.50 (3.84)	9.17	[4.54, 13.80]	.000
	Reaction time[†]	-44.87 (7.52)	-40.09 (9.46)	4.66	[-.26. 9.58]	.063
	Doors and people (recall)	18.55 (6.16)	26.26 (3.81)	7.71	[4.57, 10.85]	.000
	Doors and people (recognition)	20.05 (4.79)	28.13 (5.11)	8.08	[5.14, 11.03]	.000
	Doors and people (forgetting)	19.67 (3.84)	21.07 (2.76)	1.41	[-.14, 2.95]	.074
	Stroop inhibition[†]	-65.45 (29.16)	-47.57 (16.90)	17.87	[1.06, 34.68]	.037
	Stroop switching[†]	-86.55 (31.17)	-53.20 (17.27)	33.35	[17.12, 49.57]	.000

Note: [§]Daily computer use was based on every day that the participant was included in the study, irrespective of accessibility and use. [†]Scores were reverse coded for clinical interpretability. All *p* values held significance after false discovery rate (FDR) correction (*Q* = .20).

Cross-sectional analysis of associations between variables

After the application of the FDR, there was a significant effect of more time spent on the computer with scores on the Stroop switching test ($p = .016$) (Table 3). These scores suggest that those who are least impaired on the Stroop switching test spend longer on the computer. There was also a significant effect for keystroke speed with TMT A ($p= .028$), recall on the Doors and People Test ($p<.000$), recognition on the Doors and People Test ($p<.000$), Stroop inhibition ($p = .041$) and Stroop switching ($p=.006$). These scores suggest that individuals who are least impaired on the TMT A, recall on the Doors and People Test, recognition on the Doors and People Test, Stroop inhibition and Stroop switching tasks, have faster keystroke speed. These effects were significant after controlling for age, years of education and computer use experience.

There were no significant effects for mouse click frequency with any of the functional or cognitive test scores after the application of the FDR.

Table 3. Multi-level models for the association between cognition and computer use behaviours

			Crude			Adjusted*		
Variables		N	β	95% CI	*p* value	β	95% CI	*p* value
Daily computer use – only days of use[§] (hours)	ACE III	32	-.000	[-.039, .039]	.984	-.014	[-.066, .039]	.614
	ECog[†]	32	.016	[-.018, .050]	.353	.013	[-.024, .049]	.504
	TMT A[†]	32	.018	[-.008, .044]	.175	.015	[-.006, .035]	.170
	TMT B[†]	32	.014	[-.011, .041]	.269	.010	[-.009, .030]	.308
	DSB	32	.021	[-.023, .066]	.350	.012	[-.032, .056]	.603
	FCRST	32	.016	[-.005, .037]	.133	.010	[-.012, .033]	.364
	Reaction time[†]	30	.034	[-.058, .126]	.469	.019	[-.073, .112]	.684
	Doors and people (recall)	32	.037	[-.004, .079]	.077	.032	[-.011, .075]	.145
	Doors and people (recognition)	32	.027	[-.016, .070]	.212	.019	[-.025, .063]	.390
	Doors and people (forgetting)	32	-.084	[-.181, .013]	.089	**-.089**	**[-.173, -.005]**	**.039**
	Stroop inhibition[†]	31	.006	[-.014, .027]	.544	.001	[-.019, .022]	.901
	Stroop switching[†]	31	.040	[.005, .074]	.027	**.042**	**[.008, .076]**	**.016**[‡]
Mouse click frequency	ACE III	32	.000	[-.008, .001]	.984	-.003	[-.012, .005]	.452
	ECog[†]	32	.007	[-.000, .015]	.057	.007	[-.000, .016]	.063
	TMT A[†]	32	.007	[-.005, .019]	.233	.007	[-.004, .018]	.237
	TMT B[†]	32	.006	[-.004, .017]	.228	.005	[-.005, .014]	.311
	DSB	32	.002	[-.010, .015]	.699	-.001	[-.011, .009]	.850
	FCRST	32	.000	[-.008, .008]	.936	-.001	[-.007, .005]	.754
	Reaction time[†]	30	-.002	[-.025, .021]	.873	-.006	[-.027, .016]	.619
	Doors and people (recall)	32	.004	[-.009, .016]	.581	.001	[-.008, .010]	.838
	Doors and people (recognition)	32	.004	[-.010, .018]	.541	.002	[-.009, .013]	.729
	Doors and people (forgetting)	32	-.014	[-.036, .009]	.226	**-.020**	**[-.038, -.002]**	**.026**
	Stroop inhibition[†]	31	.007	[-.001, .014]	.077	.005	[-.004, .013]	.256
	Stroop switching[†]	31	.010	[-.004, .023]	.157	.007	[-.006, .019]	.292
Keystroke speed	ACE III	32	.541	[.147, .934]	.007	.292	[-.084, .668]	.129
	ECog[†]	32	.243	[-.082, .569]	.143	.275	[-.033, .583]	.080

TMT A†	32	.475	[-.007, .957]	.053	**.370**	**[.040, .701]**	**.028‡**
TMT B†	32	.537	[-.096, .978]	.017	-.356	[-.069, .780]	.101
DSB	32	.552	[.205, .899]	.002	.359	[-.121, .839]	.142
FCRST	32	.414	[.089, .738]	.013	.264	[-.053, .581]	.103
Reaction time†	30	.136	[-.233, .505]	.470	-.191	[-.558, .177]	.310
Doors and people (recall)	32	.667	[.407, .928]	.000	**.543**	**[.298, .788]**	**.000‡**
Doors and people (recognition)	32	.671	[.434, .908]	.000	**.537**	**[.282, .793]**	**.000‡**
Doors and people (forgetting)	32	.225	[-.016, .467]	.068	.219	[-.090, .528]	.165
Stroop inhibition†	31	.486	[.198, .774]	.001	**.217**	**[.009, .425]**	**.041‡**
Stroop switching†	31	.693	[.349, 1.04]	.000	**.344**	**[.096, .592]**	**.006‡**

Note: §Daily computer use was based only on the days when the computer was accessible and used. *Estimates adjusted for age, years of education and years of computer use experience; †scores were reverse coded for clinical interpretability. Values in bold represent a significant association between the computer use behaviour and cognitive scores ($p < .05$) for the adjusted estimates. ‡Value held significance after false discovery rate (FDR) correction ($Q = .20$).

Longitudinal analysis

No change was detected in any of the computer use behaviours over the course of the study (Table 4). Over the study period, scores on the ACE significantly increased ($p = .041$); recall on the Doors and People Test significantly decreased ($p < .001$); recognition on the Doors and People test significantly increased ($p = .032$); and no change was observed in scores on any of the other cognitive or functional tests. Only the decrease in recall over time on the Doors and People Test remained significant after applying the false discovery rate. As there was no change detected in any of the computer use variables, further analysis of associations between change in computer use behaviour and change in cognitive test scores were not pursued.

Table 4. Multi-level models to assess change in computer use behaviours and cognitive variables over time

Variables		Crude				Adjusted*		
		N	β	95% CI	p value	β	95% CI	*p* value
Computer use behaviours	Daily computer use – every day in the study[§] (mins)	32	-.032	[-.110, .046]	.417	-.032	[-.110, .046]	.417
	Mouse click frequency per day	32	-.002	[-.007, .003]	.440	-.002	[-.007, .003]	.437
	Keystroke speed per day (secs)	32	.000	[-.000, .000]	.104	.000	[-.000, .000]	.109
Cognitive variables	**ACE III**	**32**	.042	[.004, .081]	.033	**.042**	**[.002, .081]**	**.041**
	ECog[†]	32	-.001	[-.005, .004]	.829	-.001	[-.005, .004]	.829
	TMT A[†]	32	.044	[-.082, .169]	.496	.042	[-.086, .170]	.519
	TMT B[†]	32	.046	[-.255, .346]	.765	.041	[-.268, .349]	.796
	DSB	32	-.002	[-.020, .016]	.836	-.002	[-.020, .016]	.816
	FCRST	32	.047	[-.009, .102]	.098	.046	[-.011, .103]	.113
	Reaction time[†]	30	-.015	[-.107, .077]	.753	-.012	[-.107, .082]	.795
	Doors and people (recall)	**32**	-.068	[-.108, -.028]	.001[‡]	**-.069**	**[-.110, -.028]**	**.001**[‡]
	Doors and people (recognition)	**32**	.061	[.007, .115]	.026	**.060**	**[.005, .115]**	**.032**
	Doors and people (forgetting)	32	.003	[-.036, .043]	.867	.002	[-.039, .043]	.910
	Stroop inhibition[†]	31	-.057	[-.198, .084]	.430	-.055	[-.202, .091]	.457
	Stroop switching[†]	31	-.193	[-.419, .034]	.095	-.191	[-.424, .043]	.110

Note: [§]Daily computer use was based on every day that the participant was included in the study, irrespective of accessibility and use. *Estimates adjusted for age, years of education and years of computer use experience; [†]scores were reverse coded for clinical interpretability. Adjusted values in bold represent a significant change over time ($p < .05$). [‡]Value held significance after false discovery rate (FDR) correction ($Q = .20$).

Discussion

The aims of this study were to i) investigate whether passive computer use behaviour could differentiate between individuals with MCI and individuals with SCD ii) examine cross-sectional associations between passive computer use behaviour and cognitive and functional test scores; and iii) investigate the potential of continuously recorded routine home computer-use for examining change in cognitive and functional ability. Cross-sectionally, computer use duration and keystroke speed were able to discriminate between individuals with MCI and individuals with SCD. Computer use duration and keystroke speed were associated with cognitive test scores. No change was detected in any of the computer use behaviours, or with most of the cognitive and functional test scores, over time.

Cross-sectional findings

Keystroke speed

Participants with MCI had slower typing speeds than those with SCD. These findings are consistent with previous work showing a reduction in typing speed with increased cognitive impairment [25, 26]. Crucially, whilst previous studies have shown such effects during semi-directed tasks in a controlled environment, this study has demonstrated that the effects of cognitive impairment on computer use behaviours are also observable for self-directed computer tasks in an uncontrolled home-based setting.

Faster typing speed was associated with better visual attention (as measured by TMT A), recall and recognition (as measured by the Doors and People Test), task inhibition and task switching (as measured by the Stroop) in the current study. The Stroop task, the Doors and People Test recall and recognition scores and TMT A are shown to be sensitive to early stage dementia of the Alzheimer type [44-47], and the task switching version of the Stroop is particularly sensitive to cognitive decline in normal-functioning older adults [48]. In our previous work we found that ACE III and ECog Memory scores were significant predictors of keystroke speed [27]. Taken together, these results suggest that typing speed could be a particularly useful proxy measure of cognitive decline. These findings are in line with our previous work, in which an expert reference group linked errors in typing - and thus

potentially slower alphanumeric typing while correcting errors – with executive functioning [49].

Time spent on the computer

Individuals with MCI spent less time on the computer than individuals with SCD. This decreased use time could be an indication of participants with MCI stopping using the computer when they find tasks difficult or make mistakes; or using the computer less frequently because they have less activities that they need or want to do on the computer. This is consistent with Kaye et al. (2014), who found that people with MCI spent less time on the computer compared with healthy controls. This is different to our previous study that required participants to do a set number of computer tasks in a controlled environment and found that people with MCI and mild AD took longer to complete the tasks and paused more frequently [27]. This could be because in a controlled environment, when given a set task, people with MCI and mild AD persevere even if they find tasks difficult, make more errors and/or lose track of what they are doing, leading them to take longer.

Individuals with stronger task switching abilities also spent more time on the computer. This finding appears to be contradictory to the notion that better cognitive function would lead to quicker computer operation, and thus potentially less time spent on the computer. Nevertheless, we can conjecture that an increased ability to switch between computer tasks could reflect conducting multiple computer tasks at once, and so spending more time on the computer to complete these. In support, Tun and colleagues (2010) observed that increased computer use per week was associated with better task-switching performance [49]. The current study extends these findings by showing a similar pattern of results during non-directed computer use, using a more temporally precise measure.

Mouse clicks

Mouseclick frequency did not differ significantly between the two groups. This differs to the results of Seelye et al. (2015) who observed during non-directed tasks, greater cognitive impairment was associated with fewer mouse moves, however, this was based on *total* mouse moves which is likely to be a reflection of the amount of computer use. Taken together this suggests that these two different types of mouse behaviour are tapping into

different aspects of cognitive function and perhaps, total mouse moves as assessed in Seelye et al. (2015) is more sensitive to cognitive impairment than mouse click frequency as assessed in the current study.

Longitudinal findings

Computer use behaviour did not change over time. This finding partially mirrored the patterns of change in cognitive and functional assessments, for which the only changes were a significant increase in scores on the ACE III and recognition scores on the Doors and People Test and a decrease in recall scores on the Doors and People Test. An increase in ACE III scores and recognition scores on the Doors and People Test may be explained, in part, by familiarity with the test structure and therefore increased confidence: effects that are common with repeated testing [50-53]. However, the decline in recall scores, which remained significant after correcting for false discovery rate, may be indicative of cognitive decline. The lack of similar change on the FCRST recall test, and with the computer use behaviours, could therefore reflect lower sensitivity to this decline. Mitchell (2009) found that conversion rates of MCI to AD dementia was 8.1% per year in specialist clinical settings and 6.8% in community settings. Therefore, given our small sample size and a study period of less than a year, the probability of conversion, as well as the likelihood of detecting it, were low. Therefore, in order to detect change in IADL using self-chosen computer activities, future studies should examine data over a longer period of time and in a larger sample.

Limitations

There are some limitations of the study that need to be considered. First, as the work was exploratory in nature, it was not powered to detect all effects. Thus, whilst the study provides proof of concept for passive monitoring, and can inform the direction of future, larger-scale investigations, the conclusions should be considered preliminary. Second, participants varied in how many days they used their computer. It was not always known whether lack of use reflected practical constraints, such as the computer being borrowed by a partner, or their choice not to use the computer. Future studies could address this by asking why the computer is not used on specific days. Variation in use resulted in considerable number of days where there was no data, which could impact the statistical

power, cause bias in the estimation of parameters, and reduce the representativeness of the sample. A way of overcoming this challenge in the future would be to also monitor mobile devices. This would not only provide digital biomarker data outside of the home, but also inside the home when individuals choose to use a mobile device over a static home computer or laptop. The number of older adults using mobile devices outside the home is relatively low but is quickly increasing. For example, the number of adults over the age of 65 who accessed the internet on a mobile phone or smartphone outside the home increased from 9% in 2013 to 40% in 2019 [55]. Therefore, it will become even more relevant to monitor mobile devices in this age group in the coming years.

Conclusion

In summary, this study demonstrated that, passive monitoring of time spent on the computer and keystroke speed can differentiate between groups with SCD and MCI. What is more, keystroke speed was related to a number of neuropsychological test scores and shows potential as an indicator of a person's cognitive status. Importantly, this is true even though participants were engaging in non-directed computer tasks, where the exact nature of the activity was unknown. The next step is to test these relationships in a larger study sample, over a longer period, to gather a better indication of whether computer use behaviours can capture clinically significant cognitive and/or functional change. It will also be important to develop the SAMS software for touch screen devices such as tablets, smart phones and watches as their use becomes more ubiquitous amongst older adults. We do not expect computer behaviour indicators to be considered as stand-alone substitutes for traditional psychometric tests, but rather to be used as a means to provide information about a person's cognitive status in an ecologically relevant way that could be used as an at-risk indicator, while also supplementing formal cognitive testing.

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Statement of Ethics

The study was approved by the Health Research Authority - National Research Ethics Service England in accordance with the Declaration of Helsinki, and all participants signed informed consent to participate.

Conflict of Interest Statement

The authors have no conflicts of interest to declare.

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Author Contributions

All authors contributed to the design of the study. GS and SC planned and supervised data collection and collected data. GS performed the data analysis and drafted the manuscript. HH provided statistical guidance. LB, DM, SC and IL provided methodological and statistical guidance. All authors critically reviewed and agreed on the submitted manuscript for publication.

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CHAPTER 7: Discussion

7.1. Aims of the thesis

The overarching aim of this PhD was to improve methods of measuring and detecting functional impairment in people with early cognitive decline. A two-pronged approach was utilised to address the challenge: culturally adapting a subjective measure of functional impairment that covered technology-based IADLs (the A-IADL-Q) for use in the UK; and establishing proof of principle for the use of an objective digital biomarker, computer use behaviour, as an indicator of cognitive and functional impairment and decline. The two-pronged approach had two different trade-offs: a low risk approach but with lower potential for big gains and a high risk approach with potential high gains (step change). The cultural adaptation of the A-IADL-Q for the UK was a low risk study. Paper-based and electronic subjective assessment of functional ability are known methods that have the potential to be incrementally improved and this was achieved in this PhD. A novel feasibility study to investigate the potential of assessing computer use behaviours as a proxy measure of cognitive and functional change has a high risk of failure. The longitudinal study of in-home computer use behaviours had a small sample of people with SCD and MCI (n=32), therefore the chance of detecting cognitive decline over a 9 month period was relatively low. In order to mitigate this risk the longitudinal data was analysed in two ways: cross-sectionally and over time. The data was considered cross-sectionally to see if the results from study C (the cross-sectional study where computer use behaviours were semi-directed) could be replicated in study D (the longitudinal study where computer use behaviours were non-directed). This was achieved by exploring associations between computer use behaviours and cognitive and functional test scores, as well as comparing computer use behaviour between people with MCI and people with SCD.

In addressing this aim, the research reported in this thesis contributes to the measurement of functional ability in two different ways. The cultural adaptation provides a subjective measure of functional ability containing items that are technologically and culturally relevant to older adults in the UK. This relevance will be further enhanced by the integration of all new items, once item characteristics are established following additional data collection. Taken together the results from study C and D suggest that assessment of both direct and indirect computer activities can detect cognitive and functional ability and

differentiate between groups. This novel digital biomarker offers the potential for early detection of neurodegeneration in the home-setting.

7.2. Summary of findings

The cultural adaptation of the A-IADL-Q (study A: chapter 3) aimed to provide an improved IADL measurement for the UK and, in particular, to provide a questionnaire that captures activities that are both conceptually relevant to older adults in the UK and appropriate for a technologically advancing society. Items from the original A-IADL-Q were removed, added to, and amended following a review process with dementia professionals, and people with cognitive decline and their relatives, and based on the results from a questionnaire measuring item relevance, completed by older adults. This resulted in a 55-item adapted version appropriate for UK use (A-IADL-Q-UK). Pilot data revealed that the new and revised items performed well: at least half of the participants had completed each activity in the previous four weeks. All activities were perceived as either slightly more, more, or much more, difficult than they have been in the past by at least one participant per item. “Making a cup of tea or coffee” and “using keys” were the most frequently performed activities, suggesting that these are routine activities for older adults in the UK. “Using the grill” and “looking after family” were performed least frequently. Four new items (“completing household paperwork”, “recording a television program”, “reading”, and “maintaining the garden”) correlated with the weighted average score, indicating that these items are consistent with the overall construct. An exploratory analysis of convergent validity found correlations in the expected direction with cognitive and functional measures: these were significant for DSB and ECog and nonsignificant for ACE III and TMT B. In sum, the results of this study suggest that the A-IADL-Q-UK shows promise it terms of its levels of face and content validity, convergent validity and the internal consistency reliability of new items.

In the pilot study (study B: chapter 4), the feasibility and acceptability of the procedure and design for studies C (the cross-sectional study of semi-directed computer use, reported in chapter 5) and D (the longitudinal study of non-directed computer use behaviours in participants’ own homes, reported in chapter 6) were tested. The results from the pilot study suggested that study C was feasible and study D was acceptable, and also led to some key modifications to the design of both studies. Specifically, participants found the study C computer-based tasks straightforward, as evidenced by all participants completing all of the

tasks. Difficulties completing tasks were mainly due to different operating systems and software applications, resulting in difficulty finding specific functions. In order to eliminate the potentially confounding effect of system familiarity, we decided to use two operating systems Windows 7 and Windows 8 for study C. This meant that users of both types of operating system could be recruited, and participants could complete the tasks on a system they felt more comfortable with. To alleviate difficulty when using unfamiliar software two main changes were made to study C. Firstly, the participant instructions were amended to improve the clarity of the task instructions; and secondly, the practice activities were repeated to allow participants to become more comfortable with unfamiliar applications. Participants' were generally positive about having their daily computer use recorded as a proxy measure of cognitive health and all participants stated they would be willing to take part in such a study. Some participants expressed concerns about the software recording financial transactions or other people's data on their computer. These concerns were addressed in the main study (study D) by providing information to participants about how data would be recorded and protected and by changing the design of the software to limit the data capture on secure websites.

The cross-sectional reliability and proof of concept study (study C: chapter 5), which compared semi-directed computer tasks and cognitive and functional assessments, found that a selection of computer-use behaviours recorded from semi-structured tasks can discriminate between people with MCI and mild AD and cognitively healthy controls. Compared with the control group, cognitively impaired participants paused more frequently per minute, made fewer "Text" keystrokes per minute, and executed a significantly greater number of mouse clicks. A number of significant correlations were found between these computer use behaviours and each of the cognitive and functional measures, but only the memory domain of the ACE III and the ECog were significantly correlated with all three of the computer use variables. The three computer use variables were explored in relation to the memory domain of the ACE III and ECog in more detail, using hierarchical regression analyses. ACE-III and ECog Memory scores were significant predictors of total mouse clicks, pauses per minute and keyboard typing speed, with age and computer-use experience also accounting for variability in keyboard typing speed behaviour. The ROC analyses showed that, when all the selected computer use variables were combined into a single predictive

probability and compared with combined ACE-III Memory score, ECog Memory score, and Trail Making Test B, correct classification was significantly higher for the combined computer use variables. The findings of this study therefore suggest that a combine profile of computer use behaviours has potential to provide information that is sensitive to cognitive and functional decline in the early stages of neurodegeneration.

The longitudinal study (study D: chapter 6) explored the potential of passively recording in-home, non-directed computer use as a proxy measure of cognitive and functional decline. There were three aims: i) to investigate whether passive computer use behaviour could differentiate between individuals with MCI and individuals with SCD; ii) to examine cross-sectional associations between passive computer use behaviour and cognitive and functional test scores; and iii) to explore change over time in passive computer use and cognitive and functional test scores. Individuals with MCI had significantly slower keystroke speed and spent less time on the computer than individuals with SCD, even after controlling for age, years of education and computer use experience. Cross-sectionally, more time spent on the computer was associated with greater task switching abilities. Faster keystroke speed was associated with better visual attention, recall, recognition, task inhibition and task switching. Computer use behaviour did not change over time. This finding partially mirrored the patterns of change in cognitive and functional assessments, for which the only changes were a significant increase in scores on the ACE III and recognition scores on the Doors and People Test and a decrease in recall scores on the Doors and People Test. An increase in ACE III scores and recognition scores on the Doors and People Test may be explained, in part, by familiarity with the test structure and therefore increased confidence: effects that are common with repeated testing (Basso et al., 2002; Duff et al., 2001; Goldberg et al., 2015; Watson et al., 1994). However, the decline in recall scores, which remained significant after correcting for false discovery rate, may be indicative of cognitive decline. The lack of similar change on the FCRST recall test, and with the computer use behaviours, could therefore reflect lower sensitivity to this decline. Taken together, the results of this study suggest that passive monitoring of keystroke speed shows potential as an indicator of a person's cognitive status, and time spent on the computer and keystroke speed can differentiate between groups with SCD and MCI.

7.3. Contributions of the thesis

The research reported in this thesis has made a number of key contributions to knowledge that are outlined below.

7.3.1. Improved methods for measuring functional capacity.

A key contribution of the research reported in this thesis is an improvement of methods for measuring functional capacity. This is through 1) the development of the A-IADL-UK using a detailed and thorough process for assessing face and content validity, that includes culturally and conceptually relevant activities, including technology-use, and provides a self-report version and 2) by establishing proof of concept for a novel digital biomarker for the unobtrusive capture of computer use activities that has the potential to indicate cognitive status.

There are three groups of issues associated with current IADL measures that have been addressed in the research reported in this thesis. The first group of issues relate to the limitations of current questionnaires. Many assessments are used to assess IADL in people with MCI, but they have most often been constructed and validated for people with dementia and therefore may not be sensitive to more subtle changes in complex daily activities (Jekel et al., 2015). Some existing methods have not been thoroughly assessed for face and content validity (Sikkes et al., 2009), which is an important psychometric property. Activities contained in assessment measures are not always considered conceptually relevant by patients and carers (Hartry et al., 2018) and relatively few assessments of content validity utilize the knowledge and expertise of patients and caregivers, which often solely relies on the judgement of clinicians (Connell, 2018). Many measures also do not take account of technological advances that have changed the way that many IADLs are done. Also, individuals may not have someone who can act an informant, and there are only a small number of self-report options (Jekel et al., 2015).

The work reported in this thesis addressed this first group of issues by providing the A-IADL-Q-UK, a measurement of functional decline for use in the UK that captures culturally relevant activities, including those that capture technology use, and a new self-report version that is ready for testing. This built on previous literature by conducting a thorough process of establishing content validity, as reflected in the use of a sampling to redundancy

methodology in step one which meant that all suggestions from participants were considered in detail until no new information emerged. The views and opinions of people with mild cognitive impairment and their relatives were utilised to ensure that activities were meaningful to their daily lives. The A-IADL-Q-UK contributes a meaningful outcome measure that can be used in clinic and research settings and a self-report measure that is ready for further testing.

The second group of issues relates to the current episodic and clinic-based paradigm which means that functional assessments are not carried out soon enough, or often enough, and cannot pick up on subtle, insidious change in functional ability over time. This second group of issues was addressed in the research reported in this thesis by establishing a proof of concept for a novel digital biomarker, which unobtrusively captures computer use behaviours for the detection of cognitive and functional decline. This provides a basis from which to develop new methods of functional assessment that can provide ecologically valid, continuous and unobtrusive data. This addresses the current reliance on clinic-based, intermittent assessments, which depend on snapshots of information about a person and are often infrequent and insensitive to subtle change over time.

The third group of issues relates to the methodology used in previous studies to investigate relationships between computer use behaviour and cognitive functioning. Whilst previous studies have shown that computer use behaviours can provide information about cognitive functioning, they have been limited by the inclusion of novice or non-computer users in the participant sample (Kaye et al., 2014; Seelye et al., 2018; Vizer and Sears, 2015), which may limit the interpretation of findings due to the additional cognitive burden of learning to use a computer for the purposes of the study. Previous studies have also focussed on set tasks, such as an online survey via email (Seelye et al., 2018) or a typed text task (Vizer and Sears, 2015), rather than non-directed computer use behaviour, which may limit the ecological validity of the findings. The research reported in this thesis has built on previous literature by addressing these limitations. In studies C and D regular computer users were recruited, this means that when interpreting the results you can be more certain that any limitations are typical behaviour as oppose to difficulties with a new learned skill. In study C participants completed computer tasks using software they were already familiar with and in study D participants used their own computer equipment in their own home environment

and we recorded their everyday 'normal' computer use activities. This highlights a major strength of the work reported in this thesis, particularly from study D, in that these computer use behaviours can predict cognitive functioning despite variability in the types of hardware and software used and the home environment, and with no knowledge of what participants were doing during non-directed tasks.

In sum, the outcomes of the research reported in this thesis begin to address recent recommendations from the FDA, which emphasise the need for meaningful outcome measures and novel assessment measures for the detection of the earliest signs of cognitive and functional decline (Edgar et al., 2019). The findings from all four studies in this thesis have advanced the methods for assessing functional ability. The A-IADL-Q-UK represents a more traditional IADL assessment and the measurement of computer use behaviours is a novel method of assessment. The benefit of advancing both traditional and novel methods is that they can complement each other. Information from continuous assessment in the home can supplement clinic-based assessments such as the A-IADL-Q-UK and likewise an indication of functional decline from the A-IADL-Q-UK could be monitored in the home using software to record computer use behaviour.

7.3.2. Established proof of concept for continuous and unobtrusive recording of everyday home computer use behaviours as a proxy measure of cognitive health.

Previous studies have shown that computer use behaviours can be indicative of cognitive status. Some of these studies have reduced ecological validity because they have been conducted in controlled settings (Vizer and Sears, 2015) and/or have used set tasks (Seelye et al., 2018). Also, there is limited information on how participants feel about having computer monitoring software installed on their personal computers. In the research reported in this thesis, data was collected in an ecologically relevant way: in participants own homes, as part of their normal routine. In the pilot study, the feasibility of completing set tasks on a computer was demonstrated and the acceptability of installing computer recording software installed on people's home equipment was established. Participants felt that any concerns they may have about privacy and security could be addressed by providing sufficient study information. In studies C and D, the information from the pilot was used to ensure that participant information was clear and detailed in regard to privacy and security of data collected, and that participants were given the opportunity to discuss

any concerns and ask questions. Study D demonstrated the feasibility of installing software onto participants' home computers, and recording personal computer use for a period of 7 to 9 months. No participants dropped out of the study, and all home visits were completed, suggesting that the software and the study were acceptable to participants for the duration of the study period.

The results from this PhD have strong ecological validity: everyday computer use was recorded on participants' own equipment, in their own homes, where the exact nature of the activities undertaken were unknown. This has demonstrated that non-directed computer use behaviour can provide information about cognitive status and differentiate between groups of varying cognitive ability. These results are novel in that no other studies have been conducted that compare keystroke speed taken from uncontrolled home computer use with cognitive functioning.

7.3.3. Increased understanding of: the relationship between computer use, cognitive function, and functional ability; and the differences in computer use behaviours between groups who differ in cognitive ability.

Previous studies that have considered the relationship between computer use and cognitive and functional ability have a number of limitations. Firstly, studies looking at time spent on the computer and keystroke behaviours have focused on between subjects designs; looking at differences in computer use behaviours between high and low functioning groups (Kaye et al., 2014; Vizer and Sears, 2015). This is problematic because older adults' computer experience is variable both between and within individuals, so a system for monitoring change in computer use ability needs to adapt to each user (Vizer and Sears, 2015). Secondly, previous research has found differences between healthy controls and people with MCI but has not considered more subtle differences, such as those between people with MCI and SCD. Thirdly, the relationship between computer use behaviours and paper-based IADL measures has not been fully explored. Finally, previous research has focused on individual computer use behaviours such as online survey metadata (Seelye et al., 2018), time spent on the computer (Kaye et al., 2014) and mouse movements (Seelye et al., 2015) rather than considering a range of different behaviours. This is problematic because decline in performance of computer-based activities is likely to vary among individuals; therefore, capturing a range of behaviours will significantly increase the likelihood of early detection.

Vizer and Sears (2015) built a model using both linguistic and keystroke features, however this was limited to the keyboard interaction modality and was conducted in a controlled setting.

In the current research, a between subjects design was used to demonstrate differences in computer use behaviours between groups of people, and a within subjects design was used to investigate relationships between computer use and cognitive and functional ability in a single group. The use of a within group design is particularly important in this type of research because individual differences in computer use ability and experience is vast, and computer performance variability is high both between and within older adults (Fazeli et al., 2013), so information about intra-individual change is advantageous. This will help with the future design of an adaptive system that can screen for changes associated with SCD or MCI for specific individuals, and alert the user to trends that they may wish to discuss with their doctor.

This research also explores the differences in computer use behaviours between SCD and MCI groups who have subtle differences in cognitive ability. In study D, people with MCI spent less time on the computer and had slower keystroke speed compared to people with SCD. This suggests that recording computer use behaviours can enable us to detect subtle differences between cognitively impaired groups. Looking at subtle differences between people with SCD and MCI builds on previous research that has focused on groups with larger cognitive impairment differences such as healthy controls and people with MCI (Kaye et al., 2014; Seelye et al., 2015; Seelye et al., 2018).

Studies C and D also addressed a lack of research investigating the relationships between computer use behaviours and paper-based IADL measures. In study C, number of pauses per minute, keystroke speed and total mouse clicks were related to the memory domain of the ECog. In study D, no relationship was found between computer use data and the ECog. This is congruent with the work of Seelye (2018), which found no association between online survey metrics and an informant-rated IADL questionnaire. One interpretation of these conflicting results is that computer use behaviours recorded in a controlled environment (study C) could be more reflective of scores on functional tests compared to computer behaviours recorded in a home environment (study D and (Seelye et al., 2018). The next step would be to test the relationship between computer use behaviours and functional

ability using the A-IADL-Q-UK to see if a different measure that includes activities about technology, would be more sensitive to computer use behaviours.

The findings from studies C and D provide a clearer understanding of the utility of computer use behaviours for the assessment of cognitive and functional ability. In study C a combined profile of computer-use behaviours distinguished between groups of varying cognitive ability. Consistent with previous findings, in study C and study D participant groups differed on computer activity measures of time (Kaye et al., 2014) and keystrokes (Vizer and Sears, 2015) and in study C they differed on mouse operations (Seelye et al., 2015). Furthermore, the keystroke speed findings from study C using set tasks and controlled equipment were corroborated in study D using participant's home equipment and where the exact nature of the computer use activities were unknown. The results reported in this thesis therefore demonstrate that keystroke speed is indicative of cognitive health status in both a semi-controlled and uncontrolled environment. This is important because it adds reliability and validity to the findings from both studies and important opportunities for future application.

The results for keystroke speed are also in line with assessments finger dexterity, finger tapping and motor speed. In a study of finger dexterity, Suzumura and colleagues (2018) found differences between healthy controls and people with AD and people with AD and people with MCI. Finger tapping research has shown much slower reaction speed in subjects with lower MMSE scores (Rabinowitz and Lavner, 2014). Austin and colleagues (2011) found that interkeystroke interval based on repeated login data collected during regular home computer use has capabilities similar to the finger tapping test for assessing motor speed. These results indicate the potential for high frequency data collection from daily computer keyboard use (Kourtis et al., 2019).

7.4. Strengths and limitations of the thesis

Participants with MCI and AD were included in the thesis studies based on their existing diagnosis, and were not reassessed for dementia or MCI at part of the study. One limitation of this is that the diagnosis may have no longer been accurate or valid. This might also have implications for the other groups as some of the apparently cognitive healthy people may have had MCI or dementia. This could make it harder to find differences between groups, because there might be overlap between the groups in terms of cognitive status.

Consequently, any differences between groups could be underestimates of the actually differences.

As proof of principle studies, the sample sizes were small for studies C and D, as well as in step three of study A. The reason that small sample sizes was acceptable in these studies was because the work for studies C and D was preliminary, and aimed to establish proof of concept. Step 3 of study A was a pilot study for a future large scale validation of the A-IADL-Q-UK. By design, these studies were not intended to have powered samples, as the conclusions drawn from these investigations should not be generalised to larger samples and, instead, are meant to give important insight and direction for how future work should proceed. However, small sample sizes do have a number of implications for these findings. They may have limited the power to detect associations and particularly to detect differences between groups, which means that smaller differences between groups could have been missed and other behaviours might not have been flagged up as being discriminatory. Furthermore, in order to abide by the assumptions of regressions and multi-level models, it was only possible to control for a small number of variables such as age and computer use experience. This means that there could be other confounding factors that could account for the effects. Additionally, although in this work extraneous variables such as age, computer use experience, and education were controlled for, years of computer use experience was based on grouped options and could have been considered in more detail. Computer fluency may be especially important as there could be significant differences in computer use not due to cognitive decline but due to familiarity and exposure to the computer (Austin et al., 2017; van Boekel et al., 2017). To address this, computer use experience should be explored in more detail by considering specific training, employment experience and range of digital devices used.

Despite the potential limitations arising from these small sample sizes, where possible, sample sizes were optimised for the research. For example, the sample size for step one of study A was based on a sampling to redundancy criterion, whereby participants were included until no new themes emerged. This is a strength of the work as it contributed to a detailed and thorough process for assessing face and content validity. This means we are likely to have identified the majority of issues or missing items from that specific sample population. In addition, in step two of study A, of the 140 questionnaires distributed, 92

(65.7%) were returned, representing a high response rate for a postal survey (Link and Mokdad, 2005). This means that of the people recruited there is less likely to be bias and the results are likely to be more representative of the sample who was recruited.

Another issue with the studies reported in this thesis is that the majority of participants were recruited from the Greater Manchester area of the UK. Proximity of participants was an important factor in recruitment as all of the studies involved visits to participant's homes. One limitation of this is that the studies have a low geographical reach. In addition, for all the studies, participants were primarily white, well-educated and relatively healthy older adults, therefore the results may not generalize to other populations. This has specific implications for the study A, given its aims around cultural applicability. The cross-cultural validation was important because mere translation of an instrument does not always account for cultural and ethno racial disparities. Frequently used IADL instruments often include culturally specific activities such as balancing a cheque book: an activity that is only relevant to people who do not use direct bank transfers or mobile banking (Dubbelman, 2019). We found that activities such as using a coffee maker and a dishwasher were not common practice amongst current older adults in the UK, and therefore amending or removing these items enhances the validity of the measure for a UK audience. However, in order for the A-IADL-UK to be fully validated for use in the UK there must be further testing across different geographical locations and cultural groups. Williams et al. (2012) found that in the UK, Indian Asian participants reported significantly greater IADL impairment compared with Europeans, even after controlling for health behaviours and chronic disease.

In this PhD, all four studies included people who were regular computer users. As a consequence, people without access to computers regularly were excluded from sections of this work. One justification of this approach is we can be more certain when interpreting the results, that computer use behaviours represent an existing skill rather than a new skill. However, the exclusion of specific groups of people, who may be disadvantaged in their access to information and communications technology, has implications for this research. There is a digital divide in the UK between those who have access to information and communications technology and those who do not, which in turn leads to inequalities in access to opportunities, knowledge, services and goods. Digital divides are likely to exist where people do not have (1) access to appropriate equipment, (2) appropriate skills and

capabilities, and (3) motivation from the 'pull' of compelling functionality and content (Damodaran et al., 2013). The Office for National Statistics report that, in 2019, patterns of internet usage vary by geographical location, gender, age, disability, ethnic group and economic activity (Office for National Statistics, 2019a). A reduction in older adult's use of the computer could also be explained by the digital divide. Olphert and Damodaran (2013) suggest that older adults who were computer users, but have then stopped, could be part of a 'fourth digital divide'. In a review of the literature they find that reasons for non-sustaining use include: disability, complexity of the technology, social isolation, lower income, lower education and irrelevant/inappropriate content. Taken together, this means that socially disadvantaged or marginalised groups could have been excluded from the research. Future studies investigating the relationship between computer use behaviours and cognitive functioning in a larger sample, need to ensure that people from socially disadvantaged groups are given the opportunity to take part in the work and that any analysis controls for these potential confounding variables.

A strength of study A is that it has contributed to the ways in which functional ability can be measured and monitored and more specifically whether people are able to use technology. In doing so this work can assess whether older adults are engaging with the technical world and check if they are maintaining their digital skills. If support can be provided to maintain independence, this will enable older adults to connect with others, access information and services and meet the demands of the workplace and the economy.

Using time spent on the computer as a measure of cognitive and functional ability is limited because it lacks specificity when the nature of the tasks being undertaken is unknown. In study C this was not a problem because all participants were completing the same semi-structured tasks. However, in Study D time spent on the computer was based on participants' own personal computer use and was defined as a period of activity on the computer (i.e. mouse moves, clicks, and keystrokes) with a pause of no longer than fifteen minutes. What the participant was doing during this time will have differed between participants in a variety of ways, including the tasks cognitive difficulty and whether it was one task or numerous tasks. The computer could have been used for a couple of minutes every fifteen minutes or continuously for an hour. The reliability and specificity of this measure is problematic because we do not know whether they are spending longer on

something because it is difficult, because they are making mistakes or because they enjoy it and are proficient at it. We also do not know if the behaviour being captured represents lots of short tasks with breaks or one long continuous task. In future work, consideration could be given to the way time spent on the computer is calculated and measured, for example the amount of time spent on specific tasks.

Using mouse clicks is also limited as a measure of cognitive and functional ability, when the nature of the tasks being undertaken is unknown. The measure of mouse clicks may be more effective in Study C than in Study D because the frequency of mouse clicks is strongly tied to the purpose for which someone is using the mouse. Certain activities like computer games or online shopping would involve a greater number of mouse clicks than others like reading online articles or replying to emails. Also, making mistakes could lead to more mouse clicks, but also being proficient at something like a computer game would also result in a greater number of clicks. Lack of inhibitory control could also be an explanation for increased numbers of mouse clicks (Leontyev and Yamauchi, 2019; Migliaccio et al., 2020). However, without knowing more about the nature of the task and the number of clicks associated with each task it is difficult to specify how this relates to cognition. In Study C all participants completed the same set tasks and therefore the number of mouse clicks needed for each participant would be more consistent. Of course this is not exact as people have different styles in the way they use the computer, for example the use of keyboard shortcuts. In Study D because the activity was unknown the measure of mouse clicks lacks specificity and the comparison between the two groups is more problematic. Taken together, this means that mouse clicks may be a more effective measure of cognitive and functional ability when the nature of the tasks being undertaken is known. This might explain in study D the lack of an association between mouse clicks and cognitive and functional ability, and why there was no significant difference in mouse clicks between the two groups.

Keystrokes was a particularly effective and specific measure in both study C and study D. In study C it was possible to measure keystroke speed on directed tasks. In study D, where the nature of the tasks were unknown, it was still possible to add parameters to the variable in order to focus on ‘bursts’ of keystroke activity so that keystroke speed could be measured across bursts. This is a strength of this work because it was possible to investigate keystroke

speed in both a semi-controlled and uncontrolled environment, finding significant differences between groups of varying cognitive ability and also associations with specific cognitive test scores.

One issue with keystroke speed as a measure, is that it could be poorer motor skills, rather than cognitive decline, that account for slower keystroke speed in people with MCI compared to those with SCI. Motor skills can decline without neurodegeneration (Carmeli et al., 2003; Seidler et al., 2010) and motor slowing, for example due to arthritis (Liphardt et al., 2020), could explain motor skill changes in someone who is otherwise healthy. To control for motor functioning a measure of 'pure' motor functioning (e.g. finger tapping) could be added to any future test development. The ultimate aim of this work was not to identify what a reduction in keystroke speed means in terms of domains affected by neurodegeneration. Studies C and D were a first step in investigating whether computer use behaviours have meaningful predictive potential for detecting clinical manifestations of neurodegeneration. As this work is extended, research considering subtle differences in motor function, such as dexterity, as a result of neurodegeneration (de Paula et al., 2016; Hesseberg et al., 2020; Mancioppi et al., 2020), should be considered in more detail in relation to computer use behaviours.

7.5. Ethical considerations

There are a number of ethical concerns when collecting large amounts of data passively via home-based software, as in studies C and D. Ethical issues include privacy and data sharing policies, informed consent, and ownership of data (Gold et al., 2018). Ethical concerns were addressed in the studies reported in this thesis in a number of ways.

Given that participant personal computer use was to be recorded by the SAMS software, participants' privacy was a priority in this work. In the pilot study, participants expressed that privacy was one of their main concerns. Participants explained that their concerns about privacy would be alleviated with information about the use and protection of data. This information was used to make changes to the larger studies. First, in order to protect participants' privacy and their personal information, the SAMS system was designed so that passwords would not be recorded and alpha numeric information was not recorded when secure websites were in use. Second, the SAMS system could be turned off when the

participant wished to work privately. Third, participant information sheets were designed to provide clear and detailed information about how data would be used by the researchers and how it would be protected.

A number of measures were put in place to protect participant data. Study participants were assigned unique ID numbers that were used to pseudonymise any written, electronic documents, audio files or data sets. The ID number/user identity key was stored on a secured and encrypted computer with security clearance approved by NHS ethics and only specific members of the research team were able to access these computers. All data collected was automatically encrypted with full-strength encryption software at the point of capture. Periodically, the encrypted data was uploaded to a secure server restricted to the research team. Data derived from all datasets were encrypted for storage, analysis and transit with full strength security algorithms. The intention for the future is that the SAMS system will collect and analyse data automatically. This will mean the data will become more content free and context irrelevant, and will result in increased privacy for participants and users.

Consideration was also given to a range of issues related to informed consent. In the studies undertaken for this thesis, careful but tactful checks were made to establish capacity to consent. This was in line with the basic components for informed consent described by Petrini (2010): 'competence' which refers to the legal and cognitive capacity to make decisions; 'voluntariness' which would mean not having been forced to make a decision; 'information' which means having clear information which covers the risks, benefits and alternatives; and 'enrolment' which refers to the free decision to participate in the study and an understanding that they can withdraw at any time without justification or negative repercussions (Petrini, 2010: p.412) and guidance from the Mental Capacity Act (2005) with regards to research with potential vulnerable adults (Department of Health, 2005). These checks were undertaken by the research staff, who were all fully trained in capacity assessments in people with cognitive impairment, and have significant experience in undertaking research studies with this population. It was also important to consider the possibility of decline or loss of consent capacity. This was particularly important for study D due to its longitudinal nature because, although decline in consent capacity is a relatively slow process in people with MCI (Okonkwo et al., 2008), there is a risk that participants

could lose capacity to consent during the study. To address this, in study D when the researchers visited participants' homes, at the 3 times during the 7 to 9 month duration, they would check participants' capacity to consent to the study. In addition participants received a telephone call every month checking they were happy to continue. However, the issue with on-going assessments of capacity is that they are time and resource intensive, something which the development of digital biomarkers is aiming to reduce. In the future, following further development, the SAMS software could be installed onto older adults' home computers to monitor cognitive and functional ability for longer periods without the need for interaction with a clinician or researcher. A potential concern with this would be if the individual lost the capacity to consent to having their personal computer data recorded. Therefore consideration would need to be given to how capacity to consent could be checked remotely. One potential way to address this would be develop an online tool for assessing capacity to consent.

As described in the previous paragraph, if in the future the SAMS software could assess computer use behaviours over long periods of time, without the need for a clinician or researcher, it could be possible that the participant could forget they are in the study, and that there data is being recorded. This could be addressed by implementing a system of regular reminders to let the user know when the software is recording and how they can turn the system off.

Finally, another ethical consideration of this work relates to data ownership i.e. who owns the data; how the data should be shared; and who is ultimately accountable (Kostkova, 2015). Failure to address concerns over ownership of data can lead to a loss of patient and citizen trust and patients withdrawing their co-operation from data collection and sharing activities. Therefore, in order to overcome potential barriers in regard to ownership of data, and to ensure that people trust the purposes of sharing their data, careful thought and consideration is required when communicating with patients and participants. For the studies reported in this thesis, considerations relating to data ownership were addressed in a number of ways. Firstly, participants' concerns about how data would be used were identified and addressed. In the pilot (study B), participants explained that they would want sufficient information about the how data was to be used when making a decision about taking part. These findings were used to inform the materials provided to, and discussion

with, potential participants for the larger studies to ensure that appropriate information was provided about how data would be used and shared. Secondly, the purpose and potential benefits of the research were clearly explained to potential participants. Support of technologies and the sharing of data are more likely when there is a demonstrable benefit to patients and health and social care (Watts, 2019). Participants in the pilot expressed how they were happy to be part of something that would help others and contribute to medical research. In future work, in order to protect both the researcher and the participants, data use agreements could be produced that contain clear statements regarding the conditions for data usage (Coravos et al., 2019). It may also be important for these agreements to be time-limited, requiring further agreement periodically so that people can reassess their involvement.

7.6. Recommendations for future research

The cultural adaptation of the A-IADL-Q was a first step in validating the scale for use in the UK. To further develop this work I suggest five future directions. First, a further validation of the A-IADL-Q-UK using a larger sample. This will allow for a comprehensive demonstration of construct validity, more data to enable the development of item characteristics for the new items, and the development of a short version of the questionnaire in line with the existing Dutch short version (Jutten et al., 2017). This would also allow for further testing across different geographical locations and cultural groups (as discussed in 7.4). Second, future work should investigate predictive validity of the A-IADL-Q-UK. Comparing scores on the measure with observations of daily activities in the home would assess the extent to which the A-IADL-Q-UK can predict a person's ability to function in the real world. Third, a longitudinal study that included individuals with AD, MCI, SCD and healthy controls could explore the sensitivity to change over time of the A-IADL-Q-UK, alongside its ability to distinguish between cognitively impaired groups. Fourth, a strength of the cultural adaptation was the detailed and thorough process for assessing face and content validity and the use of a range of stakeholders, including people with cognitive impairment. With further development, this methodology could be presented as a guiding framework for the cultural adaptation of other subjective assessment scales. Lastly, the new item 'looking after family' was not significantly related to total score and was performed least frequently by participants. However, participants who had this responsibility expressed the importance

of this activity in their lives, which is why it was retained in the questionnaire. To address this it would useful to complete a principal component analysis of the questionnaire in a larger sample in order to determine whether there are any sub-components within it.

The next step for studies C and D should be a longitudinal study over at least a one year period in a large sample of participants with presymptomatic AD across the UK to definitively characterise change in computer use behaviour as a proxy measure of cognitive and functional ability. This would involve developing the SAMS software so it could be automatically downloaded by participants onto their home computers. The NIA-AA research framework emphasises the need for biomarker based diagnosis to enable a more accurate characterization and understanding of the sequence of events that lead to cognitive impairment that is associated with AD (Jack et al., 2018). Therefore, a future longitudinal study would benefit from the addition of using biological biomarkers to grade disease severity based on the ATN classification system (Jack et al., 2016). This would then allow for an investigation of the relationship between information from digital biomarkers (computer use) and disease severity as measured by biological biomarkers, including whether information about computer use behaviour can be used to differentiate between different biological biomarker profiles.

The addition of machine learning (ML) techniques could improve the way that data collected by the SAMS software could be analysed in the future. Evaluating the feasibility of a computer based assessment for functional impairment was a first step in establishing proof of concept and the type of data collected as part of this PhD, shown to be associated with cognitive test scores, could provide a firm basis for the developmental of digital tools for monitoring cognitive health. However, a general limitation of using continuous, high-frequency behavioural data is that processing, analysing and distilling very large amounts of data into meaningful measures are time and resource intensive. To address this further improvements are needed in the computer software and the analysis of the data so that data from a large sample of participants can be analysed automatically. A potential method for this would be using ML algorithms to mine the data and allow for further analysis. Adding ML expertise to the research team could mean the application of ML to draw automatic classifiers of cognitive and functional change from the data set. Recent developments in ML techniques for the detecting risk of conversion to dementia in cognitive

aging are showing great potential (Facal et al., 2019; Pellegrini et al., 2018; Spasov et al., 2019) but further advancements in the field are necessary in order for ML to become an integrated part of dementia assessment (Pellegrini et al., 2018). Text mining could also be used to analyse text data that was captured by the SAMS software. For example the linguistic features used in emails, word documents and internet searches provided a vast amount of data that could be analysed using text mining techniques. Exploring the linguistics features drawn from everyday uncontrolled typing tasks would be an extension of previous work that has focused on controlled typing tasks (Vizer and Sears, 2015).

Studies C and D should also be developed in different countries and cultures in order to account for the potentially different cultural nuances. There are a number of potential cultural factors that could be considered when assessing computer use behaviours in other countries. Firstly, differences in language, which would impact on linguistic predictors of cognitive and functional ability (Wijaythilake et al., 2019). Secondly, cultural differences in computer use behaviours, computer use habits and attitudes to computer use (Ein-Dor and Segev, 1990; Graff et al., 2004; Igbaria and Zviran, 1991; Li and Kirkup, 2007; Sensales and Greenfield, 1995). Thirdly, researchers must spend time building rapport and trust with participants (Liamputtong, 2008), different cultures may have different levels of trust in relation to the use of technology (Kim, 2008; Lee et al., 2013) and more specifically when it comes to having software installed on their personal computers, and therefore time for trust building must be built into future work.

Enhanced activities of daily living (EADLs) could be considered for future revised versions of the A-IADL-Q-UK and in relation to the assessment of computer use behaviours. EADLs have been defined as activities that involve new learning, hobbies and social engagement (Rogers et al., 1998). It would also be interesting to consider the sensitivity of EADL activities to functional impairment compared with more general IADL activities. A number of questions in the A-IADL-Q-UK could come under the category of EADL such as “Did they use a mobile phone?” and “Did they pay card or board games?” The concept of EADL and new learning might also have been helpful when developing the question “Did they use new technology?” This question was removed due to confusion about what it meant, but perhaps needs to be reconsidered in future revisions. One way of doing this would be to focus on new learning by asking “Did they learn to use new technology?” Furthermore, it would be useful in future

revisions of the questionnaire to consider activities that fall under the category of EADL, this could open up inclusion criteria for new activities that were suggested but discounted in the cultural adaptation because they were either not considered a cognitive task (i.e. “Did they exercise?”) or considered to be more of a social task (i.e. “Did they socialise?”). With respect to assessment of computer use behaviours, future work could consider variations in computer use behaviours when engaging with EADL activities, for example mouse clicks when playing an online game or differences in time spent on social media platforms or video communication applications.

An important consideration for a study involving technology is the need for future proofing. We must plan for the next digital generation, but we do not know what that is going to be, although we do have some very clear indictors. The SAMS software was designed to be used on computers and the computer predictors are duration of use, keystrokes and mouse clicks. In recent years however, there has been a move from the use of computers to mobile devices. For example, recent statistics about internet usage show that in 2016 mobile and tablet internet usage (51.3%) exceeded desktop computers (48.7%) for the first time worldwide (StatCounter, 2016). In addition, technology is also changing in relation to keyboard and mouse. Potential replacements for the traditional keyboard and mouse include voice control, iris tracking technology and gesture interface (Chatterjee et al., 2015; Deng et al., 2017; Nonaka, 2003). One example of such replacements that are already being used in people’s homes includes intelligent personal assistants (IPAs) such as Amazon’s Alexa. IPA’s perform personal tasks such as managing calendar events, creating to-do lists and providing weather information (Ford and Palmer, 2019). Not only could these types of devices take over traditional methods for interacting with computers, they are also designed with the management of daily activities in mind and could be very useful technology for supporting older generations with IADL. Therefore, the SAMS software will need to be developed for use on mobile devices and will need to consider voice control as a potential computer predictor. With such technological developments in mind, changes will also need to be made to the A-IADL-UK so that the activities are up to date, for example the inclusion of questions about tablets, smart watches and IPAs.

7.7. Implications for healthcare, policy and practice

The growth of technology for improving health and well-being (mHealth) provides an unprecedented opportunity to transform the healthcare sector and empower citizens in taking charge of their own health (Kostkova, 2015). The outcomes of the research reported in this thesis offer practical and relevant solutions for the assessment of functional capacity for clinicians, researchers and patients now and in the future. The A-IADL-Q-UK provides a subjective assessment of IADL, which includes activities that are meaningful for older adults in the UK and includes modern day activities such as mobile phone and internet use. This will give the clinician, researcher and patients a more relevant and appropriate understanding of changes in their functional ability.

The results from studies C and D emphasise the importance of considering the use of digital biomarkers now and in the future for the assessment of cognitive and functional ability. With further development, these novel digital biomarkers could enable in-home monitoring of cognitive ability that has the potential to detect problems with cognition earlier than conventional testing. Computer behaviour indicators would not be considered stand-alone substitutes for traditional psychometric tests, and, instead, should be used as a means to provide information about a person's cognitive status, in an ecologically relevant way, that would supplement and provide converging data with formal cognitive testing.

There also remain substantial challenges to the use of digital technologies as a method for monitoring cognitive and functional status. To prepare for digital technologies in the future, consideration must be given to both the patient and the clinician. Research in the field must maintain credibility and trust with the patient community through careful and thoughtfully planned procedures and the provision of sufficient information. Findings from the pilot (study B) were used to ensure that participants were provided with detailed information regarding the use of data and how it would be protected. It is necessary to educate clinicians about the meaning of outcomes from devices and when they may signal the need for more comprehensive testing (Gold et al., 2018). There is a general apprehension amongst clinicians as to the reliability and contribution of technological innovations. In his address to the House of Delegates at the American Medical Association (AMA) Annual Meeting (2016), AMA CEO James L Madara, M.D. expressed mixed feelings relating to emerging digital technologies for health:

"From ineffective electronic health records, to an explosion of direct-to-consumer digital health products, to apps of mixed quality – it's the digital snake oil of the early 21st century." (American Medical Association, 2016).

The successful development, integration and implementation of new digital health technologies require a radical shift from the traditional and single-disciplinary academic and clinical approaches (Kostkova, 2015). A joint multidisciplinary collaboration is required between healthcare professionals/medical scientists and computer scientists/engineers so both professions contribute to joint research at equal levels.

The demographic change associated with the aging population presents significant challenge for governments and society. Digital technologies can play a significant role in reducing the so-called 'burden of care' associated with the aging population (Damodaran et al., 2013). Computers and the internet are powerful assistive technologies, helping older adults to maintain their independence, social connectedness and sense of worth in the face of declining health or limited capabilities, as well as offering new opportunities to improve quality of life (Wangberg et al., 2008). It is therefore important to ensure that older adults are able to continue to use such technologies and to intervene if decline in ability to use the computer is identified. Furthermore, access to tools that can be used in the home to self-monitor functional and cognitive abilities, can empower older adults to independently monitor and self-manage their conditions (Kostkova, 2015). In this PhD, participants who took part in studies B, C and D were interested in using the SAMS software to monitor their cognition as it might provide useful information about their health. Use of the SAMS software in the future can allow older adults to take ownership of their mental and physical well-being, maintain independence for longer and if decline is detected, seek help and start treatment earlier.

7.8. Conclusions

The ways in which we complete our daily activities are changing as technology develops. Therefore, it is essential to continuously update and redefine the ways in which we measure functional capacity for the assessment of cognitive decline in early dementia. It is also important that the instruments we use to measure function and cognition are meaningful to the lives of the people they assess. In this PhD this need has been addressed by culturally

adapting a subjective functional assessment scale for use in the UK. This scale includes activities relevant to the lives of older adults in the UK. After further testing, the self-report version will provide people, who may not have someone who can complete an informant version, with the opportunity to describe their own current abilities.

A novel digital biomarker records computer use behaviours, such as computer use duration and keystroke speed, which can provide an indication of a person's cognitive status and can differentiate between groups of varying cognitive abilities. Importantly, non-directed computer use behaviour, particularly keystroke speed, where the exact nature of the activities are unknown, can provide useful information about a person's cognitive abilities.

In conclusion, this PhD has contributed to the field of functional capacity measurement in two distinct ways: 1) producing a culturally-adapted subjective questionnaire, which provides a direct measure of IADL that has cultural and technological relevance to older adults in the UK, and a new self-report version; 2) establishing proof of principle for the use of computer use behaviour as a digital biomarker of cognitive health, that is passive, continuous and has the potential to be sensitive to early changes in cognition that could indicate subtle change in functional ability. Both of these measures have potential clinical utility: The A-IADL-Q-UK provides a subjective assessment of IADL that will give the clinician, researcher and patient a more relevant and appropriate understanding of changes in their functional ability. With further development, the novel digital biomarker could enable in-home monitoring of cognitive ability, which can provide information about a person's cognitive status, in an ecologically relevant way, which would supplement and provide converging data with formal cognitive testing.

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NB. These references are for chapters 1, 2, 4 and 7. References for studies A, C and D can be found at the end of each respective chapter (3, 5 and 6).

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Appendices

Appendix A - Participant information sheets (study A)

Three separate information sheets are included for dementia professionals (clinicians) (Step 1), self-report participants and relatives (Step 1) and the applicability questionnaire participants (Step 2) used in Study A:

Stringer, G., Leroi, I., Sikkes, S. A. M., Montaldi, D. & Brown, L. J. E. (2020). 'Enhancing 'meaningfulness' of functional assessments: UK adaptation of the Amsterdam IADL questionnaire', International Psychogeriatrics, pp. 1-12.

Daily Activities Project - Clinician Information Leaflet
Clinician review

We would like to invite you to take part in a research study that is developing a measure of people's ability to complete daily activities, such as cooking a meal and using the telephone. This study is part of a PhD project being used for educational purposes.

This information sheet explains what taking part would involve.

What is the study all about?

The study is taking a daily activities questionnaire developed in Amsterdam and modifying it to suit people in the UK. Measuring ability to complete daily activities is part of how we diagnose dementia, however current measures are not as good as we need them to be. Therefore we are doing this study so that we can improve the way we measure people's ability to complete daily activities. This will help to improve the way we diagnose and support people with dementia.

Why have I been invited?

You have been invited because you are a clinician with experience of diagnosing dementia in the UK.

What will I be required to do?

We will ask you to read through the UK adapted questionnaire and to provide feedback about the clarity of the questions and the relevance of the activities.

The researchers will collect the feedback using a range of methods. A focus group will be organised where the questionnaire will be discussed and comments will be recorded. If you are unable to attend the focus group, your feedback will be collected either via a face to face or telephone interview or via email. In addition to handwritten notes taken by the researcher, the focus groups and interviews will be audio recorded with your permission. The audio recording can be stopped at any time and words deleted or replaced and a break from the questionnaire can be taken when required.

Can I choose whether or not to take part?

Yes. It is up to you to decide whether or not you want to take part. If you do, we will ask you to complete a consent form. If you do decide to take part, you will be given this information sheet to keep and will be asked to sign a consent form. You are still free to withdraw at any time in the process of the study without giving a reason. If you decide not to take part, your employment will not be affected.

What happens if I change my mind after I have agreed to take part?

Participants can withdraw from the study at any time without having to justify their decision. The data collected from you to the point of withdrawal will still be used.

What will happen if I decide to take part?

If after reading this information sheet, you are happy to take part, then a suitable date and time will be arranged to complete the review. The discussion will take approximately 1 hour and the discussion will be audio recorded to supplement any notes taken by the researchers.

What are the risks of taking part?

There is minimal risk in taking part in this study. The study may slightly inconvenience for about 1 hour.

How will the study benefit me?

Taking part in this study may not directly benefit you however your involvement will contribute significantly to our wider understanding of how to assess functional capacity and cognitive problems. It will increase knowledge in the scientific community and improve our understanding of functional capacity and how we improve our current ways of diagnosing dementia.

Will my participation in the study be kept confidential?

Your participation and all the information we collect about you will be kept confidential.

Only the study team at the University of Manchester will have access to your personal information. Your personal data will be held securely at the University of Manchester and will be carefully destroyed as soon as it is not needed. The research data will be stored at the University of Manchester. The data will be analysed by researchers involved in this study.

The audio recordings will be used for backup purposes only and will not be transcribed but may be used to check accuracy of the handwritten notes.

Anonymised direct quotes will be used in the final write up with your permission.

All data collected will be safely destroyed after 7 years in line with The University of Manchester policy.

Individuals from the University, regulatory authorities or NHS Trust may need to access the data collected to ensure that the study is being carried out properly. This is to protect you by ensuring that we are doing the research in a safe and ethical way. All individuals will be authorised representatives from each organisation and will have a **duty of confidentiality** to all research participants.

What will happen to the results of the study?

When the study is complete, we will present the findings at conferences and publish them in scientific journals. **All your data will be anonymised** and **you will not be identified personally**.

What if there is a problem?

If you have a concern about any aspect of this study, please ask to speak to the researchers who will do their best to answer your questions.

If there are any issues regarding this research that you would prefer not to discuss with members of the research team, please contact the Research Governance and Integrity Team by either writing to 'The Research Governance and Integrity Manager, Research Office, Christie Building, The University of Manchester, Oxford Road, Manchester M13 9PL', by emailing: Research.Complaints@manchester.ac.uk, or by telephoning 0161 275 7583 or 275 8093.

In the event that something does go wrong and you are harmed during the research you may have grounds for a legal action for compensation against the University of Manchester but you may have to pay your legal costs.

Who has reviewed the study?

All NHS research is looked at by an independent group of people, called a Research Ethics Committee to protect your safety, rights, well-being and dignity. This study has been reviewed and been given a favourable opinion by the NRES Committee North West - Preston.

Who can I contact for further information?

For more information, please contact:
Gemma Stringer (Research Associate)
University of Manchester,
Jean McFarlane Building,
Oxford Road,
Manchester, M13 9PL

Tel: 0161 306 7493
Email: gemma.stringer@manchester.ac.uk

Thank you for reading this information sheet and considering whether to take part in the study

Daily Activities Project - Participant Information Leaflet Self-report/caregiver review

We would like to invite you to take part in a research study that is developing a measure of people's ability to complete daily activities, such as cooking a meal and using the telephone. This study is part of a PhD project being used for educational purposes.

This information sheet explains what taking part would involve. Please read it carefully, discuss it with others if you wish, and ask us if anything is unclear or if you would like more details.

What is the study all about?

The study is taking a daily activities questionnaire developed in Amsterdam and amending it to suit people in the UK. Measuring ability to complete daily activities is part of how we diagnose memory or thinking problems, however current measures are not as good as we need them to be. Therefore we are doing this study so that we can improve the way we measure people's ability to complete daily activities. This will help to improve the way we diagnose and support people with memory or thinking problems.

Why have I been invited?

You have been invited because you are either someone who has been experiencing memory concerns or problems or you live with, are related to or care for someone with memory or thinking problems.

What will I be required to do?

We will ask you to complete a questionnaire about daily activities while thinking out loud. During the process the researchers will make notes, this is so that changes can be made to improve the questionnaire. The process will also be audio recorded with your permission to supplement the researcher's notes. The audio recording can be stopped at any time and words deleted or replaced and a break from the questionnaire can be taken when required.

Can I choose whether or not to take part?

Yes. It is up to you to decide whether or not you want to take part. If you do, we will ask you to complete a consent form. If you do decide to take part, you will be given this information sheet to keep and will be asked to sign a consent form. You are still free to withdraw at any time in the process of the study without giving a reason. If you decide not to take part, your medical care and legal rights will not be affected.

What happens if I change my mind after I have agreed to take part?

Participants can withdraw from the study at any time without having to justify their decision. The data collected from you to the point of withdrawal will still be used.
If you withdraw, your medical care and legal rights will not be affected.

What will happen if I decide to take part?

If after reading this information sheet, you are happy to take part, a date and time will be arranged with you to complete the review process. You will be asked to attend a session at the University of Manchester or, if this is not possible, at your home address. The review process will take approximately 1 hour. You will be reimbursed for any reasonable travel expenses should you make a special trip to the University.

What are the risks of taking part?

There is minimal risk in taking part in this study. The study may slightly inconvenience for about 1 hour.

How will the study benefit me?

Taking part in this study may not directly benefit you however your involvement will contribute significantly to our wider understanding of how to assess functional capacity and cognitive problems. It will increase knowledge in the scientific community and improve our understanding of functional capacity and how we improve our current ways of diagnosing memory or thinking problems.

Will my participation in the study be kept confidential?

Your participation and all the information we collect will be kept confidential.

Only the study team at the University of Manchester will have access to your personal information. Your personal data will be held securely at the University of Manchester and will be carefully destroyed as soon as it is not needed. The research data will be stored at the University of Manchester. The data will be analysed by researchers involved in this study.

The audio recordings will be used for backup purposes only and will not be transcribed but may be used to check accuracy of the handwritten notes.

Anonymised direct quotes will be used in the final write up with your permission.

All data collected will be safely destroyed after 7 years in line with The University of Manchester policy.

Individuals from the University, regulatory authorities or NHS Trust may need to access the data collected to ensure that the study is being carried out properly. This is to protect you by ensuring that we are doing the research in a safe and ethical way. All individuals will be authorised representatives from each organisation and will have a **duty of confidentiality** to all research participants.

What will happen to the results of the study?

When the study is complete, we will present the findings at conferences and publish them in scientific journals. **All your data will be anonymised** and **you will not be identified personally**.

With your permission, we would also like to use the anonymised data for future research carried out by the research team and other researchers. You will be able to indicate on the consent form if you agree for your data to be used in this way. If not, your data will be destroyed.

What if there is a problem?

If you have a concern about any aspect of this study, please ask to speak to the researchers who will do their best to answer your questions.

If there are any issues regarding this research that you would prefer not to discuss with members of the research team, please contact the Research Governance and Integrity Team by either writing to The Research Governance and Integrity Manager, Research Office, Christie Building, The University of Manchester, Oxford Road, Manchester M13 9PL, by emailing: Research.Complaints@manchester.ac.uk, or by telephoning 0161 275 7583 or 275 8093.

In the event that something does go wrong and you are harmed during the research you may have grounds for a legal action for compensation against the University of Manchester but you may have to pay your legal costs.

Who has reviewed the study?

All NHS research is looked at by an independent group of people, called a Research Ethics Committee to protect your safety, rights, well-being and dignity. This study has been reviewed and been given a favourable opinion by the NRES Committee North West - Preston.

Who can I contact for further information?

For more information, please contact:

Gemma Stringer (Research Associate)
University of Manchester,
Jean McFarlane Building,
Oxford Road,
Manchester, M13 9PL

Tel: 0161 306 7493
Email: gemma.stringer@manchester.ac.uk

Thank you for reading this information sheet and considering whether to take part in the study.

Daily Activities Project – Activities questionnaire Participant Information Leaflet

We would like to invite you to take part in a research study that is developing a measure of people's ability to complete daily activities, such as cooking a meal and using the telephone. This study is part of a PhD project being used for educational purposes.

This information sheet explains what taking part would involve. Please read it carefully, discuss it with others if you wish, and ask us if anything is unclear or if you would like more details.

What is the study all about?

The study is taking a daily activities questionnaire developed in Amsterdam and amending it to suit people in the UK. Measuring ability to complete daily activities is part of how we diagnose dementia, however current measures are not as good as we need them to be. Therefore we are doing this study so that we can improve the way we measure people's ability to complete daily activities. This will help to improve the way we diagnose and support people with dementia.

Why have I been invited?

You have been invited because you are over 65 years old.

What will I be required to do?

We will ask you to complete a questionnaire, asking you about your daily activities. The questionnaire will take approximately 15 minutes. You will be provided with a pre-paid envelope for you to use to return the completed questionnaire. This information sheet is for you to keep.

Can I choose whether or not to take part?

Yes. It is up to you to decide whether or not you want to take part. If you do wish to take part, we will ask you to complete the questionnaire. If you choose to complete the questionnaire you are consenting for the information you provide to be used in the study. If you do not want to take part, then please dispose of the questionnaire.

How will the study benefit me?

Taking part in this study may not directly benefit you however your involvement will contribute significantly to our wider understanding of how to assess functional capacity and cognitive problems. It will increase knowledge in the scientific community and improve our understanding of functional capacity and how we improve our current ways of diagnosing dementia.

Will my participation in the study be kept confidential?

Your participation and all the information we collect about you will be kept confidential. All of your questionnaire answers are anonymous and cannot be linked to your personal information.

Only the study team at the University of Manchester will have access to your personal information. Your personal data will be held securely at the University of Manchester and will be carefully destroyed as soon as it is not needed. The anonymous research data will be stored at the University of Manchester. The data will be analysed by researchers involved in this study.

Individuals from the University, regulatory authorities or NHS Trust may need to access the data collected to ensure that the study is being carried out properly. This is to protect you by ensuring that we are doing the research in a safe and ethical way. All individuals will be authorised representatives from each organisation and will have a **duty of confidentiality** to all research participants.

What will happen to the results of the study?

When the study is complete, we will present the findings at conferences and publish them in scientific journals. **All your data will be anonymised** and **you will not be identified personally**.

What if there is a problem?

If you have a concern about any aspect of this study, please ask to speak to the researchers who will do their best to answer your questions.

If there are any issues regarding this research that you would prefer not to discuss with members of the research team, please contact the Research Governance and Integrity Team by either writing to The Research Governance and Integrity Manager, Research Office, Christie Building, The University of Manchester, Oxford Road, Manchester M13 9PL, by emailing: Research.Complaints@manchester.ac.uk, or by telephoning 0161 275 7583 or 275 8093.

In the event that something does go wrong and you are harmed during the research you may have grounds for a legal action for compensation against the University of Manchester but you may have to pay your legal costs.

Who has reviewed the study?

This research has been looked at by an independent group of people, called a Research Ethics Committee to protect your safety, rights, well-being and dignity. This study has been reviewed and been given a favourable opinion by the NRES Committee North West - Preston.

Who can I contact for further information?

For more information, please contact:

Gemma Stringer (Research Associate)
University of Manchester,
Jean McFarlane Building,
Oxford Road,
Manchester, M13 9PL
Tel: 0161 306 7493
Email: gemma.stringer@manchester.ac.uk

Thank you for reading this information and considering whether to take part in the study.

Appendix B – Recruitment materials (study A)

Three separate recruitment materials used in study A are included: the advert for self-report participants and relatives (Step 1), the letter of invite for self-report participants and relatives (Step 1) and the letter of invite for the applicability questionnaire participants (Step 2):

Stringer, G., Leroi, I., Sikkes, S. A. M., Montaldi, D. & Brown, L. J. E. (2020). 'Enhancing 'meaningfulness' of functional assessments: UK adaptation of the Amsterdam IADL questionnaire', International Psychogeriatrics, pp. 1-12.

Are you over 65 and want to contribute to memory research?

Have you been diagnosed with a mild memory problem or do you care for someone who has?

We are seeking volunteers to help in a study investigating the ability to complete everyday tasks when you have memory difficulties.

If you are interested in finding out more about this research and the possibility of taking part please contact:

Gemma Stringer

The University of Manchester

Tel: 0161 306 7493

The University of Manchester
Institute of Brain Behaviour and Mental Health
Room 3.306, 3rd Floor
Jean McFarlane Building, Oxford Road
Manchester, M13 9PL
Tel: 0161 306 7493
Email: Iracema.Leroi@manchester.ac.uk

[Name and address of participant]

[date]

[Dear [insert participant name]]

RE: Daily Activities Project

Thank you for expressing an interest in hearing more about the Daily Activities Project.

We are seeking volunteers over 65 years old to help in a study that is developing a measure of people's ability to complete daily activities, such as cooking a meal and using the telephone. We will do this by developing a current measure of daily activities to make it more appropriate for use in the UK.

Measuring ability to complete daily activities is part of how we diagnose dementia, however current measures are not as good as we need them to be. Therefore we are doing this study so that we can improve the way we measure people's ability to complete daily activities. This will help to improve the way we diagnose and support people with dementia.

A full information sheet explaining the study in more detail is enclosed. We would appreciate it if you could read the information sheet and let us know by phone or email if you are interested in taking part.

Please contact Gemma Stringer (Research Associate) Tel: 0161 306 7493 or email: gemma.stringer@manchester.ac.uk if you have any questions about the study.

Yours sincerely

Dr Iracema Leroi
Clinical Senior Lecturer / Honorary Consultant

Enc: Participant Information Sheet

The University of Manchester
Institute of Brain Behaviour and Mental Health
Room 3.309, 3rd Floor
Jean McFarlane Building, Oxford Road
Manchester, M13 9PL
Tel: 0161 306 7493
Email: Iracema.Leroi@manchester.ac.uk

Dear Sir/Madam

RE: Daily Activities Project

Thank you for expressing an interest in hearing more about the Daily Activities Project.

We are seeking volunteers over 65 years old to help in a study that is developing a measure of people's ability to complete daily activities, such as cooking a meal and using the telephone. We will do this by developing a current measure of daily activities to make it more appropriate for use in the UK.

Measuring ability to complete daily activities is part of how we diagnose dementia, however current measures are not as good as we need them to be. Therefore we are doing this study so that we can improve the way we measure people's ability to complete daily activities. This will help to improve the way we diagnose and support people with dementia.

A full information sheet explaining the study in more detail is enclosed. We would appreciate it if you could read the information sheet. If after reading the information sheet you would like to take part then **please complete the enclosed questionnaire and post it back to us using the pre-paid addressed envelope.**

Please contact Gemma Stringer (Research Associate) by phone: 0161 306 7493 or email: gemma.stringer@manchester.ac.uk if you have any questions about the study.

Yours sincerely

Dr Iracema Leroi
Clinical Senior Lecturer / Honorary Consultant

Enc: Participant Information Sheet, Daily Activities Questionnaire, pre-paid addressed envelope.

Appendix C - Applicability questionnaire (study A)

Two applicability questionnaires used in study A are included, the informant version and the self-report version:

Stringer, G., Leroi, I., Sikkes, S. A. M., Montaldi, D. & Brown, L. J. E. (2020). 'Enhancing ‘meaningfulness’ of functional assessments: UK adaptation of the Amsterdam IADL questionnaire', International Psychogeriatrics, pp. 1-12.

Daily Activities Project – Daily Activities Questionnaire

Study information

This questionnaire is part of a research study that is developing a measure of people's ability to complete daily activities, such as cooking a meal and using the telephone. As part of this we need to know what activities people do on a regular basis.

Measuring ability to complete daily activities is part of how we diagnose dementia, however current measures are not as good as we need them to be. Therefore we are doing this study so that we can improve the way we measure people's ability to complete daily activities. This will help to improve the way we diagnose and support people with dementia.

Your participation and all the information we collect about you will be kept confidential.

If you are happy with the information that has been provided and you are willing to take part in the study please complete the questionnaire below.

General questions

1. What is your age?

   _____ Years

2. What is your gender? (please tick)

   ☐ Male

   ☐ Female

3. What is the highest degree or level of school you have completed? (please tick)

- ☐ Left school before 16
- ☐ Left school at 16
- ☐ College
- ☐ Bachelor's degree
- ☐ Master's degree
- ☐ Doctorate

4. What is your ethnic group?

White

- ☐ British
- ☐ Irish
- ☐ Any other White background (write in _____)

Mixed

- ☐ White and Black Caribbean
- ☐ White and Black African
- ☐ White and Asian
- ☐ Any other mixed background (write in _____)

Asian or Asian British

☐ Indian

☐ Pakistani

☐ Bangladeshi

☐ Any other Asian background (write in _____)

Black or Black British

☐ Caribbean

☐ African

☐ Any other Black background (write in _____)

Chinese or other ethnic group

☐ Chinese

☐ Any other (write in _____)

5. Are you retired?

☐ Yes

☐ No

6. What was/is your occupation?

_____ (please state)

7. Do you use a computer?

☐ Yes

☐ No

8. How long have you been using computers?

_____ (please write number of years)

(If less than one year, please write number of months _____)

9. How frequently do you use a computer?

☐ Every day

☐ 5-6 days a week

☐ 3-4 days a week

☐ 1-2 days a week

☐ Less than once a week _____ (please state)

Please answer the following about **your friend or relative:**

10. What is their age?

_____ Years

11. What is their gender? (please tick)

☐ Male

☐ Female

12. What is the highest degree or level of school they have completed? (please tick)

☐ Left school before 16

☐ Left school at 16

☐ College

☐ Bachelor's degree

☐ Master's degree

☐ Doctorate

13. What is their ethnic group?

White

☐ British

☐ Irish

☐ Any other White background (write in _____)

Mixed

☐ White and Black Caribbean

☐ White and Black African

☐ White and Asian

☐ Any other mixed background (write in _____)

Asian or Asian British

☐ Indian

☐ Pakistani

☐ Bangladeshi

☐ Any other Asian background (write in _____)

Black or Black British

☐ Caribbean

☐ African

☐ Any other Black background (write in _____)

Chinese or other ethnic group

☐ Chinese

☐ Any other (write in _____)

14. Are they retired?

☐ Yes

☐ No

15. What was/is their occupation?

_____ (please state)

16. Do they use a computer?

☐ Yes

☐ No

17. How long have they been using computers?

_____ (please write number of years)

(If less than one year, please write number of months _____)

18. How frequently do they use a computer?

- ☐ Every day
- ☐ 5-6 days a week
- ☐ 3-4 days a week
- ☐ 1-2 days a week
- ☐ Less than once a week _____ (please state)

19. How long have you known the participant in years? (if less than two years please also state months)

_____

20. On average how many hours of contact per week do you have with them?

_____

21. Do you live together?

- ☐ Yes
- ☐ No

22. Do they have a diagnosis of cognitive impairment / dementia?

☐ Yes *If yes please answer questions 23-24*

☐ No

23. What is their diagnosis? (i.e. Mild cognitive impairment (MCI), Alzheimer's Disease)

_____

24. How long ago in years was their diagnosis? (if less than two years please also state months)

_____

Activity questions

We will now show some lists of activities. Please read each activity carefully and rate how often your friend or relative does that activity in their day-to-day life.

Rate how often they do each activity on the following scale: 1) Never (they never do the activity); 2) Very rarely (they do the activity very rarely); 3) Rarely (they do the activity rarely); 4) Sometimes (they sometimes do the activity); 5) Often (they do the activity often); 6) Very often (they do the activity very often). Put a cross in the box that fits your response. If you have never heard of the activity then put a cross in the box "I have never heard of this".

Choose the answer that best reflects how often they do the activity. Occasionally it may be difficult to choose one answer. In these cases try not to spend too much time thinking about each question. Your first reaction is probably the most accurate.

In the past 4 weeks how often did he/she do the following activities?								
Q#	**Activities**	**Never**	**Very rarely**	**Rarely**	**Sometimes**	**Often**	**Very often**	**I have never heard of this**
1	Carrying out household duties							
2	Doing the shopping							
3	Cooking							
4	Preparing hot meals							
5	Preparing cold meals							
6	Cooking using a recipe							

In the past 4 weeks how often did he/she do the following activities?								
Q#	**Activities**	**Never**	**Very rarely**	**Rarely**	**Sometimes**	**Often**	**Very often**	**I have never heard of this**
7	Operating the coffee maker							
8	Operating the microwave oven							
9	Operating the cooker top							
10	Operating the oven							
11	Operating kitchen appliances							

In the past 4 weeks how often did he/she do the following activities?								
Q#	**Activities**	**Never**	**Very rarely**	**Rarely**	**Sometimes**	**Often**	**Very often**	**I have never heard of this**
12	Operating appliances for cleaning							
13	Operating the dishwasher							
14	Operating the washing machine							
15	Making minor repairs to the house							

In the past 4 weeks how often did he/she do the following activities?								
Q#	**Activities**	**Never**	**Very rarely**	**Rarely**	**Sometimes**	**Often**	**Very often**	**I have never heard of this**
16	Thinking about household finances							
17	Paying bills							
18	Managing household budget							
19	Managing household finances							
20	Electronic banking							
21	Logging in to do electronic banking							
22	Using electronic banking to make payments							
23	Using a PIN code							
24	Using a cash machine							
25	Using cash							
26	Using cheques							

In the past 4 weeks how often did he/she do the following activities?								
Q#	**Activities**	**Never**	**Very rarely**	**Rarely**	**Sometimes**	**Often**	**Very often**	**I have never heard of this**
27	Making appointments							
28	Filling in forms							
29	Working							
30	Looking up telephone numbers							
31	Using an instruction manual							

In the past 4 weeks how often did he/she do the following activities?								
Q#	**Activities**	**Never**	**Very rarely**	**Rarely**	**Sometimes**	**Often**	**Very often**	**I have never heard of this**
32	Using a computer							
33	Emailing							
34	Using a computer to write or process words							
35	Printing documents							
36	Viewing photographs on the computer							
37	Editing photographs							
38	Installing software updates							
39	Installing new programs							
40	Learning to do new things on the computer							
41	Searching the internet for information							
42	Booking a trip on the internet							
43	Buying on the internet							
44	Booking tickets on the internet							

In the past 4 weeks how often did he/she do the following activities?								
Q#	**Activities**	**Never**	**Very rarely**	**Rarely**	**Sometimes**	**Often**	**Very often**	**I have never heard of this**
45	Operating the television remote control							
46	Operating a video recorder							
47	Programming a video recorder							
48	Operating a DVD player							
49	Operating a DVD recorder							
50	Recording a television show							
51	Using electronic devices							
52	Using new electronic devices							

In the past 4 weeks how often did he/she do the following activities?								
Q#	**Activities**	**Never**	**Very rarely**	**Rarely**	**Sometimes**	**Often**	**Very often**	**I have never heard of this**
53	Operating an answering machine / voicemail							
54	Using a smartphone							
55	Using a mobile phone							
56	Playing card and board games							
57	Booking holidays							
58	Playing computer games							

In the past 4 weeks how often did he/she do the following activities?								
Q#	**Activities**	**Never**	**Very rarely**	**Rarely**	**Sometimes**	**Often**	**Very often**	**I have never heard of this**
59	Driving a car							
60	Reading a map							
61	Reading a map of an unfamiliar city or area							
62	Using a map to find your way to an unfamiliar place							
63	Using a sat-nav system							
64	Using public transport							

In the past 4 weeks how often did he/she do the following activities?								
Q#	**Activities**	**Never**	**Very rarely**	**Rarely**	**Sometimes**	**Often**	**Very often**	**I have never heard of this**
65	Looking for important things at home							
66	Using your keys							
67	Experiencing unplanned events							
68	Using medication							
69	Meeting people							

Completing daily activities

The following questions cover problems encountered by your friend/relative in completing various daily activities. The questions relate to the past four weeks. Choose the answer that best describes the actual situation.

1. In the past four weeks did he/she operate domestic appliances? *(please tick)*	
	Yes
	No
	Don't know
***If yes**, did he/she find it more difficult to operate domestic appliances than they have in the past? (please tick one)*	
	No
	Yes, slightly more difficult
	Yes, more difficult
	Yes, much more difficult
	Yes, he/she is no longer able to perform this task
***If no,** please tick the main reason why he/she did not operate any domestic appliances:*	
	He/she was unable to do so due to difficulties with his/her thinking and/or memory
	He/she was unable to do so due to his/her physical problems
	He/she has never done that before
	Other, please state _____

2. In the past four weeks did he/she use a computer? *(please tick)*	
	Yes
	No
	Don't know
***If yes,** did he/she find it more difficult to use a computer than they have in the past? (please tick one)*	
	No
	Yes, slightly more difficult
	Yes, more difficult
	Yes, much more difficult
	Yes, he/she is no longer able to perform this task
***If no,** please tick the main reason why he/she did not use a computer:*	
	He/she was unable to do so due to difficulties with his/her thinking and/or memory
	He/she was unable to do so due to his/her physical problems
	He/she has never done that before
	Other, please state _____

3. In the past four weeks did he/she use public transport? *(please tick)*	
	Yes
	No
	Don't know
***If yes,** did he/she find it more difficult to use public transport than they have in the past? (please tick one)*	
	No
	Yes, slightly more difficult
	Yes, more difficult
	Yes, much more difficult
	Yes, he/she is no longer able to perform this task
***If no,** please tick the main reason why he/she did not use of public transport:*	
	He/she was unable to do so due to difficulties with his/her thinking and/or memory
	He/she was unable to do so due to his/her physical problems
	He/she has never done that before
	Other, please state _____

In this questionnaire, you have seen several day-to-day activities. Are there any activities that your friend or relative does in their everyday life that have been missed?

If yes, please list them below and rate how often they do the activity:

	Activities	Very rarely	Rarely	Sometimes	Often	Very often
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						

Do you have any other comments, concerns or suggestions regarding the questionnaire?

Thank you very much for completing this questionnaire!

Daily Activities Project - Daily Activities Questionnaire

Study information

This questionnaire is part of a research study that is developing a measure of people's ability to complete daily activities, such as cooking a meal and using the telephone. As part of this we need to know what activities people do on a regular basis.

Measuring ability to complete daily activities is part of how we diagnose dementia, however current measures are not as good as we need them to be. Therefore we are doing this study so that we can improve the way we measure people's ability to complete daily activities. This will help to improve the way we diagnose and support people with dementia.

Your participation and all the information we collect about you will be kept confidential.

If you are happy with the information that has been provided and you are willing to take part in the study please complete the questionnaire below.

General questions

1. What is your age?

   _____ Years

2. What is your gender? (please tick)

   ☐ Male

   ☐ Female

3. What is the highest degree or level of school you have completed? (please tick)

- ☐ Left school before 16
- ☐ Left school at 16
- ☐ College
- ☐ Bachelor's degree
- ☐ Master's degree
- ☐ Doctorate

4. What is your ethnic group?

White

- ☐ British
- ☐ Irish
- ☐ Any other White background (write in _____)

Mixed

- ☐ White and Black Caribbean
- ☐ White and Black African
- ☐ White and Asian
- ☐ Any other mixed background (write in _____)

Asian or Asian British

☐ Indian

☐ Pakistani

☐ Bangladeshi

☐ Any other Asian background (write in _____)

Black or Black British

☐ Caribbean

☐ African

☐ Any other Black background (write in _____)

Chinese or other ethnic group

☐ Chinese

☐ Any other (write in _____)

5. Are you retired?

☐ Yes

☐ No

6. What was/is your occupation?

_____ (please state)

7. Do you use a computer?

☐ Yes

☐ No

8. How long have you been using computers?

_____ (please write number of years)

(If less than one year, please write number of months _____)

9. How frequently do you use a computer?

☐ Every day

☐ 5-6 days a week

☐ 3-4 days a week

☐ 1-2 days a week

☐ Less than once a week _____ (please state)

10. Are you concerned that you have a memory or thinking problem?

☐ Yes

☐ No

11. Have you been to visit your GP to discuss your memory or thinking concerns?

☐ Yes

☐ No

12. Do you have a diagnosis of cognitive impairment / dementia?

☐ Yes *If yes please answer questions 13-14*

☐ No

13. What is your diagnosis? (i.e. MCI, Alzheimer's Disease)

_____

14. How long ago in years was your diagnosis? (if less than two years please also state months)

_____

Activity questions

We will now show some lists of activities. Please read each activity carefully and rate how often you do that activity in your day-to-day life.

Rate how often you do each activity on the following scale: 1) Never (I never do the activity); 2) Very rarely (I do the activity very rarely); 3) Rarely (I do the activity rarely); 4) Sometimes (I sometimes do the activity); 5) Often (I do the activity often); 6) Very often (I do the activity very often). Put a cross in the box that fits your response. If you have never heard of the activity then put a cross in the box "I have never heard of this".

Choose the answer that best reflects how often you do the activity. Occasionally it may be difficult to choose one answer. In these cases try not to spend too much time thinking about each question. Your first reaction is probably the most accurate.

In the past 4 weeks how often did you do the following activities?								
Q#	**Activities**	**Never**	**Very rarely**	**Rarely**	**Sometimes**	**Often**	**Very often**	**I have never heard of this**
1	Carrying out household duties							
2	Doing the shopping							
3	Cooking							
4	Preparing hot meals							
5	Preparing cold meals							
6	Cooking using a recipe							

In the past 4 weeks how often did you do the following activities?								
Q#	**Activities**	**Never**	**Very rarely**	**Rarely**	**Sometimes**	**Often**	**Very often**	**I have never heard of this**
7	Operating the coffee maker							
8	Operating the microwave oven							
9	Operating the cooker top							
10	Operating the oven							
11	Operating kitchen appliances							

In the past 4 weeks how often did you do the following activities?								
Q#	**Activities**	**Never**	**Very rarely**	**Rarely**	**Sometimes**	**Often**	**Very often**	**I have never heard of this**
12	Operating appliances for cleaning							
13	Operating the dishwasher							
14	Operating the washing machine							
15	Making minor repairs to the house							

In the past 4 weeks how often did you do the following activities?								
Q#	**Activities**	**Never**	**Very rarely**	**Rarely**	**Sometimes**	**Often**	**Very often**	**I have never heard of this**
16	Thinking about household finances							
17	Paying bills							
18	Managing household budget							
19	Managing household finances							
20	Electronic banking							
21	Logging in to do electronic banking							
22	Using electronic banking to make payments							
23	Using a PIN code							
24	Using a cash machine							
25	Using cash							
26	Using cheques							

In the past 4 weeks how often did you do the following activities?								
Q#	**Activities**	**Never**	**Very rarely**	**Rarely**	**Sometimes**	**Often**	**Very often**	**I have never heard of this**
27	Making appointments							
28	Filling in forms							
29	Working							
30	Looking up telephone numbers							
31	Using an instruction manual							

In the past 4 weeks how often did you do the following activities?								
Q#	**Activities**	**Never**	**Very rarely**	**Rarely**	**Sometimes**	**Often**	**Very often**	**I have never heard of this**
32	Using a computer							
33	Emailing							
34	Using a computer to write or process words							
35	Printing documents							
36	Viewing photographs on the computer							
37	Editing photographs							
38	Installing software updates							
39	Installing new programs							
40	Learning to do new things on the computer							
41	Searching the internet for information							
42	Booking a trip on the internet							
43	Buying on the internet							
44	Booking tickets on the internet							

In the past 4 weeks how often did you do the following activities?								
Q#	**Activities**	**Never**	**Very rarely**	**Rarely**	**Sometimes**	**Often**	**Very often**	**I have never heard of this**
45	Operating the television remote control							
46	Operating a video recorder							
47	Programming a video recorder							
48	Operating a DVD player							
49	Operating a DVD recorder							
50	Recording a television show							
51	Using electronic devices							
52	Using new electronic devices							

In the past 4 weeks how often did you do the following activities?								
Q#	**Activities**	**Never**	**Very rarely**	**Rarely**	**Sometimes**	**Often**	**Very often**	**I have never heard of this**
53	Operating an answering machine / voicemail							
54	Using a smartphone							
55	Using a mobile phone							
56	Playing card and board games							
57	Booking holidays							
58	Playing computer games							

In the past 4 weeks how often did you do the following activities?								
Q#	**Activities**	**Never**	**Very rarely**	**Rarely**	**Sometimes**	**Often**	**Very often**	**I have never heard of this**
59	Driving a car							
60	Reading a map							
61	Reading a map of an unfamiliar city or area							
62	Using a map to find your way to an unfamiliar place							
63	Using a sat-nav system							
64	Using public transport							

In the past 4 weeks how often did you do the following activities?								
Q#	**Activities**	**Never**	**Very rarely**	**Rarely**	**Sometimes**	**Often**	**Very often**	**I have never heard of this**
65	Looking for important things at home							
66	Using your keys							
67	Experiencing unplanned events							
68	Using medication							
69	Meeting people							

Completing daily activities

The following questions ask for some more information about completing various daily activities. The questions relate to the past four weeks. Choose the answer that best describes the actual situation.

1. In the past four weeks did you operate domestic appliances? *(please tick)*	
	Yes
	No
	Don't know
***If yes**, did you find it more difficult to operate domestic appliances than you have in the past? (please tick one)*	
	No
	Yes, slightly more difficult
	Yes, more difficult
	Yes, much more difficult
	Yes, I am no longer able to perform this task
***If no,** please tick the main reason why you did not operate any domestic appliances:*	
	I was unable to do so due to difficulties with my thinking and/or memory
	I was unable to do so due to my physical problems
	I have never done it before
	Other, please state _____

2. In the past four weeks did you use a computer? *(please tick)*	
	Yes
	No
	Don't know
***If yes,** did you find it more difficult to use a computer than you have in the past? (please tick one)*	
	No
	Yes, slightly more difficult
	Yes, more difficult
	Yes, much more difficult
	Yes, I am no longer able to perform this task
***If no,** please tick the main reason why you did not use a computer:*	
	I was unable to do so due to difficulties with my thinking and/or memory
	I was unable to do so due to my physical problems
	I have never done it before
	Other, please state _____

3. In the past four weeks did you use public transport? *(please tick)*	
	Yes
	No
	Don't know
***If yes,** did you find it more difficult to use public transport than you have in the past? (please tick one)*	
	No
	Yes, slightly more difficult
	Yes, more difficult
	Yes, much more difficult
	Yes, I am no longer able to perform this task
***If no,** please tick the main reason why you did not use public transport:*	
	I was unable to do so due to difficulties with my thinking and/or memory
	I was unable to do so due to my physical problems
	I have never done it before
	Other, please state _____

In this questionnaire, you have seen several daily activities. Are there any activities that you do in your everyday life that have been missed?

If yes, please list them below and rate how often you do the activity:

	Activities	Very rarely	Rarely	Sometimes	Often	Very often
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						

Do you have any other comments, concerns or suggestions regarding the questionnaire?

Thank you very much for completing this questionnaire!

Appendix D – Supplementary table 1 (study A)

Supplementary table 1: Number (and %) of participants endorsing each response to new items, and correlation coefficients of new items with weighted average score split by self-report and informant report.

From Study A:

Stringer, G., Leroi, I., Sikkes, S. A. M., Montaldi, D. & Brown, L. J. E. (2020). 'Enhancing 'meaningfulness' of functional assessments: UK adaptation of the Amsterdam IADL questionnaire', International Psychogeriatrics, pp. 1-12.

Supplementary table 1. Number (and %) of participants endorsing each response to new items, and correlation coefficients of new items with weighted average score split by self-report and informant report.

	Relevance		Difficulty			Kendall's tau-b correlation coefficients of new items and weighted average score (without new items)	
Item	Did not do activity in previous 4 weeks or never done activity (informant report / self-report)	Completed activity in previous 4 weeks (informant report / self-report)	Did not find the activity more difficult (informant report / self-report)	Found activity slightly more difficult (informant report / self-report)	Found activity more/much more difficult (informant report / self-report)	Correlation with total score without new items (informant report / self-report)	p value (informant report / self-report)
Making a cup of tea or coffee*	0 (0.0) / 0 (0.0)	21 (100.0) / 7 (100.0)	20 (95.2) / 7 (100.0)	1 (4.8) / 0 (0.0)	0 (0.0) / 0 (0.0)	-.32 / 1.0	.10 / N/A
Using the hob*	1 (4.8) / 1 (14.3)	20 (95.2) / 6 (85.7)	18 (85.7) / 6 (85.7)	2 (9.5) / 0 (0.0)	0 (0.0) / 0 (0.0)	-.12 / N/A	.53 / N/A
Using the grill‡	7 (33.3) / 4 (57.1)	14 (66.7) / 3 (42.9)	13 (61.9) / 3 (42.9)	1 (4.8) / 0 (0.0)	0 (0.0) / 0 (0.0)	-.38 / N/A	.11 / N/A
Completing household paperwork*	6 (28.6) / 0 (0.0)	15 (71.4) / 7 (100.0)	13 (61.9) / 6 (85.7)	2 (9.5) / 0 (0.0)	0 (0.0) / 1 (14.3)	-.50 / -.55	.03 / .13
Recording a TV program*	6 (28.6) / 4 (57.1)	15 (71.4) / 3 (42.9)	12 (57.1) / 3 (42.9)	2 (9.5) / 0 (0.0)	1 (4.8) / 0 (0.0)	-.61 / N/A	.01 / N/A
Using keys*	0 (0.0) / 0 (0.0)	21 (100.0) / 7 (100.0)	21 (100.0) / 6 (85.7)	0 (0.0) / 0 (0.0)	0 (0.0) / 1 (14.3)	N/A / -.55	N/A / .13
Reading‡	1 (4.8) / 0 (0.0)	20 (95.2) / 7 (100.0)	19 (90.5) / 5 (71.4)	0 (0.0) / 2 (28.6)	1 (4.8) / 0 (0.0)	-.32 / -.71	.01 / .05
Maintaining the garden‡	4 (19.0) / 2 (28.6)	17 (81.0) / 5 (71.4)	15 (71.4) / 3 (42.9)	1 (4.8) / 1 (14.3)	1 (4.8) / 1 (14.3)	-.14 / -.84	.50 / .05
Looking after family‡	13 (61.9) / 0 (0.0)	14 (66.7) / 1 (14.3)	13 (61.9) / 1 (14.3)	1 (4.8) / 0 (0.0)	0 (0.0) / 0 (0.0)	-.38 / N/A	.10 / N/A

*classified as new because of significant changes to language and/or meaning
‡completely new item
N/A – all participants in the group gave the same response so there is no variation in the data

Appendix E – Supplementary table 2 (study A)

Supplementary table 2: Means and Kendall's tau-b correlation coefficients of weighted average scores (including the new items) of the A-IADL-Q-UK with clinical measures and demographics split by self-report and informant report.

From Study A:

Stringer, G., Leroi, I., Sikkes, S. A. M., Montaldi, D. & Brown, L. J. E. (2020). 'Enhancing 'meaningfulness' of functional assessments: UK adaptation of the Amsterdam IADL questionnaire', International Psychogeriatrics, pp. 1-12.

Supplementary table 2. Means and Kendall's tau-b correlation coefficients of weighted average scores (including the new items) of the A-IADL-Q-UK with clinical measures and demographics split by self-report and informant report.

Measure	N (informant report / self-report)	Mean (SD) (informant report / self-report)	Weighted average score with new items (Kendall's tau-b) (informant report / self-report)	p value (informant report / self-report)
Demographic data				
Age	21 / 7	72.11 (3.66) / 74.24 (6.20)	-.129 / .000	.451 / 1.00
Cognitive functioning				
ACE III‡	21 / 7	94.71 (4.60) / 90.00 (6.78)	-.023 / .264	.895 / .428
DSB§	21 / 7	8.14 (2.39) / 6.71 (2.29)	.281 / .474	.111 / .154
TMT B‖	21 / 7	80.24 (42.55) / 71.14 (39.63)	-.011 / .103	.948 / .754
Everyday functioning				
ECog¶	21 / 7	1.66 (.76) / 1.41 (.28)	-.578 / .000	.001 / 1.00

‡ACE III = Addenbrooke's Cognitive Examination-III (ACE III); §DSB = Digit Span Backwards Task; ‖TMT B = Trails Making Test B; ¶ECog = Measurement of Everyday Cognitive Function.

Appendix F – Participant information sheets (study B)

Three separate information sheets are included for cognitively healthy controls, people with cognitive impairment, and informants used in Study B.

SAMS (Software Architecture for Mental Health Self-Management)

Pilot Study
Participant Information Leaflet

We would like to invite you to take part in a pilot study, called 'SAMS', investigating the impact of cognitive problems on computer use.

This information sheet explains what taking part would involve. Please read it carefully, discuss it with others if you wish, and ask us if anything is unclear or if you would like more details.

What is the study all about?
We are trying to find a way of using information about computer use to detect whether people have problems with memory or with thinking, referred to as cognitive problems. We are doing this because older people are using the computer more often which gives us an opportunity to use this type of information. Using computer data to help detect whether people have memory or cognitive problems has not been done before.
In order to do this, though, we need to trial out the software to see how well it works.

Why have I been invited?
You have been invited because you have **not** been experiencing memory or cognitive problems. We need people who do not have memory or cognitive problems to enable us to compare with those who do have memory or cognitive problems.

Can I choose whether or not to take part?
If you wish, a researcher can visit you at home to discuss the study with you. It is up to you to decide whether or not you want to take part. If you do, we will give you this information sheet to keep and we will ask you to sign a consent form. If you decide not to take part, your medical care and legal rights will not be affected.

What happens if I change my mind after I have agreed to take part?
If you change your mind after agreeing to take part, you can withdraw at any time, without giving a reason. Again, if you decide to withdraw, your medical care and legal rights will not be affected.

What will happen if I decide to take part?
Once you have signed the consent form you will be invited to the University where you will be asked to complete a number of basic tasks on a computer, such as writing emails or browsing the internet. The SAMS software will be installed on the computer and will collect information about all the activities you complete and these tasks will take about 45 minutes. We will also ask you to complete some tasks and questionnaires to assess your cognition (i.e. memory), health, mood and day to day functioning, this will take approximately 90 minutes. The process

will be followed by a short interview (approximately 15 minutes), asking you about your experiences of completing the computer activities and we will ask if you are happy for us to audio record this. This study is a pilot of a larger study and so throughout the process we will ask you for your informal feedback about the activities we ask you to do, this will help us to improve the design of the larger study. Your participation in the study may take several hours (approximately 2 to 3 hours) over a few sessions.

What are the risks of taking part?
There is minimal risk of taking part in the study. The study may add a slight inconvenience to your day over a few hours.

How will the study benefit me?
Taking part in this study may not directly benefit you however your involvement will contribute significantly to our wider understanding of how to detect memory and cognitive problems. It will add to the scientific community and increase our understanding of memory problems.

As a thank you for taking part and giving up your time you will be offered a small amount of high street store vouchers (£10).

Will my participation in the study be kept confidential?
Your participation and all the information we collect about you will be kept confidential. The only exception to this is if we feel that you or others around you may be at risk. If this happens, we have a duty to inform an appropriate professional.

In some cases people are not aware that they are having memory problems that might be considered clinically important. We will ask you if you would like us to inform your GP if we detect any clinically significant problems.

Only the study team at the University of Manchester will have access to your personal information. Researchers at the University of Manchester and University of Lancaster will have access to the data you have supplied, but no personal information about you will be provided to them. Your personal data will be held securely at the University of Manchester and will be carefully destroyed as soon as it is not needed. The research data which has your name and any other personal data removed (anonymised) will be stored at both the University of Lancaster and the University of Manchester. The data will be analysed by researchers involved in this study.

What will happen to the results of the study?
When the pilot is complete, we will use the results to improve the SAMS software and prepare it for a larger study which will involve comparing healthy volunteers such as yourself with people with mild Alzheimer's disease.

When the study is complete, we will present the findings at conferences and publish them in scientific journals. All your data will be anonymised and you will not be identified personally. We will let you have a copy of the study results and we will send out a newsletter informing you of the outcome of the study.

With your permission, we would also like to use the anonymised data for future research carried out by the research team and other researchers. You will be able to indicate on the consent form if you agree for your data to be used in this way.

What if something goes wrong?
If there are any issues regarding this research that you would prefer not to discuss with members of the research team, please contact the Research Governance and Integrity Team by either writing to 'The Research Governance and Integrity Manager, Research Office, Christie Building, The University of Manchester, Oxford Road, Manchester M13 9PL', by emailing: Research.Complaints@manchester.ac.uk, or by telephoning 0161 275 7583 or 275 8093.

Who is organising and funding the research?
The research is funded by the EPSRC (Engineering and Physical Sciences Research Council). This grant was led by Professor Pete Sawyer at the University of Lancaster and covers the running costs of the research project which is led by Dr Iracema Leroi, who is a Consultant Psychiatrist at Manchester Mental Health and Social Care NHS Trust and a Clinical Senior Lecturer in Psychiatry at the University of Manchester.

Who has reviewed the study?
All University of Manchester research is looked at by a Research Ethics Committee to protect your safety, rights, well-being and dignity. This study has been reviewed and been given a favourable opinion by the University of Manchester Ethics Committee.

Who can I contact for further information?
For more information, please contact:

Gemma Stringer (Research Associate)
University of Manchester,
Jean McFarlane Building,
Oxford Road,
Manchester, M13 9PL

Tel: 0161 306 7493
Email: gemma.stringer@manchester.ac.uk

OR
Dr Iracema Leroi,
University of Manchester,
Jean McFarlane Building, Oxford Road,
Manchester, M13 9PL

Tel: 0161 306 7944.
E-mail: Iracema.Leroi@manchester.ac.uk

Thank you for reading this information sheet and considering whether to take part in the study.

SAMS (Software Architecture for Mental Health Self-Management)

Pilot Study
Participant Information Leaflet

We would like to invite you to take part in a pilot study, called 'SAMS', investigating whether your personal computer use can help us detect whether you might have some memory or cognitive problems.

This information sheet explains what taking part would involve. Please read it carefully, discuss it with others if you wish, and ask us if anything is unclear or if you would like more details.

What is the study all about?
We are trying to find a way of using information about computer use to detect whether people have problems with memory or with thinking, referred to as cognitive problems. We are doing this because older people are using the computer more often which gives us an opportunity to use this type of information. Using computer data to help detect whether people have memory or cognitive problems has not been done before.
In order to do this, though, we need to trial out the software to see how well it works.

Why have I been invited?
You have been invited because you have been experiencing memory or cognitive problems.

Can I choose whether or not to take part?
If you wish, a researcher can visit you at home to discuss the study with you. It is up to you to decide whether or not you want to take part. If you do, we will give you this information sheet to keep and we will ask you to sign a consent form. If you decide not to take part, your medical care and legal rights will not be affected.

What happens if I change my mind after I have agreed to take part?
If you change your mind after agreeing to take part, you can withdraw at any time, without giving a reason. Again, if you decide to withdraw, your medical care and legal rights will not be affected.

What will happen if I decide to take part?
Once you have signed the consent form a SAMS' researcher will visit you at home and will ask you to complete a number of basic tasks on a computer, such as writing emails or browsing the internet. The SAMS software will be installed on the computer and will collect information about all the activities you complete and these tasks will take about 45 minutes. We will also ask you to complete some tasks and questionnaires to assess your cognition (i.e. memory), health, mood and day to day functioning, this will take approximately 90 minutes. The process

will be followed by a short interview (approximately 15 minutes), asking you about your experiences of completing the computer activities and we will ask if you are happy for us to audio record this. This study is a pilot of a larger study and so throughout the process we will ask you for your informal feedback about the activities we ask you to do, this will help us to improve the design of the larger study. Your participation in the study may take several hours (approximately 2 to 3 hours) over a few sessions.

What are the risks of taking part?
There is minimal risk of taking part in the study. The study may slightly inconvenience you over a few hours.

How will the study benefit me?
Taking part in this study may not directly benefit you however your involvement will contribute significantly to our wider understanding of how to detect memory and cognitive problems. It will add to the scientific community and increase our understanding of memory problems.

As a thank you for taking part and giving up your time you will be offered a small amount of high street store vouchers (£10).

Will my participation in the study be kept confidential?
Your participation and all the information we collect about you will be kept confidential. The only exception to this is if we feel that you or others around you may be at risk. If this happens, we have a duty to inform an appropriate professional.

We would like to inform your GP, with your permission, that you have agreed to take part. Your GP will not be informed of any of the results of the tasks or assessments you have carried out, unless you specifically wish us to.

Only the study team at the University of Manchester will have access to your personal information. Researchers at the University of Manchester and University of Lancaster will have access to the data you have supplied, but no personal information about you will be provided to them. Your personal data will be held securely at the University of Manchester and will be carefully destroyed as soon as it is not needed. The research data which has your name and any other personal data removed (anonymised) will be stored at both the University of Lancaster and the University of Manchester. The data will be analysed by researchers involved in this study.

What will happen to the results of the study?
When the pilot is complete, we will use the results to improve the SAMS software and prepare it for a larger study which will involve comparing people who do not have memory difficulties with people who do.

When the study is complete, we will present the findings at conferences and publish them in scientific journals. All your data will be anonymised and you will not be identified personally.

We will let you have a copy of the study results and we will send out a newsletter informing you of the outcome of the study.

With your permission, we would also like to use the anonymised data for future research carried out by the research team and other researchers. You will be able to indicate on the consent form if you agree for your data to be used in this way.

What if something goes wrong?
If there are any issues regarding this research that you would prefer not to discuss with members of the research team, please contact the Research Governance and Integrity Team by either writing to 'The Research Governance and Integrity Manager, Research Office, Christie Building, The University of Manchester, Oxford Road, Manchester M13 9PL', by emailing: Research.Complaints@manchester.ac.uk, or by telephoning 0161 275 7583 or 275 8093.

If you want further advice and support, you can also contact the patient advice and liaison service (PALS – 0161 882 2084).

Who is organising and funding the research?
The research is funded by the EPSRC (Engineering and Physical Sciences Research Council). This grant was led by Professor Pete Sawyer at the University of Lancaster and covers the running costs of the research project which is led by Dr Iracema Leroi, who is a Consultant Psychiatrist at Manchester Mental Health and Social Care NHS Trust and a Clinical Senior Lecturer in Psychiatry at the University of Manchester.

Who has reviewed the study?
All University of Manchester research is looked at by a Research Ethics Committee to protect your safety, rights, well-being and dignity. This study has been reviewed and been given a favourable opinion by the University of Manchester Ethics Committee.

Who can I contact for further information?
For more information, please contact:

Gemma Stringer (Research Associate)
University of Manchester,
Jean McFarlane Building,
Oxford Road,
Manchester, M13 9PL

Tel: 0161 306 7493
Email: gemma.stringer@manchester.ac.uk

OR

Dr Iracema Leroi,
University of Manchester,
Jean McFarlane Building, Oxford Road,
Manchester, M13 9PL

Tel: 0161 306 7944.
E-mail: Iracema.Leroi@manchester.ac.uk

Thank you for reading this information sheet and considering whether take part in the study

SAMS (Software Architecture for Mental Health Self-Management)

Pilot Study
Participant Information Leaflet – relatives, friends and carers

We would like to invite you to take part in a pilot study, called 'SAMS', investigating the impact of cognitive problems on computer use.

This information sheet explains what taking part would involve. Please read it carefully, discuss it with others if you wish, and ask us if anything is unclear or if you would like more details.

What is the study all about?
The study is trying to find a way of using information about computer use to detect whether people have problems with memory or with thinking, referred to as cognitive problems. We are doing this because older people are using the computer more often which gives us an opportunity to use this type of information. Using computer data to help detect whether people have memory or cognitive problems has not been done before.
In order to do this, though, we need to trial out the software to see how well it works.

Why have I been invited?
You have been invited because you are a friend, relative or carer of someone who has been experiencing memory or cognitive problems and who has agreed to take part in the study. We need friends, carers or relatives so they can help us to answer some questions about the participant relating to their memory and general well-being.

Can I choose whether or not to take part?
If you wish, a researcher can visit you at home to discuss the study with you. It is up to you to decide whether or not you want to take part. If you do, we will give you this information sheet to keep and we will ask you to sign a consent form. If you decide not to take part, your medical care and legal rights will not be affected. We will only ask you if you would like to take part if the person you are related to or care for who is experiencing a memory or cognitive problem has agreed to take part.

What happens if I change my mind after I have agreed to take part?
If you change your mind after agreeing to take part, you can withdraw at any time, without giving a reason. Again, if you decide to withdraw, your medical care and legal rights will not be affected.

What will happen if I decide to take part?
Following your written consent, the researcher will ask you some questions about the health and daily activities of your friend, relative or person you care for. This will take approximately 30 minutes.

What are the risks of taking part?
There is minimal risk of taking part in the study. The study may add a slight inconvenience to your day.

How will the study benefit me?
Taking part in this study may not directly benefit you however your involvement will contribute significantly to our wider understanding of how to detect memory and cognitive problems. It will add to the scientific community and increase our understanding of memory problems.

As a thank you for taking part and giving up your time you will be offered a small amount of high street store vouchers (£10).

Will my participation in the study be kept confidential?
All the information we collect about you during the course of the study will be kept confidential. The only exception to this is if we feel that you or others around you may be at risk. If this happens, we have a duty to inform an appropriate professional.

Only the study team at the University of Manchester will have access to your personal information. Researchers at the University of Manchester and University of Lancaster will have access to the data you have supplied, but no personal information about you will be provided to them. Your personal data will be held securely at the University of Manchester and will be carefully destroyed as soon as it is not needed. The research data which has your name and any other personal data removed (anonymised) will be stored at both the University of Lancaster and the University of Manchester. The data will be analysed by researchers involved in this study.

What will happen to the results of the study?
When the pilot is complete, we will use the results to improve the SAMS software and prepare it for a larger study which will involve comparing healthy volunteers such as yourself with people with mild Alzheimer's disease.

When the study is complete, we will present the findings at conferences and publish them in scientific journals. All your data will be anonymised and you will not be identified personally. We will let you have a copy of the study results and we will send out a newsletter informing you of the outcome of the study.

With your permission, we would also like to use the anonymised data for future research carried out by the research team and other researchers. You will be able to indicate on the consent form if you agree for your data to be used in this way.

What if something goes wrong?
If there are any issues regarding this research that you would prefer not to discuss with members of the research team, please contact the Research Governance and Integrity Team by either writing to 'The Research Governance and Integrity Manager, Research Office,

Christie Building, The University of Manchester, Oxford Road, Manchester M13 9PL', by emailing: Research.Complaints@manchester.ac.uk, or by telephoning 0161 275 7583 or 275 8093.

Who is organising and funding the research?
The research is funded by the EPSRC (Engineering and Physical Sciences Research Council). This grant was led by Professor Pete Sawyer at the University of Lancaster and covers the running costs of the research project which is led by Dr Iracema Leroi, who is a Consultant Psychiatrist at Manchester Mental Health and Social Care NHS Trust and a Clinical Senior Lecturer in Psychiatry at the University of Manchester.

Who has reviewed the study?
All University of Manchester research is looked at by a Research Ethics Committee to protect your safety, rights, well-being and dignity. This study has been reviewed and been given a favourable opinion by the University of Manchester Ethics Committee.

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E-mail: Iracema.Leroi@manchester.ac.uk

Thank you for reading this information sheet and considering whether take part in the study.

Appendix G – Recruitment materials (study B)

See appendix X (study C) for recruitment materials used in study B. The recruitment materials for study B and C were the same.

Appendix H – Participant instructions sheet for the computer activities (study B)

For Facilitator Use Only	Participant ID	
	Date	
	Start time	
	End time	

Participant instruction sheet – Computer activities

Log-in Name: _____

Password: _____

Task one – General computer operations

In this task, you will do various activities relating to the Windows desktop. For example logging in; opening, viewing and closing documents; or moving and deleting folders.

1	In the log-in screen, enter your username and password, as written above.	
2	Click on the (→) arrow button to log in.	
3	Go to the desktop and find the icon for the Word document called 'Participant instruction sheet'.	
4	Open the document.	
5	Scroll down the open document, so that you can see the end of the document in the window 'Participant instruction sheet'.	
6	Minimise the document window.	
7	Maximise the document window.	

8	Close the MS Word application.	
9	Locate the folder on the desktop called '1st draft'.	
10	Delete this folder ('1st draft') by dragging it to the recycle bin.	
11	Locate the document on the desktop called '2nd draft'.	
12	Move the document ('2nd draft') into the folder called 'Tests'.	
13	Click on the time / date display on the 'Taskbar' (along bottom of screen, on the right hand side).	
14	Click on January 16th 2015 on the calendar.	

Task two – Email

In this task you will be asked to perform various activities relating to receiving and sending e-mails, using the Outlook application. A pretend e-mail account has been set up, and you will be asked to view and reply to various pretend e-mails.

1	Start email program (Microsoft Outlook).	
2	Somebody has sent you an e-mail with the subject 'Important-study'. Locate this message in the inbox.	
3	Open and view this message.	
4	Close the message.	
5	Delete all messages with a subject that includes the word 'SPAM', from the inbox.	
6	Open the message in the inbox which has the subject 'Important-your participation'.	
7	Reply to this message, acknowledging that you are willing to take part in the study, followed by your participant ID.	
8	Locate the message in the inbox which has the subject 'Study schedule'.	
9	Move this message to the folder (in Outlook) called 'SAMS'.	
10	Close the email program (Outlook).	

Task three - Word Processing

1	Start Microsoft Word.	
2	Locate the document on the desktop called ‘Editme’ and open.	
3	Swap the first 2 title lines, i.e. put the ‘Eat well over 60’ heading below the title ‘Nutrition’.	
4	Change the text in line 1 of the second paragraph from ‘Whatever your age and health’ to ‘Whatever your age’.	
5	Delete the first paragraph.	
6	Change the format of the last two lines of the document to italic and bold.	
7	Save the document to the desktop as ‘editme-2’ adding your Participant ID (see top of first sheet) to the title.	
8	Close Word.	

Task four - Diary entry

In this task you will be asked to perform a set of steps involving the creation of a pretend diary entry, using MS Word.

1	Start Microsoft Word (a blank document will open).	
2	Type the title 'Diary Entry'.	
3	Underline the title.	
4	Type a diary entry for today. Write as much as you can in 5 minutes. Use the following prompts if required: • What have you done today? • Who did you spend time with today? What did you do? • What was the weather like today? • Where did you go today and what did you like about this place? • What did you eat for breakfast? • How do you feel about your experiences today? • What are you thankful for today? • What are you looking forward to in the next week?	
5	Save the document to the desktop, as 'diary entry', also adding your participant ID (see top of first sheet) to this title.	
6	Close Word.	

Task five – Web Search

1	Open Internet Explorer	
2	In the Google search engine, do a search for 'John Wayne'.	
3	From the results list, click on the 'John Wayne – Wikipedia' link.	
4	Scroll down the page until you get to the 'Awards and Nominations'. section	
5	In the 1969 nominations table, click on the link for 'True Grit' (highlighted in yellow).	
6	Return to the Wikipedia web page for John Wayne. (This could be done by using the back arrow button (←) at the top of the page.)	
7	Scroll up to the top of the page.	
8	Close Internet Explorer	
9	Log off from the computer.	

Thank-you for participating in this study.

Appendix I - Participant information sheets (study C)

Three separate information sheets are included for cognitively healthy controls, people with cognitive impairment, and informants used in Study C:

Stringer, G., Couth, S., Brown, L. J. E., Montaldi, D., Gledson, A., Mellor, J., Sutcliffe, A., Sawyer, P., Keane, J., Bull, C., Zeng, X., Rayson, P. & Leroi, I. (2018). 'Can you detect early dementia from an email? A proof of principle study of daily computer use to detect cognitive and functional decline', *International journal of geriatric psychiatry*, 33(7), pp. 867-874.

SAMS (Software Architecture for Mental Health Self-Management)

Participant Information Leaflet

We would like to invite you to take part in a research study, called 'SAMS', investigating the impact of cognitive problems on computer use.

This information sheet explains what taking part would involve. Please read it carefully, discuss it with others if you wish, and ask us if anything is unclear or if you would like more details.

What is the study all about?
The study is trying to find a way of using information about computer use to detect whether people have problems with memory or with thinking, referred to as cognitive problems. We are doing this because older people are using the computer more often which gives us an opportunity to use this type of information. Using computer data to help detect whether people have memory or cognitive problems has not been done before.

Why have I been invited?
You have been invited because you have **not** been experiencing memory or cognitive problems. We need people who do not have memory or cognitive problems to enable us to compare with those who do have memory or cognitive problems.

Can I choose whether or not to take part?
If you wish, a researcher can visit you at home to discuss the study with you. It is up to you to decide whether or not you want to take part. If you do, we will give you this information sheet to keep and we will ask you to sign a consent form. If you decide not to take part, your medical care and legal rights will not be affected.

What happens if I change my mind after I have agreed to take part?
If you change your mind after agreeing to take part, you can withdraw at any time, without giving a reason. Again, if you decide to withdraw, your medical care and legal rights will not be affected.

What will happen if I decide to take part?
You will be invited to the University where the SAMS researcher will answer any questions you may have, if you choose to continue you will sign a consent form. Following your written consent, the researcher will ask you to complete a number of assessments to evaluate your cognitive functioning, your mood, your usual computer use practices and how you manage on a day-to-day basis. This will take approximately 90 minutes. You will then be asked to complete a number of basic computer tasks with the researcher beside you. For example, you may be asked to switch on the computer, log on to the computer and send an email. This will take about 45 minutes. You will also be asked to take part in an audio-recorded conversation

asking you about your experience of the tasks and your feelings about having your computer use monitored, this will last about 15 minutes.

What are the risks of taking part?
There is minimal risk of taking part in the study. The study may add a slight inconvenience to your day as you will be required to complete assessments and computer tasks for approximately 2 hours.

How will the study benefit me?
Taking part in this study may not directly benefit you however your involvement will contribute significantly to our wider understanding of how to detect memory and cognitive problems. It will add to the scientific community and increase our understanding of memory problems.

As a thank you for taking part and giving up your time you will be offered a small amount of high street store vouchers (£10).

Will my participation in the study be kept confidential?
Your participation will be kept confidential, but we would like to inform your GP, with your permission, that you have agreed to take part. In some cases people are not aware that they are having memory problems that might be considered clinically important. We will ask you if you would like us to inform your GP if we detect any clinically significant problems.

Only the study team at the University of Manchester will have access to your personal information. Researchers at the University of Manchester and University of Lancaster will have access to the data you have supplied, but no personal information about you will be provided to them. Your personal data will be held securely at the University of Manchester and will be carefully destroyed as soon as it is not needed. The research data which has your name and any other personal data removed (anonymised) will be stored at both the University of Lancaster and the University of Manchester. The data will be analysed by researchers involved in this study.

Individuals from the University, regulatory authorities or NHS Trust may need to access the data collected to ensure that the study is being carried out properly. All individuals will be authorised representatives from each organisation and will have a duty of confidentiality to all research participants.

What will happen to the results of the study?
When the study is complete, we will present the findings at conferences and publish them in scientific journals. All your data will be anonymised and you will not be identified personally. We will let you have a copy of the study results and we will send out a newsletter informing you of the outcome of the study.

With your permission, we would also like to use the anonymised data for future research carried out by the research team and other researchers. You will be able to indicate on the consent form if you agree for your data to be used in this way.

What if something goes wrong?
If there are any issues regarding this research that you would prefer not to discuss with members of the research team, please contact the Research Governance and Integrity Team by either writing to 'The Research Governance and Integrity Manager, Research Office, Christie Building, The University of Manchester, Oxford Road, Manchester M13 9PL', by emailing: Research.Complaints@manchester.ac.uk, or by telephoning 0161 275 7583 or 275 8093.

If you want further advice and support, you can also contact the patient advice and liaison service (PALS – 0161 882 2084).

Who is organising and funding the research?
The research is funded by the EPSRC (Engineering and Physical Sciences Research Council). Professor Pete Sawyer at the University of Lancaster was awarded the grant that covers the running costs of the research project. The research is led by Dr Iracema Leroi, who is a Consultant Psychiatrist at Manchester Mental Health and Social Care NHS Trust and a Clinical Senior Lecturer in Psychiatry at the University of Manchester.

Who has reviewed the study?
All NHS research is looked at by an independent group of people, called a Research Ethics Committee to protect your safety, rights, well-being and dignity. This study has been reviewed and been given a favourable opinion by the NRES Committee North West – GM Central.

Who can I contact for further information?
For more information, please contact:

Gemma Stringer (Research Associate)
University of Manchester,
Jean McFarlane Building,
Oxford Road,
Manchester,
M13 9PL

Tel: 0161 306 7493
Email: gemma.stringer@manchester.ac.uk

OR
Dr Iracema Leroi,
University of Manchester,
Jean McFarlane Building,
Oxford Road,
Manchester, M13 9PL

Tel: 0161 306 7944.
E-mail: Iracema.Leroi@manchester.ac.uk

Thank you for reading this information sheet and considering whether take part in the study.

SAMS (Software Architecture for Mental Health Self-Management)

Participant Information Leaflet

We would like to invite you to take part in a research study, called 'SAMS', investigating whether your personal computer use can help us detect whether you might have some memory or cognitive problems.

This information sheet explains what taking part would involve. Please read it carefully, discuss it with others if you wish, and ask us if anything is unclear or if you would like more details.

What is the study all about?
The study is trying to find a way of using information about computer use to detect whether people have problems with memory or with thinking, referred to as cognitive problems. We are doing this because older people are using the computer more often which gives us an opportunity to use this type of information. Using computer data to help detect whether people have memory or cognitive problems has not been done before.

Why have I been invited?
You have been invited because you have been experiencing memory or cognitive problems and at some point have had a memory assessment.

Can I choose whether or not to take part?
If you wish, a researcher can visit you at home to discuss the study with you. It is up to you to decide whether or not you want to take part. If you do, we will give you this information sheet to keep and we will ask you to sign a consent form. If you decide not to take part, your medical care and legal rights will not be affected.

What happens if I change my mind after I have agreed to take part?
If you change your mind after agreeing to take part, you can withdraw at any time, without giving a reason. Again, if you decide to withdraw, your medical care and legal rights will not be affected.

What will happen if I decide to take part?
A SAMS' researcher will visit you at home to answers any questions you may have, if you choose to continue you will sign a consent form. Following your written consent, the researcher will ask you to complete a number of tasks to evaluate your cognitive functioning, your mood, your usual computer use practices and how you manage on a day-to-day basis. This will take approximately 90 minutes. You will then be asked to complete a number of basic computer tasks with the researcher beside you. For example, you may be asked to switch on the computer, log on to the computer and send an email. This will take about 45 minutes. You will

also be asked to take part in an audio-recorded conversation asking you about your experience of the tasks and your feelings about having your computer use monitored, this will last about 15 minutes.

A friend or family member will also be asked whether they are happy to complete some questionnaires about how you are. This will take approximately 30 minutes.

What are the risks of taking part?
There is minimal risk of taking part in the study. The study may add a slight inconvenience to your day as you will be required to complete assessments and computer tasks for approximately 2 hours.

How will the study benefit me?
Taking part in this study may not directly benefit you however your involvement will contribute significantly to our wider understanding of how to detect memory and cognitive problems. It will add to the scientific community and increase our understanding of memory problems.

As a thank you for taking part and giving up your time you will be offered a small amount of high street store vouchers (£10).

Will my participation in the study be kept confidential?
Your participation will be kept confidential, but we would like to inform your GP, with your permission, that you have agreed to take part. Your GP will not be informed of any of the results of the tasks or assessments you have carried out, unless you specifically wish us to.

Only the study team at the University of Manchester will have access to your personal information. Researchers at the University of Manchester and University of Lancaster will have access to the data you have supplied, but no personal information about you will be provided to them. Your personal data will be held securely at the University of Manchester and will be carefully destroyed as soon as it is not needed. The research data which has your name and any other personal data removed (anonymised) will be stored at both the University of Lancaster and the University of Manchester. The data will be analysed by researchers involved in this study

Individuals from the University, regulatory authorities or NHS Trust may need to access the data collected to ensure that the study is being carried out properly. All individuals will be authorised representatives from each organisation and will have a duty of confidentiality to all research participants.

What will happen to the results of the study?
When the study is complete, we will present the findings at conferences and publish them in scientific journals. All your data will be anonymised and you will not be identified personally. We will let you have a copy of the study results and we will send out a newsletter informing you of the outcome of the study.

With your permission, we would also like to use the anonymised data for future research carried out by the research team and other researchers. You will be able to indicate on the consent form if you agree for your data to be used in this way.

What if something goes wrong?
If there are any issues regarding this research that you would prefer not to discuss with members of the research team, please contact the Research Governance and Integrity Team by either writing to 'The Research Governance and Integrity Manager, Research Office, Christie Building, The University of Manchester, Oxford Road, Manchester M13 9PL', by emailing: Research.Complaints@manchester.ac.uk, or by telephoning 0161 275 7583 or 275 8093.

If you want further advice and support, you can also contact the patient advice and liaison service (PALS – 0161 882 2084).

Who is organising and funding the research?
The research is funded by the EPSRC (Engineering and Physical Sciences Research Council). Professor Pete Sawyer at the University of Lancaster was awarded the grant that covers the running costs of the research project. The research is led by Dr Iracema Leroi, who is a Consultant Psychiatrist at Manchester Mental Health and Social Care NHS Trust and a Clinical Senior Lecturer in Psychiatry at the University of Manchester.

Who has reviewed the study?
All NHS research is looked at by an independent group of people, called a Research Ethics Committee to protect your safety, rights, well-being and dignity. This study has been reviewed and been given a favourable opinion by the NRES Committee North West – GM Central.

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SAMS (Software Architecture for Mental Health Self-Management)

Participant Information Leaflet – relatives, friends and carers

We would like to invite you to take part in a research study, called 'SAMS', investigating the impact of cognitive problems on computer use.

This information sheet explains what taking part would involve. Please read it carefully, discuss it with others if you wish, and ask us if anything is unclear or if you would like more details.

What is the study all about?
The study is trying to find a way of using information about computer use to detect whether people have problems with memory or with thinking, referred to as cognitive problems. We are doing this because older people are using the computer more often which gives us an opportunity to use this type of information. Using computer data to help detect whether people have memory or cognitive problems has not been done before.

Why have I been invited?
You have been invited because you are a friend, relative or carer of someone who has been experiencing memory or cognitive problems and who has agreed to take part in the study. We need friends, carers or relatives so they can help us to answer some questions about the participant relating to their memory and general well-being. The study involves 30 people experiencing memory or cognitive problems and their friends, relatives or carers and as a comparison 30 healthy controls subjects.

Can I choose whether or not to take part?
If you wish, a researcher can visit you at home to discuss the study with you. It is up to you to decide whether or not you want to take part. If you do, we will give you this information sheet to keep and we will ask you to sign a consent form. If you decide not to take part, your medical care and legal rights will not be affected. We will only ask you if you would like to take part if the person you are related to or care for who is experiencing a memory or cognitive problem has agreed to take part.

What happens if I change my mind after I have agreed to take part?
If you change your mind after agreeing to take part, you can withdraw at any time, without giving a reason. Again, if you decide to withdraw, your medical care and legal rights will not be affected.

What will happen if I decide to take part?
A SAMS' researcher will visit you at home to answers any questions you may have, if you choose to continue you will sign a consent form, this will be done after gaining consent from the person experiencing memory or cognitive problems. Following your written consent, the

researcher will ask you some questions about the participant (your friend, relative or person you care for). This will take approximately 30 minutes.

What are the risks of taking part?

There is minimal risk of taking part in the study. The study may add a slight inconvenience to your day as you will be required to complete assessments and computer tasks for approximately 2 hours.

How will the study benefit me?

Taking part in this study may not directly benefit you however your involvement will contribute significantly to our wider understanding of how to detect memory and cognitive problems. It will add to the scientific community and increase our understanding of memory problems.

As a thank you for taking part and giving up your time you will be offered a small amount of high street store vouchers (£10).

Will my participation in the study be kept confidential?

Your participation and all the information we collect will be kept confidential. The only exception to this is if we feel that you or others around you may be at risk. If this happens, we have a duty to inform an appropriate professional.

Only the study team at the University of Manchester will have access to your personal information. Researchers at the University of Manchester and University of Lancaster will have access to the data you have supplied, but no personal information about you will be provided to them. Your personal data will be held securely at the University of Manchester and will be carefully destroyed as soon as it is not needed. The research data which has your name and any other personal data removed (anonymised) will be stored at both the University of Lancaster and the University of Manchester. The data will be analysed by researchers involved in this study.

What will happen to the results of the study?

When the study is complete, we will present the findings at conferences and publish them in scientific journals. All your data will be anonymised and you will not be identified personally. We will let you have a copy of the study results and we will send out a newsletter informing you of the outcome of the study.

With your permission, we would also like to use the anonymised data for future research carried out by the research team and other researchers. You will be able to indicate on the consent form if you agree for your data to be used in this way.

What if something goes wrong?

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emailing: Research.Complaints@manchester.ac.uk, or by telephoning 0161 275 7583 or 275 8093.

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University of Manchester,
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Manchester, M13 9PL

Tel: 0161 306 7944.
E-mail: Iracema.Leroi@manchester.ac.uk

OR

Thank you for reading this information sheet and considering whether take part in the study.

Appendix J – Recruitment materials (study C)

Three separate recruitment materials are included from study C: the advert for cognitively healthy controls, the advert for people with cognitive impairment and the letter of invite:

Stringer, G., Couth, S., Brown, L. J. E., Montaldi, D., Gledson, A., Mellor, J., Sutcliffe, A., Sawyer, P., Keane, J., Bull, C., Zeng, X., Rayson, P. & Leroi, I. (2018). 'Can you detect early dementia from an email? A proof of principle study of daily computer use to detect cognitive and functional decline', *International journal of geriatric psychiatry*, 33(7), pp. 867-874.

Do you use a computer?

Are you interested in how your thinking and cognition can affect the way you use a computer?

The **SAMS** (Software Architecture for Mental health Self-management) project is researching computer software which may be able to detect early signs of memory problems by analysing recordings of normal computer use.

We are seeking volunteers over the age of 65 to help in an experiment to test the SAMS computer software.

If you are interested in finding out more about this research and the possibility of taking part please contact:

Gemma Stringer
Tel: 0161 306 7493
E: gemma.stringer@manchester.ac.uk
OR

Dr Iracema Leroi,
Tel: 0161 306 7944.
E: iracema.leroi@manchester.ac.uk

Do you use a computer?

Are you interested in how your thinking and cognition can affect the way you use a computer?

Have you been experiencing memory or cognitive problems?

The **SAMS** (Software Architecture for Mental health Self-management) project is researching computer software which may be able to detect early signs of memory problems by analysing recordings of normal computer use.

We are seeking volunteers over the age of 65 to help in an experiment to test the SAMS computer software.

If you are interested in finding out more about this research and the possibility of taking part please contact:

Gemma Stringer
Tel: 0161 306 7493
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OR

Dr Iracema Leroi,
Tel: 0161 306 7944.
E: iracema.leroi@manchester.ac.uk

[insert date]

Dear Sir/Madam

The SAMS project – Software Architecture for Mental health Self-management.

We are seeking volunteers over 65 years old to help in an experiment researching computer software which could detect early signs of memory problems by analysing recordings of computer use.

Diagnosis of memory related problems normally requires several tests in memory clinics. Computer programs are being developed to recognise these problems from recordings of interaction with home computers and email messages. The programs monitor people's use of the mouse and keyboard when doing routine tasks such as email or word-processing. This data and the content of emails and documents is analysed to detect cognitive functioning, for example, memory and language.

The aim of the experiment is to test whether the SAMS computer programs can reliably detect the difference between cognitively healthy older people and people who have been experiencing memory or cognitive problems.

A full information sheet explaining the study in more detail is enclosed. We would appreciate it if you could read the information sheet and let us know by phone or email if you are interested in taking part. You do not have to take part in the study, and your treatment will not be affected in any way.

The research is funded by the EPSRC (Engineering and Physical Sciences Research Council) and is being co-ordinated by the University of Manchester.

Please contact Gemma Stringer (Research Associate) Tel: 0161 306 7493 or email: gemma.stringer@manchester.ac.uk if you have any questions about the study.

Yours sincerely

Dr Iracema Leroi,

University of Manchester,
Jean McFarlane Building,
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Appendix K – Computer activities materials (study C)

Four materials from the computer use activities in study C are included: the participant ID and log-in sheet, the computer activities script, the participant instructions for the practice activities and the participant instructions for the main computer activities.

Stringer, G., Couth, S., Brown, L. J. E., Montaldi, D., Gledson, A., Mellor, J., Sutcliffe, A., Sawyer, P., Keane, J., Bull, C., Zeng, X., Rayson, P. & Leroi, I. (2018). 'Can you detect early dementia from an email? A proof of principle study of daily computer use to detect cognitive and functional decline', *International journal of geriatric psychiatry*, 33(7), pp. 867-874.

Participant ID and Log-in Sheet

Participant details

Participant ID: ……

(Type this ID at the end of the document title when instructed to save documents)

Computer log–on details

Username: ……

Password: B!llythek!d1

Computer activities script

Practice Laptop Activities

Set up the laptop in front of the participant and **give them the practice laptop activities sheet**.

Then say:

"We are going to start with some practice activities on the laptop. This is just so that you can familiarise yourself with the laptops and some of the programs that we will be using today. The aim of this short, practice exercise is to check you are familiar with the Windows user interface. It is only a practice run and will not be recorded. Please have a go at the tasks below in your own time and feel free to ask any questions as you go along."

Help the participant as much as they need at this stage to enable them to complete the practice activities. Record any observations during this activity on the observation form.

Main computer activities

Set logger running (see experiment set up sheet)

Give participant the key info sheet (check filled out).

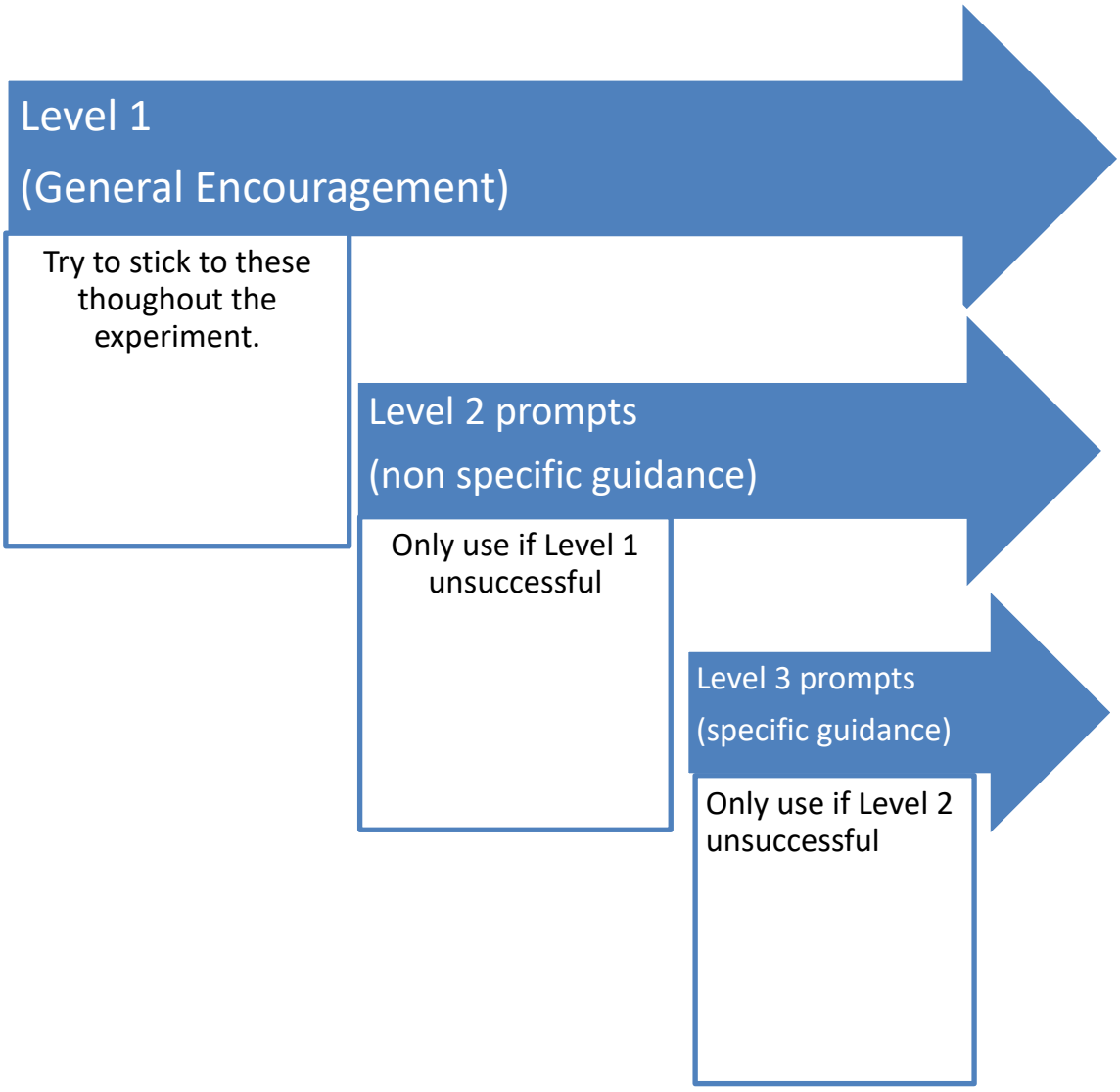
Then say:

"Now we are going to do the main activities. We want you to work through the instructions on this sheet ***(hand participant the participant instruction sheet)*** *in your own time. We want you to try to do the activities on your own. If you are unsure about anything try and work it out on your own and go with what you think is right. I will be here the whole time."*

Sit back from the participant and use the participant observation sheet to make notes. Note down anything that the participant struggles with and answer questions they ask. Record your responses using the prompts guidance below.

Prompts explanation

Record all prompt level and specific wording of support on the participant observation sheet.



Level 1 prompts

This level is general encouragement – try to stick to the following comments:

Keep going

You're doing fine

Go with what you think

Check the instruction sheet

Level 2 prompts

At this level you may need to provide non-specific guidance – again try to stick to the following comments where relevant:

It is on the screen

You did it in the last task

You're in the right place

You're not quite in the right place, try looking somewhere else

Level 3 prompts

At this level the prompts will be very specific, use the following example as a guideline. If possible write down what you had to say.

It's in the bottom right hand corner

I'll point to it on the screen

You need to double click

You only need to click once

You need to right click rather left

Practice Laptop Activities

The aim of this short, practice exercise is to check you are familiar with the Windows 7 user interface. It is only a practice run and will not be recorded. Please have a go at the tasks below in your own time and feel free to ask any questions as you go along.

Desktop/Word

1. Click on the time/date display on the 'Taskbar' (located along bottom of screen, on the right hand side) and scroll to the next month.
2. Open the Word document on the desktop titled 'Thank you letter to speaker'.
3. Scroll to the top of that document.
4. Highlight all the text and make it bold.
5. Minimise the Word document window, maximise it.
6. Close Word (clicking on 'Don't Save').

Email

1. Open Microsoft Outlook.
2. Click on 'New Email'.

3. Type “Hi” in the message box.
4. Close email without sending (select “No” when asked if you want to save the changes).
5. Close Microsoft Outlook

Internet Explorer

1. Open Internet Explorer.
2. In the Google search box type in “Frogs”.
3. Click on the first result in the list.
4. Close Internet Explorer.

For Facilitator Use Only	Participant ID	
	Windows edition (please circle)	Windows 7 Windows 8
	Date	
	Start time	
	End time	

Participant instruction sheet – Computer activities

Task one – General computer operations

In this task, you will do various activities relating to the Windows desktop. For example logging in; opening, viewing and closing documents; or moving and deleting folders.

1	Open the Word document called '*Participant instruction sheet*', which is located on the desktop.	
2	Scroll to the bottom of the document.	
3	Minimise the document window.	
4	Maximise the document window.	
5	Close the Word document. (If prompted to save, click '*Don't Save*'.)	
6	Delete the folder on the desktop, called '*1st draft*', by dragging it to the recycle bin.	
7	Move the document on the desktop, called '*2nd draft'*, into the folder called '*Tests*'.	
8	Click on the time / date display on the '*Taskbar*' (located along bottom of screen, on the right hand side).	
9	Click on *January 16th 2015*.	

Task two – Email

In this task you will be asked to perform various activities relating to receiving and sending e-mails, using the Outlook application. A pretend e-mail account has been set up, and you will be asked to view and reply to various pretend e-mails.

1	Start email program (‘*Microsoft Outlook’*).	
2	Find the email somebody has sent you, with the subject ‘*Important-study*’.	
3	Open the email in a new window.	
4	Close the email.	
5	Delete all emails, with the word ‘*SPAM*’ in the title, from the *inbox*.	
6	Open the email, in the inbox, which has the subject ‘*Important-your participation*’.	
7	Reply to this email, saying: “I am willing to take part in the study”, followed by typing your *participant ID*. Send the email.	
8	Move the email located in the inbox, with the subject ‘*Study schedule’*, to the Outlook folder called ‘*SAMS*’.	
9	Close the email program (‘*Microsoft Outlook’*).	

Task three - Word Processing

In this task you will be asked to perform a set of steps involving editing a document and the creation of a diary entry, using MS Word.

1	Open the document, on the desktop, called '*Editme*'.	
2	Cut the title '*Eat well over 60*' and paste it below the title '*Nutrition*'.	
3	Edit the text in line 1 (of the second paragraph) from '*Whatever your age and health*' to '*Whatever your age'*.	
4	Delete all the text in the document.	
5	Type the title '*Diary Entry*'.	
6	For the next 3 minutes, type a diary entry for today. Write as much as you can. The experimenter will tell you when 3 minutes have passed. Below are some examples of what you could write about: • *What have you done today?* • *Where did you go today and what did you like about this place?* • *Who did you spend time with? What did you do?* • *What was the weather like today?* • *How do you feel about your experiences today?* • *What are you looking forward to in the next week?*	
7	Save the document to the desktop, as '*Diary Entry*' adding your *participant ID* to this title.	
8	Close Word.	

Task four – Web Search

1	Open '*Internet Explorer*'	
2	In the 'Google' search engine, type and search for '*John Wayne*'.	
3	From the results list, click on the '*John Wayne – Wikipedia*' link.	
4	Scroll down the Wikipedia page until you get to the '*Awards and Nominations*' section	
5	In the *1969 nominations* table, click on the link for '*True Grit*' (*highlighted in yellow*).	
6	Return to the Wikipedia web page for John Wayne. (You can do this by clicking the back arrow button (←) at the top of the page.)	
7	Scroll up to the top of the page.	
8	Close Internet Explorer	

Thank-you for participating in this study.

☺

Appendix L – Participant information (study D)

Two separate information sheets are included for people with SCI or MCI and informants used in Study D:

Stringer, G., Couth, S., Heuvelman, H., Bull, C., Gledson, A., A., Keane, Rayson, P., Sawyer, P., Sutcliffe, J., Zeng, X., Montaldi, D., Brown, L. J. E., & Leroi, I. (2020) 'Passive assessment of computer use behaviours in the home can indicate early cognitive impairment: An exploratory longitudinal study'.

SAMS (Software Architecture for Mental Health Self-Management): Longitudinal Study

Participant Information Leaflet

We would like to invite you to take part in a research study, called 'SAMS', investigating the impact of cognitive problems on computer use.

This information sheet explains what taking part would involve. Please read it carefully, discuss it with others if you wish, and ask us if anything is unclear or if you would like more details.

What is the study all about?

The study is trying to find a way of using information about computer use to detect problems with memory or thinking ('cognitive' difficulties). We are doing this because the numbers of older people using computers is increasing and this gives us an opportunity to find out whether changes in a person's computer use can reveal clues about their thinking and memory ability. Using computer information in this way has not been done before.

Why have I been invited?

You have been invited because you may have noticed a change in your memory or thinking and because you are a computer user, who uses a computer at least once a week.

What will I be required to do?

We will ask you to continue your normal computer use (i.e. emails, internet etc.) for a 9 month period. The types of activity that we are interested in include: typing, mouse moves, using the desktop, internet searching, emails and written text. We will record aspects of this activity using SAMS software which will be installed onto your home computer but will not interfere with the normal functioning of your computer. Once the SAMS software is installed on your computer you will have complete control over it. You will not notice that SAMS has been installed other than the appearance of 'pop-up' reminders:

- You will be reminded that that the SAMS software is running whenever it starts up and, if you keep your computer and the SAMS software running continuously, at daily intervals thereafter.

- You will be able to stop the SAMS software running whenever you want. If you stop the SAMS software and do not restart it, you will receive a pop-up reminder after 24 hours have passed and at daily intervals thereafter to remind you that you have disabled SAMS and to invite you to re-start the software. If after 5 reminders you have not re-started the SAMS software, we will telephone you to find out if there is something concerning you or if you would like us to disable the reminders.

At weekly intervals over the course of the year you will be asked to complete a diary that will help us to keep track of your progress. Completing the diary entries is an optional part of the study and it is up to you how often you decide to complete them. At three times during the 9 months we will ask you to complete a number of brief assessments to record your memory and thinking, your mood and your daily activities. This will be completed at the start of the investigation, midway through (month 4.5), and at the end (month 9). On two of these occasions we will ask you to complete an interview with our researcher in your own home or on the phone. In this interview we will ask you about your computer use and daily activities. We may also invite you to take part in a one-off focus group at the University of Manchester to discuss your computer activities and opinions on modern technology with other participants involved in this study. Finally, we will give you a brief phone call every month to check how you are doing.

We will ask if there is someone who knows you well who could take part in the study with you as an informant. This person could be your spouse, partner, a relative, a friend or a carer. In addition to the information you provide, we would ask them to provide information about your memory, thinking, health and well-being. This would take place three times during the 9 months and can happen at the same time as your scheduled assessments or at an alternative time within 2 weeks of your assessment. This person would only take part and provide information about you if you consent for them to do so. This is not a compulsory part of the research and if you prefer you can take part in the study without an informant.

Can I choose whether or not to take part?

If you wish, a researcher can visit you at home to discuss the study with you. It is up to you to decide whether or not you want to take part. If you do, we will give you this information sheet to keep and we will ask you to sign a consent form. If you decide not to take part, your medical care and legal rights will not be affected.

What happens if I change my mind after I have agreed to take part?

If you change your mind after agreeing to take part, you can withdraw at any time, without giving a reason. If you withdraw, your medical care and legal rights will not be affected. The data collected from you to the point of withdrawal will still be used.

What will happen if I decide to take part?

- A member of the research team will speak to you over the phone and ask you a few questions to check your eligibility for the study. We will ask your age, your experience of memory problems and some general computer questions including how often you use a computer, if you have the internet at your home address and some questions to check that the SAMS software will work on your computer.

- If you are eligible and happy to continue the research team will then visit you at your home address to complete the consent process and screening process which will take approximately 1 hour. The screening will include a brief assessment of your memory and thinking and questions about your daily activities. If you have agreed for an informant to take part with you, we will also ask them to complete the consent process at this time.

- After the screening we will install the SAMS software on your home computer and we will provide you with all of the information you need regarding the computer software and the technical helpline (which is there for you to call if you have any technical problems relating to the study). You will also be provided with a telephone number and email address to contact if you have any other questions during the study.

- After the screening visit, a second visit to your home will be arranged to conduct a short audio recorded interview asking you about your current computer use and daily activities, this will last approximately 30 minutes. We will then complete a more detailed assessment of your memory and how you think. This will take approximately 90 minutes. The SAMS software will then be turned on.

If an informant is taking part with you, we will also ask them to complete some questionnaires.

- The assessments of your memory and cognition will be completed two more times over the 9 months that you will be enrolled in the study: 1) halfway through the study (4.5 months) and 2) at the end of the study (9 months). The interview will be conducted again at the end of the study. If an informant is taking part with you, we will also ask them to complete some questionnaires at these two time points.

- At weekly intervals over the course of the year you will be asked to complete a short diary entry that should take approximately 20 minutes. Completing the diary entries is an optional part of the study and it is up to you how often you decide to complete them. Information about the diary and a short demonstration of what it will look like on the screen will be provided when the SAMS software is installed.

- We will call you every month to check how you are doing and to ask if there has been any change in your circumstances that might impact on your computer use. We will also ask if you have had any technical difficulties that you have not reported to the technical team (via the helpline).

- You may also be invited to take part in a one-off focus group at the University of Manchester to discuss your computer use activities with other participants involved in this study. This will take place within the 9 month testing period at a time that is convenient to all participants. This is also an optional part of the study

<u>What are the risks of taking part?</u>

There is minimal risk in taking part in this study. The study may add an inconvenience to your day at the following times: screening assessment (1 hour); weekly diary entry (15-30 minutes); monthly phone calls (10 minutes) and the 1 month (2 hours), 4.5 month (90 minutes), 9 month (2 hours) assessments, and the focus group (2 hours).

Travel to and from the University for the focus group involves some risks. The researcher will discuss the best and safest travel options with you beforehand and reasonable travel expenses will be reimbursed.

How will the study benefit me?

Taking part in this study may not directly benefit you however your involvement will contribute significantly to our wider understanding of how to detect memory and thinking problems. It will increase knowledge in the scientific community and improve our understanding of memory problems and how we might detect them earlier than we currently do.

Will my participation in the study be kept confidential?

Your participation and all the information we collect about you will be kept confidential. The only exceptions to this are:

- If we feel that something you reveal suggests that you or others around you may be at risk of harm. If this happens, we have a duty to inform an appropriate professional.
- If we find evidence of criminal activity on your computer. If this happens, we have a legal duty to inform the police.

With your permission, we would like to inform your GP that you have agreed to take part. We will ask you if you would like us to inform your GP if we detect any clinically significant change in your memory or thinking following the assessments.

Only the research team at the University of Manchester including clinical and research staff will have access to your personal information. Your personal data will be held securely at the University of Manchester and will be carefully destroyed as soon as it is not needed. The research data which has your name and any other personal data removed (anonymised) will be stored at both the University of Lancaster and the University of Manchester. The data will be analysed by researchers involved in this study.

Your medical records will only be viewed by members of the clinical team within the NHS who are part of the larger research team.

Audio recorded interview and focus group data will be transcribed and, when used in publications, quotes will be anonymised.

The SAMS software is designed to record all input through the keyboard and mouse. All of the data that the SAMS software records will be protected with a high level of

security. The SAMS software DOES NOT record information entered on certain websites such as banking websites; this is to protect your security information. The SAMS software WILL NOT record passwords entered into password fields. The types of websites where the SAMS software would record input include Google searches and email systems such as Yahoo mail and Hotmail.

Individuals from the University, regulatory authorities or NHS Trust may need to access the data collected to ensure that the study is being carried out properly. This is to protect you by ensuring that we are doing the research in a safe and ethical way. All individuals will be authorised representatives from each organisation and will have a **duty of confidentiality** to all research participants.

What will happen to the results of the study?

When the study is complete, we will present the findings at conferences and publish them in scientific journals. **All your data will be anonymised** and **you will not be identified personally**. We will let you have a copy of the study results and we will send out a newsletter informing you of the study findings.

With your permission, we would also like to use the anonymised data for future research carried out by the research team and other researchers. You will be able to indicate on the consent form if you agree for your data to be used in this way. If not, your data will be destroyed.

What if something goes wrong?

If there are any issues regarding this research that you would prefer not to discuss with members of the research team, please contact the Research Governance and Integrity Team by either writing to 'The Research Governance and Integrity Manager, Research Office, Christie Building, The University of Manchester, Oxford Road, Manchester M13 9PL', by emailing: Research.Complaints@manchester.ac.uk, or by telephoning 0161 275 7583 or 275 8093.

In the event that something does go wrong and you are harmed during the research you may have grounds for a legal action for compensation against the University of Manchester, University of Lancaster or NHS Trust but you may have to pay your legal costs. The normal National Health Service complaints mechanisms will still be available to you.

If you want further advice and support, you can also contact the patient advice and liaison service (PALS – 0161 882 2084).

Who is organising and funding the research?

The research is funded by the EPSRC (Engineering and Physical Sciences Research Council). Professor Pete Sawyer at the University of Lancaster was awarded the grant that covers the running costs of the research project. The research is led by Dr Iracema Leroi, who is a Consultant Psychiatrist at Manchester Mental Health and Social Care NHS Trust and a Clinical Senior Lecturer in Psychiatry at the University of Manchester.

Who has reviewed the study?

All NHS research is looked at by an independent group of people, called a Research Ethics Committee to protect your safety, rights, well-being and dignity. This study has been reviewed and been given a favourable opinion by the NRES Committee North West – GM South.

Who can I contact for further information?

For more information, please contact:

Gemma Stringer (Research Associate) University of Manchester, Jean McFarlane Building, Oxford Road, Manchester, M13 9PL Tel: 0161 306 7493 Email: gemma.stringer@manchester.ac.uk	OR Dr Iracema Leroi, University of Manchester, Jean McFarlane Building, Oxford Road, Manchester, M13 9PL Tel: 0161 306 7944 Email: Iracema.Leroi@manchester.ac.uk

Thank you for reading this information sheet and considering whether take part in the study.

SAMS (Software Architecture for Mental Health Self-Management): Longitudinal Study

Participant Information Leaflet – Informant

We would like to invite you to take part in a research study, called 'SAMS', investigating the impact of cognitive problems on computer use.

This information sheet explains what taking part would involve. Please read it carefully, discuss it with others if you wish, and ask us if anything is unclear or if you would like more details.

What is the study all about?

The study is trying to find a way of using information about computer use to detect problems with memory or thinking ('cognitive' difficulties). We are doing this because the numbers of older people using computers is increasing and this gives us an opportunity to find out whether changes in a person's computer use can reveal clues about their thinking and memory ability. Using computer information in this way has not been done before.

Why have I been invited?

You have been invited because you know someone who has noticed a change in their memory and/or thinking and that person has also agreed to take part in this study. We need people who know the participants taking part in the study so they can help us to answer some questions relating to their memory and general well-being.

Can I choose whether or not to take part?

If you wish, a researcher can visit you at home to discuss the study with you. It is up to you to decide whether or not you want to take part. If you do, we will give you this information sheet to keep and we will ask you to sign a consent form.

What happens if I change my mind after I have agreed to take part?

If you change your mind after agreeing to take part, you can withdraw at any time, without giving a reason. The data collected from you to the point of withdrawal will still be used.

What will happen if I decide to take part?

A SAMS' researcher will visit you at home to answers any questions you may have, if you choose to continue you will sign a consent form. After gaining your consent (and the consent of the person you know), we will ask you some questions on four occasions across a 9 month period, on each occasion the questions will take approximately 30 minutes. The questions will be about the person you know, regarding their health, well-being and ability to complete various activities.

What are the risks of taking part?

There is minimal risk of taking part in the study. The study may add an inconvenience to your day on the four days when we complete the data collection (approximately 30 minutes per visit).

How will the study benefit me?

Taking part in this study may not directly benefit you however your involvement will contribute significantly to our wider understanding of how to detect memory and cognitive problems. It will add to the scientific community and increase our understanding of memory problems.

Will my participation in the study be kept confidential?

Your participation and all the information we collect will be kept confidential. The only exception to this is if we feel that something you reveal suggests that you or others around you may be at risk of harm. If this happens, we have a duty to inform an appropriate professional.

Only the study team at the University of Manchester will have access to your personal information. Your personal data will be held securely at the University of Manchester and will be carefully destroyed as soon as it is not needed. The research data which has your name and any other personal data removed (anonymised) will be stored at both the

University of Lancaster and the University of Manchester. The data will be analysed by researchers involved in this study.

What will happen to the results of the study?

When the study is complete, we will present the findings at conferences and publish them in scientific journals. **All your data will be anonymised** and **you will not be identified personally**. We will let you have a copy of the study results and we will send out a newsletter informing you of the outcome of the study.

With your permission, we would also like to use the anonymised data for future research carried out by the research team and other researchers. You will be able to indicate on the consent form if you agree for your data to be used in this way.

What if something goes wrong?

If there are any issues regarding this research that you would prefer not to discuss with members of the research team, please contact the Research Governance and Integrity Team by either writing to 'The Research Governance and Integrity Manager, Research Office, Christie Building, The University of Manchester, Oxford Road, Manchester M13 9PL', by emailing: Research.Complaints@manchester.ac.uk, or by telephoning 0161 275 7583 or 275 8093.

In the event that something does go wrong and you are harmed during the research you may have grounds for a legal action for compensation against the University of Manchester, University of Lancaster or NHS Trust but you may have to pay your legal costs. The normal National Health Service complaints mechanisms will still be available to you.

If you want further advice and support, you can also contact the patient advice and liaison service (PALS – 0161 882 2084).

Who is organising and funding the research?

The research is funded by the EPSRC (Engineering and Physical Sciences Research Council). Professor Pete Sawyer at the University of Lancaster was awarded the grant that covers the running costs of the research project. The research is led by Dr Iracema Leroi,

who is a Consultant Psychiatrist at Manchester Mental Health and Social Care NHS Trust and a Clinical Senior Lecturer in Psychiatry at the University of Manchester.

Who has reviewed the study?

All NHS research is looked at by an independent group of people, called a Research Ethics Committee to protect your safety, rights, well-being and dignity. This study has been reviewed and been given a favourable opinion by the NRES Committee North West – GM South.

Who can I contact for further information?

For more information, please contact:

Gemma Stringer (Research Associate) University of Manchester, Jean McFarlane Building, Oxford Road, Manchester, M13 9PL Tel: 0161 306 7493 Email: gemma.stringer@manchester.ac.uk	OR Dr Iracema Leroi, University of Manchester, Jean McFarlane Building, Oxford Road, Manchester, M13 9PL Tel: 0161 306 7944 Email: Iracema.Leroi@manchester.ac.uk

Thank you for reading this information sheet and considering whether take part in the study.

SAMS (Software Architecture for Mental Health Self-Management): Longitudinal Study

Verbal Participant Information Sheet (version 1)

Researcher name:

Date:

Time:

First, **let the participant know who you are** and **why you are calling (if contacting JDR participants only):** state that you are contacting them because they have expressed an interest in taking part in the SAMS study.

Ask them **whether they would like to know a little more about the study**. If **yes, see below**. If **no, thank them for their time and end the call**.

"*This study is trying to find a way of using information about computer use to detect problems with memory or thinking. We are doing this because the numbers of older people using computers is increasing and this gives us an opportunity to find out whether changes in a person's computer use can reveal clues about their thinking and memory ability*."

Ask them whether they are **interested in taking part in this research**. If **yes, see below**. If **no, thank them for their time and end the call**.

"*Before we include you in this study, I would like you to complete a 10-15 minute questionnaire over the phone with me today."*

Establish **whether the participant is available now** for them to complete the questionnaire, or if you should **call back at a more convenient time**/date. Proceed if/when it is convenient.

"First, I need to tell you what this questionnaire involves and why we are doing this. Please stop me at any point if anything is unclear or if you would like me to repeat anything:

- *The questionnaire will involve you rating your ability to perform everyday tasks now, compared to your ability to perform these tasks 10 years ago.*
- *This will take approximately 10-15 minutes to complete.*
- *Based on the answers you give, we will be able to assess whether you are suitable for taking part in this study or not.*
- *I will be in contact within 3 working days of you completing this questionnaire to let you know whether we can include you in this study and, if you are eligible, provide you with more details about taking part.*
- *All of the data you provide will be encrypted and stored on a secure database for up to 7 years.*

- *All of the data that you provide is confidential and will only be accessible to the research team involved in the SAMS project. Your data will be assigned a unique participant code which can only be identified by the research team.*
- *You're involvement in this questionnaire is completely voluntary and you are free to provide as much or as little information as you wish.*
- *You are free to withdraw at any time, without giving your reasons, and if you wish, your data will be destroyed.*
- *Your medical and legal rights will not be affected if choose to withdraw."*

Once complete, ask the participant if they have any questions or if they would like you to repeat anything.

Continue to consent.

Appendix M – Recruitment materials (study D)

Two separate recruitment materials are included from study D: the advert and the letter of invite:

Stringer, G., Couth, S., Heuvelman, H., Bull, C., Gledson, A., A., Keane, Rayson, P., Sawyer, P., Sutcliffe, J., Zeng, X., Montaldi, D., Brown, L. J. E., & Leroi, I. (2020) 'Passive assessment of computer use behaviours in the home can indicate early cognitive impairment: An exploratory longitudinal study'.

Are you over 65 and want to contribute to memory research?

Do you use a computer at least once a week?

Are you worried about your memory and/or thinking? Or have you been diagnosed with a mild memory problem in a clinic?

We are seeking volunteers to help in a study called 'SAMS' to find out if the way people use computers can provide information about memory and thinking.

If you are interested in finding out more about this research and the possibility of taking part please contact:

Gemma Stringer
The University of Manchester
Tel: 0161 306 7493
Email: gemma.stringer@manchester.ac.uk
SAMS website: http://ucrel.lancs.ac.uk/sams/

The University of Manchester
Institute of Brain Behaviour and Mental Health
Room 3.306, 3rd Floor
Jean McFarlane Building, Oxford Road
Manchester, M13 9PL
Tel: 0161 306 7944
Email: Iracema.Leroi@manchester.ac.uk

[Name and address of participant]

[date]

[Dear [insert participant name]]

SAMS (Software Architecture for Mental Health Self-Management): Longitudinal Study

[*Delete as appropriate:*

This letter is being sent by your clinical care team on behalf of the SAMS research team.

OR

Thank you for expressing an interest in hearing more about the SAMS study.]

We are seeking volunteers over 65 years old to help in a scientific study to find out whether the way you use a computer can reveal early signs of memory problems. We will do this by analysing recordings of your normal daily computer use.

The diagnosis of memory related problems normally requires a complex assessment in a memory clinic. Computer programs are being developed to recognise these problems earlier in a simpler way using information about how the person uses their home computer (i.e. email and internet use). This information will be analysed to detect cognitive functioning, for example, memory and language.

The aim of the study is to test whether the SAMS computer programs can reliably detect change over time.

A full information sheet explaining the study in more detail is enclosed. We would appreciate it if you could read the information sheet and let us know by phone or email if you are interested in taking part.

The research is funded by the EPSRC (Engineering and Physical Sciences Research Council) and is being coordinated by the University of Manchester.

Please contact Gemma Stringer (Research Associate) Tel: 0161 306 7493 or email: gemma.stringer@manchester.ac.uk if you have any questions about the study.

Yours sincerely

Dr Iracema Leroi
Principal Investigator SAMS
Clinical Senior Lecturer / Honorary Consultant

Enc: Participant Information Sheet

Appendix N – SAMS software participant information (study D)

The SAMS software information provided to participants is included from study D:

Stringer, G., Couth, S., Heuvelman, H., Bull, C., Gledson, A., A., Keane, Rayson, P., Sawyer, P., Sutcliffe, J., Zeng, X., Montaldi, D., Brown, L. J. E., & Leroi, I. (2020) 'Passive assessment of computer use behaviours in the home can indicate early cognitive impairment: An exploratory longitudinal study'.

SAMS Participant Guide

INSTRUCTIONS AND HOW TO CONTACT US

Ann Gledson | SAMS | December 14, 2015 (Version 2.0)

Table of Contents

About SAMS

Thank you for agreeing to be a participant in the SAMS study.

SAMS is a three-year project that is investigating whether memory or thinking problems ('cognitive' difficulties) can be detected from the way people use their computer. Many older people now use a home computer for all sorts of purposes and this gives us an opportunity to use the computer as a tool that passively monitors their cognitive health as they use it.

The types of computer activity that we are interested in include: typing, mouse moves, using the desktop, internet searching, emails and written text. We will record aspects of this activity using the SAMS software which has been installed onto your computer. The software will not interfere with the normal functioning of your computer. You will have complete control over the SAMS software and can decide to halt recording whenever you wish. You will not notice that SAMS has been installed other than the appearance of 'pop-up' reminders. We would like for you to continue your normal computer use (i.e. emails, internet etc.) for a 9 month period.

This guide will lead you through how to control the SAMS software and provide contact information should you have any problems with the operation of the software.

Please also see our website: http://ucrel.lancs.ac.uk/sams for more information.

How to use the SAMS monitoring software

The SAMS application can be in 3 states: a) Running AND Monitoring user activities, b) Running and Paused and c) Not running (it has exited). These are defined in the table below.

SAMS Application is	Definition
Running and Monitoring	The SAMS application is running AND is monitoring you. 'Monitoring you' means that the SAMS software is storing data that you generate when you use the computer. This data takes many forms, but includes things like which icons you click the mouse on, where you move the mouse cursor from and to, and what keys you press. All this data is encrypted so that no-one, except selected members of the SAMS study team, has access to it. From this, the SAMS software will generate statistics that are used to characterize your use of the computer over time.
Running and Paused	The SAMS application is running but is NOT monitoring you. The reasons for this are either: • You have clicked 'Pause' (see Pause and Resume Monitoring section below). • Someone with a user account who is not you is logged in and using your computer (see section Reminder pop-ups – "Who is currently using the computer?" below). • Someone other than you is using your computer but not from their personal account – perhaps you share your account with them – and they have clicked 'Pause' or have responded to a reminder pop-up by notifying SAMS that they are not you (see section Reminder pop-ups – "Who is currently using the computer?" below). (As the SAMS application will still be running, you can go to the SAMS window to resume monitoring, as explained in the section Pause and Resume Monitoring below)
Not Running / Exited	The SAMS application has stopped running, and is no longer monitoring you. The SAMS tray icon and the SAMS window (see section on User Interface Instructions below) will NOT be visible. To restart the SAMS application, double click the SAMS desktop icon (see **Figure 7**). If you cannot find this or you are unsure, please contact us for support (see Contact Details below).

While your computer is switched on, the SAMS application should be running continuously. If the SAMS application is running properly you will be able to view the tray icon and the SAMS window (as explained in the section on User Interface Instructions below).

USER INTERFACE INSTRUCTIONS

The following screenshots illustrate how the SAMS monitoring tool will look when the SAMS application is running. Whilst SAMS is running we would expect it to record your computer activities, (but it will not necessarily be recording activities at all times, for example if it is paused).

Figure 1 shows an example of a Windows desktop with the SAMS application running. In the bottom right-hand corner of the screen, the Windows notification tray is highlighted, as this is where the main link to the SAMS application is to be found. **Figure 2** shows an enlarged version of this notification tray, and the SAMS tray icon is highlighted. If you left click on this once, the SAMS window will appear, as shown in **Figure 3**.

Figure 3 *The SAMS window (visible when the SAMS tray icon clicked)*

Figure 1 *An example of a Windows desktop with the SAMS application running*

Figure 2 *SAMS tray icons (left when paused, right when monitoring)*

PAUSE AND RESUME MONITORING

Figure 4 shows two close-ups of the SAMS window, with either the blue Pause or Resume button showing. Simply click the blue button once to either Pause or Resume the

monitoring of the current user's activities. (Note that clicking Pause will not stop the SAMS application from running altogether, and the SAMS window will remain accessible, so that you can resume monitoring as required.)

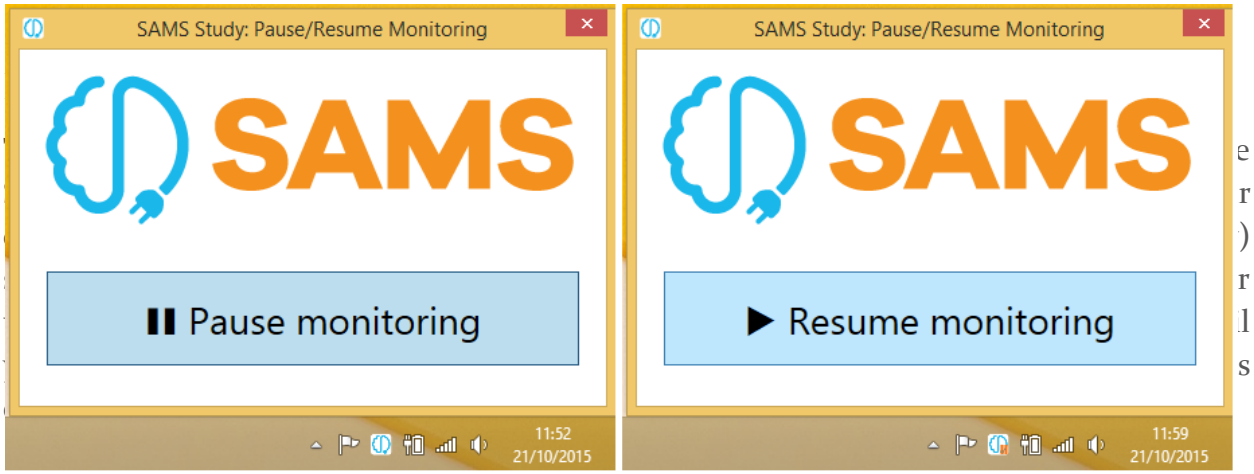


Figure 4 *Two close-ups of the SAMS window (monitoring and paused)*

MULTIPLE USERS – POP-UP MESSAGES

Note: This section is only relevant if you share your Windows account with another user (that is you both share the same Windows log-in username.).

Figure 5 shows a SAMS pop-up window that will appear:

a) every time you log on, or
b) if you do not use your mouse or keyboard (or other input device) for 10 or more minutes.

***Figure 5** Multi-user pop-up message*

This is to confirm that it is the SAMS participant that is currently using the computer and to prevent the monitoring and recording of somebody who is not a SAMS participant. Please click on the relevant button: 'Yes, I am' or 'No, I am not'. By doing this, you will be telling the SAMS application whether to monitor you or not.

If you do not wish to see the pop up message every 10 minutes and you (or someone else who is using your computer) know that you will be using the computer for a longer period of time, you can extend the time until the next pop-up temporarily to 30 minutes, 1 hour, 2 hours or 4 hours. (An example might be if you are watching a long video on your computer and don't want the pop-up to keep interrupting it.)

To extend the time between pop-ups, click on the 'Do not ask again for a while?' down arrow as highlighted in **Figure** 5. Then in the drop down menu, as shown in **Figure 6**, select the amount of time you wish to delay the next pop-up by.

Figure 6 *Changing the time interval before the next SAMS pop-up appears*

Once you have selected the time interval, please choose whether you are a SAMS participant or not with the usual buttons: 'Yes, I am' or 'No, I am not'.

ADVANCED

We anticipate that this section will not be required by most SAMS participants. You should rarely need to stop/exit the application. Please call us if you need assistance with this, you think that the SAMS application might not be working, or you are unsure of what to do (see the section on Technical Support below).

Stop/Exit the SAMS application

To stop the application, RIGHT click on the SAMS tray icon (**Figure 2**) and on the context menu that appears (see **Figure 7**), click on 'Exit'. Once you have clicked on this a pop-up will appear (see **Figure 8**), click OK. The SAMS application will now be in the 'Not Running / Exited' state (see table on page 3 above).

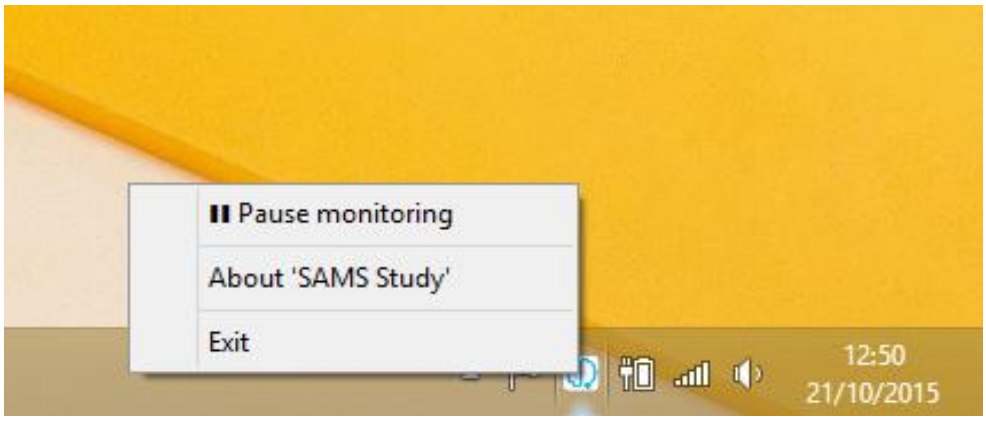


Figure 7 *SAMS Context menu (after right-clicking on SAMS tray icon)*

Figure 8 *Warning message when exiting the SAMS software*

Restarting the SAMS application after it has been exited

The SAMS tray icon (**Figure 2**) will not be visible if the SAMS application is not running. You will need to click on the SAMS desktop icon (see **Figure 9**) and this will start the SAMS application. It will start running and monitoring right away, but you can Pause the monitoring by going to the SAMS window and clicking Pause (see section Pause and Resume monitoring above).

Figure 9 *The SAMS Desktop Icon – For re-starting the SAMS Application*

Diary Entries

At weekly intervals over the course of the 9 months you will be asked to complete a diary entry that will help us to keep track of your progress. Completing the diary entries is an optional part of the study and it is up to you how often you decide to complete them.

Once a week, you will receive an email from us reminding you to complete your diary entry. Please save each diary entry into a folder named 'SAMS Diaries' which will be added to your desktop automatically by the SAMS application. Each diary entry can be saved to its own file, or all diary entries can be saved into the same file, please do whichever you find easiest. Full instructions will also be included in the email reminder.

INSTRUCTIONS

a) Open the application

Please open the application that you prefer to use for writing documents such as letters, memos, reports and invitations. This might be Microsoft Word, Open Office Writer, Notepad or WordPad, but as long as it is an application where you can write and edit text, it does not matter.

b) Write your diary

Write a diary of the things you have done over the last week, or longer if you wish. We will email you with a list of questions to answer. These questions are designed to act as a guide only, and you are free to write about anything that you wish (e.g. a new recipe, poem, short chapter etc.), and you can write as much or as little or as you want to.

c) Save your diary

Go to 'File' and then select 'Save As'. Using the browser window, find the 'SAMS Diaries' folder on the desktop and save it in there.

Once saved to that folder, the SAMS application will find your diary entry file, encrypt it and send it to the server.

If you have difficulties with completing your diary entry, please contact one of the NON-TECHNICAL support team (see General SAMS assistance (non-Technical) below).

Going away, holidays and other long-term periods of inactivity

For long-term periods where you are aware that you will not be using your computer, it would be helpful to let us know. Please contact us to let us know, if possible (see General SAMS assistance (non-Technical) below). Do not worry if you forget, it will not affect your participation in the SAMS study.

Contact details

TECHNICAL SUPPORT

Chris Bull: 01524 510501

Ann Gledson: 07825 696761

GENERAL SAMS ASSISTANCE (NON-TECHNICAL)

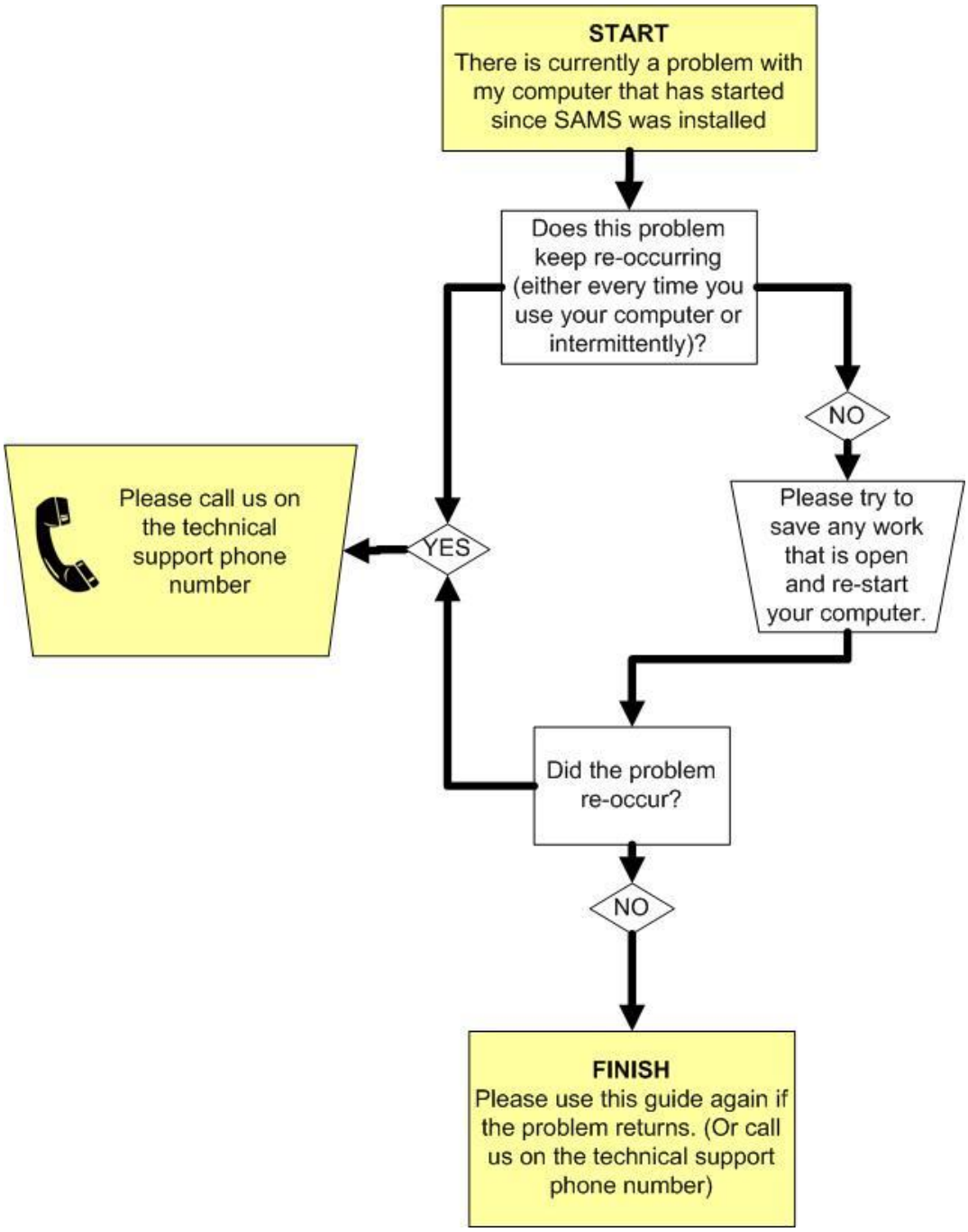
Gemma Stringer: 0161 306 7493

Sam Couth: 0161 275 5223

WHEN TO CONTACT US

Please contact us whenever you are unsure of anything relating to your participation in the SAMS project. In the Contact Details section above there are two numbers, for technical and non-technical queries.

For technical queries, please use the following flowchart as an initial guide, where possible. If in any doubt, please call the technical contact number (see the Technical Support section above).



Appendix O – Supplementary Table 1 (study D)

Supplementary table 1. Multi-level models for the comparison of MCI participants to SCD participants on computer-use behaviours and cognition (including daily computer use minus inaccessible days)

Variables		MCI (N=14)	SCD (18)	β	95% CI	*p* value
		Mean (SD)	Mean (SD)			
Computer use behaviours	Daily computer use – every day in the study[§] (mins)	43.95 (66.46)	87.14 (112.01)	45.81	[5.41, 86.20]	.026
	Daily computer use minus inaccessible days[¶] (mins)	48.21 (68.11)	93.00 (113.33)	47.74	[6.98, 88.51]	.022
	Mouse click frequency per minute	7.47 (5.94)	8.08 (6.73)	.83	[-1.68, 3.35]	.516
	Keystroke speed (secs)	2.05 (.64)	2.92 (.71)	.89	[.55, 1.22]	.000
Cognitive variables	ACE III	88.36 (4.73)	96.28 (3.49)	7.92	[5.35, 10.49]	.000
	ECog[†]	-1.93 (.75)	-1.46 (.42)	.47	[.07, .87]	.021
	TMT A[†]	-44.81 (23.49)	-33.33 (10.42)	11.48	[-.86, 23.81]	.068
	TMT B[†]	-108.93 (65.12)	-66.35 (29.73)	42.58	[8.33, 76.83]	.015
	DSB	6.62 (1.89)	8.85 (1.75)	2.23	[1.16, 3.31]	.000
	FCRST	27.33 (8.98)	36.50 (3.84)	9.17	[4.54, 13.80]	.000
	Reaction time[†]	-44.87 (7.52)	-40.09 (9.46)	4.66	[-.26. 9.58]	.063
	Doors and people (recall)	18.55 (6.16)	26.26 (3.81)	7.71	[4.57, 10.85]	.000
	Doors and people (recognition)	20.05 (4.79)	28.13 (5.11)	8.08	[5.14, 11.03]	.000
	Doors and people (forgetting)	19.67 (3.84)	21.07 (2.76)	1.41	[-.14, 2.95]	.074
	Stroop inhibition[†]	-65.45 (29.16)	-47.57 (16.90)	17.87	[1.06, 34.68]	.037
	Stroop switching[†]	-86.55 (31.17)	-53.20 (17.27)	33.35	[17.12, 49.57]	.000

Note: [§]Daily computer use was based on every day that the participant was included in the study, irrespective of accessibility and use. [¶] Daily computer use was based only on the days that participants reported that the computer was accessible (i.e. not on holiday), irrespective of whether the computer was used or not. [†]Scores were reverse coded for clinical interpretability. All *p* values held significance after false discovery rate (FDR) correction (Q = .20).

Appendix P – Supplementary Table 2 (study D)

Supplementary table 2. Multi-level models for the association between cognition and computer use behaviours (including daily computer use minus inaccessible days)

			Crude			Adjusted*		
Variables		N	β	95% CI	*p* value	β	95% CI	*p* value
Daily computer use – only days of use[§] (hours)	ACE III	32	-.000	[-.039, .039]	.984	-.014	[-.066, .039]	.614
	ECog[†]	32	.016	[-.018, .050]	.353	.013	[-.024, .049]	.504
	TMT A[†]	32	.018	[-.008, .044]	.175	.015	[-.006, .035]	.170
	TMT B[†]	32	.014	[-.011, .041]	.269	.010	[-.009, .030]	.308
	DSB	32	.021	[-.023, .066]	.350	.012	[-.032, .056]	.603
	FCRST	32	.016	[-.005, .037]	.133	.010	[-.012, .033]	.364
	Reaction time[†]	31	.034	[-.058, .126]	.469	.019	[-.073, .112]	.684
	Doors and people (recall)	32	.037	[-.004, .079]	.077	.032	[-.011, .075]	.145
	Doors and people (recognition)	32	.027	[-.016, .070]	.212	.019	[-.025, .063]	.390
	Doors and people (forgetting)	32	-.084	[-.181, .013]	.089	**-.089**	**[-.173, -.005]**	**.039**
	Stroop inhibition[†]	31	.006	[-.014, .027]	.544	.001	[-.019, .022]	.901
	Stroop switching[†]	31	.040	[.005, .074]	.027	**.042**	**[.008, .076]**	**.016**[‡]
Daily computer use minus inaccessible days[¶] (hours)	ACE III	32	-.002	[-.028, .025]	.908	-.012	[-.052, .028]	.551
	ECog[†]	32	.010	[-.010, .031]	.326	.007	[-.014, .028]	.527
	TMT A[†]	32	.012	[-.004, .027]	.139	.010	[-.004, .024]	.178
	TMT B[†]	32	.008	[-.007, .022]	.312	.005	[-.008, .017]	.457
	DSB	32	.011	[-.014, .037]	.385	.004	[-.022, .031]	.719
	FCRST	32	.009	[-.003, .021]	.147	.005	[-.007, .017]	.398
	Reaction time[†]	31	.028	[-.046, .102]	.457	.017	[-.054, .088]	.640
	Doors and people (recall)	32	.023	[.002, .045]	.032	.019	[-.005, .042]	.116
	Doors and people (recognition)	32	.018	[-.005, .041]	.127	.012	[-.012, .037]	.334
	Doors and people (forgetting)	32	-.059	[-.133, .015]	.117	-.056	[-.120, .009]	.090
	Stroop inhibition[†]	31	.001	[-.014, .015]	.924	-.003	[-.018, .012]	.700
	Stroop switching[†]	31	.023	[.003, .044]	.027	**.026**	**[.003, .048]**	**.027**

Mouse click frequency	ACE III	32	.000	[-.008, .001]	.984	-.003	[-.012, .005]	.452
	ECog†	32	.007	[-.000, .015]	.057	.007	[-.000, .016]	.063
	TMT A†	32	.007	[-.005, .019]	.233	.007	[-.004, .018]	.237
	TMT B†	32	.006	[-.004, .017]	.228	.005	[-.005, .014]	.311
	DSB	32	.002	[-.010, .015]	.699	-.001	[-.011, .009]	.850
	FCRST	32	.000	[-.008, .008]	.936	-.001	[-.007, .005]	.754
	Reaction time†	31	-.002	[-.025, .021]	.873	-.006	[-.027, .016]	.619
	Doors and people (recall)	32	.004	[-.009, .016]	.581	.001	[-.008, .010]	.838
	Doors and people (recognition)	32	.004	[-.010, .018]	.541	.002	[-.009, .013]	.729
	Doors and people (forgetting)	32	-.014	[-.036, .009]	.226	**-.020**	**[-.038, -.002]**	**.026**
	Stroop inhibition†	31	.007	[-.001, .014]	.077	.005	[-.004, .013]	.256
	Stroop switching†	31	.010	[-.004, .023]	.157	.007	[-.006, .019]	.292
Keystroke speed	ACE III	32	.541	[.147, .934]	.007	.292	[-.084, .668]	.129
	ECog†	32	.243	[-.082, .569]	.143	.275	[-.033, .583]	.080
	TMT A†	32	.475	[-.007, .957]	.053	**.370**	**[.040, .701]**	**.028‡**
	TMT B†	32	.537	[-.096, .978]	.017	-.356	[-.069, .780]	.101
	DSB	32	.552	[.205, .899]	.002	.359	[-.121, .839]	.142
	FCRST	32	.414	[.089, .738]	.013	.264	[-.053, .581]	.103
	Reaction time†	31	.136	[-.233, .505]	.470	-.191	[-.558, .177]	.310
	Doors and people (recall)	32	.667	[.407, .928]	.000	**.543**	**[.298, .788]**	**.000‡**
	Doors and people (recognition)	32	.671	[.434, .908]	.000	**.537**	**[.282, .793]**	**.000‡**
	Doors and people (forgetting)	32	.225	[-.016, .467]	.068	.219	[-.090, .528]	.165
	Stroop inhibition†	31	.486	[.198, .774]	.001	**.217**	**[.009, .425]**	**.041‡**
	Stroop switching†	31	.693	[.349, 1.04]	.000	**.344**	**[.096, .592]**	**.006‡**

Note: §Daily computer use was based only on the days when the computer was accessible and used. ¶ Daily computer use was based only on the days that participants reported that the computer was accessible (i.e. not on holiday), irrespective of whether the computer was used or not. *Estimates adjusted for age, years of education and years of computer use experience; † scores were reverse coded for clinical interpretability. Values in bold represent a significant association between the computer use behaviour and cognitive scores ($p < .05$) for the adjusted estimates. ‡Value held significance after false discovery rate (FDR) correction ($Q = .20$).

Appendix Q – Supplementary Table 3 (study D)

Supplementary table 3. Multi-level models to assess change in computer use behaviours and cognitive variables over time (including daily computer use minus inaccessible days)

Variables		Crude				Adjusted*		
		N	β	95% CI	p value	β	95% CI	*p* value
Computer use behaviours	Daily computer use – every day in the study[§] (mins)	32	-.032	[-.110, .046]	.417	-.032	[-.110, .046]	.417
	Daily computer use minus inaccessible days[¶] (mins)	32	-.028	[-.096, .041]	.424	-.028	[-.096, .040]	.423
	Mouse click frequency per day	32	-.002	[-.007, .003]	.440	-.002	[-.007, .003]	.437
	Keystroke speed per day (secs)	32	.000	[-.000, .000]	.104	.000	[-.000, .000]	.109
Cognitive variables	**ACE III**	**32**	.042	[.004, .081]	.033	**.042**	**[.002, .081]**	**.041**
	ECog[†]	32	-.001	[-.005, .004]	.829	-.001	[-.005, .004]	.829
	TMT A[†]	32	.044	[-.082, .169]	.496	.042	[-.086, .170]	.519
	TMT B[†]	32	.046	[-.255, .346]	.765	.041	[-.268, .349]	.796
	DSB	32	-.002	[-.020, .016]	.836	-.002	[-.020, .016]	.816
	FCRST	32	.047	[-.009, .102]	.098	.046	[-.011, .103]	.113
	Reaction time[†]	30	-.015	[-.107, .077]	.753	-.012	[-.107, .082]	.795
	Doors and people (recall)	**32**	-.068	[-.108, -.028]	.001[‡]	**-.069**	**[-.110, -.028]**	**.001**[‡]
	Doors and people (recognition)	**32**	.061	[.007, .115]	.026	**.060**	**[.005, .115]**	**.032**
	Doors and people (forgetting)	32	.003	[-.036, .043]	.867	.002	[-.039, .043]	.910
	Stroop inhibition[†]	31	-.057	[-.198, .084]	.430	-.055	[-.202, .091]	.457
	Stroop switching[†]	31	-.193	[-.419, .034]	.095	-.191	[-.424, .043]	.110

Note: [§]Daily computer use was based on every day that the participant was included in the study, irrespective of accessibility and use. [¶]Daily computer use was based only on the days that participants reported that the computer was accessible (i.e. not on holiday), irrespective of whether the computer was used or not. *Estimates adjusted for age, years of education and years of computer use experience; [†]scores were reverse coded for clinical interpretability. Adjusted values in bold represent a significant change over time ($p < .05$). [‡]Value held significance after false discovery rate (FDR) correction ($Q = .20$).