Influences on the biopsychosocial health of older adults

by

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ABSTRACT

On average the last 12 to 16 years of life are spent in ill health, which represents a gradual decline in health and quality of life for individuals aged 65 and over. This demographic group is also the fastest growing in the UK and hence present significant financial implications for the health service.

Despite these age-related health declines, spanning physical, cognitive and psychosocial dimensions of health, known as biopsychosocial health, understanding of how these health dimensions interact is sparse. Recent research has suggested potential bi-directional relationship between physical and cognitive function with declining executive brain functions expressed through changes in walking gait (Ijmker & Lamoth, 2012; Verghese et al., 2012; Smith-Ray et al., 2013). Similarly, social isolation has been demonstrated to be severely detrimental to physical health; whereas strong social relationships reportedly elevate psychosocial and physical health (Holt-Lunstad et al., 2010). This evidence therefore suggests a potential tri-directional relationship between different manifestations of biopsychosocial health, with each dimension directly influencing one another. Traditionally, research in this field has used controlled environments and expensive equipment to establish functional abilities in older adults. Therefore, identifying whether simple field-based assessments can accurately assess aspects of biopsychosocial health may provide a basis for novel practical interventions and inform professional practice.

Hence, the aims of this thesis were to enhance current understanding of biopsychosocial health in older adults and explore the relationship and integration between health dimensions. A further aim was to investigate whether simple, field-based measures can be utilised effectively to identify biopsychosocial health, in order to translate these findings into impactful interventions to aid promotion of longevity and functional independence in old age.

Literature reviews and a series of empirical studies were conducted to achieve these aims. Results illustrated that biopsychosocial health dimensions shared a complex relationship. Furthermore, it is possible to measure biopsychosocial functions with simple field-based and self-administered assessments. These findings are combined with advances in technology to provide a potential novel and impactful practical application to enable identification of declining health in older age. The thesis then concludes with final thoughts and reflections on professional practice and future directions.

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"And in the end, it is the life in our years that count, not the years in our life" – Abraham Lincoln

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CHAPTER 1 – INTRODUCTION TO BIOPSYCHOSOCIAL AGEING

Introduction - We live in an ageing nation

According to the World Health Organisation (WHO), in the developed world the term *'elderly'* or '*older adult'* refers to someone aged 65 years or older (WHO, 2002). Using this categorisation, there are approximately 12 million older adults currently living in the United Kingdom (UK) (Coates, 2018). This number is expected to rise further, such that between 2010 and 2030 the number of over 65s will have increased by 51%, and the number of people aged 85 and over will have doubled (Batty & Steptoe, 2016).

One contributing factor to these demographic increases in the UK are the 'Baby Boomers', born post war between 1946 and 1964 (CMO, 2015). The term '*Baby Boomer'* relates to the phenomenon of a sudden increase in births following the end of the Second World War and hence typically relates to adults who are presently 55-75 years old (CMO, 2015). The UK is not alone however, as an increasingly ageing population is a trend predicted for all continents across the world. Globally, the number of people aged 60 and over is expected to rise in every continent, so that by the year 2050 there will be approximately two billion older people inhabiting the earth (Department of Economic and Social Affairs: Population Division, United Nations, 2017). Europe and North America are estimated to have the highest proportion of over 60s, comprising 34% and 27% of their respective populations by 2050 (Department of Economic and Social Affairs: Population Division, United Nations, 2017). This equates to 242 million and 123 million older adults in Europe and North America, respectively. However, this pales in comparison to ageing rates in Asia, where an estimated 1.3 billion over 60s will reside by 2050 equating to 24% of the continent's population (Department of Economic and Social Affairs: Population Division, United Nations, 2017). While ageing itself is not necessarily an issue, advancing age is typically accompanied by natural declines in health.

Health has been defined as "*a person's mental or physical condition"* (Oxford, 2016), hence a reduction in health can influence one's ability to function independently. This ability is expressed through completing activities of daily living (ADLs) such as bathing, rising from a chair, dressing, using the toilet and walking. When a person's health has declined to a point of needing assistance to complete ADLs, the ability to function independently has been lost. This highlights the importance of maintaining good health into old age to continue functioning independently.

Unfortunately however, for many older people the last 12 to 16 years of life is spent with physical illness, often combined with a cognitive impairment impacting the ability to perform ADLs (Brayne, Matthews, McGee & Jagger, 2001).

In a recent report by The Richmond Group of Charities, the authors aptly state *“we have added years to our lives, but not necessarily life to our years”* (The Richmond Group of Charities, 2015, pp. 13). This claim is supported by the fact that almost half of adults aged 75 and over are living with two or more chronic health conditions (Storey, 2018). Unsurprisingly, the number of people with two or more chronic diseases or disorders, termed multi-morbidity, increases with advancing age (Welmer, Kareholt, Angleman, Rydwik & Fratiglioni, 2012). The consequence of this is an increased requirement for medical treatment, hospital admissions and GP appointments often resulting in a high number of prescribed medications. The result of this is polypharmacy – the prescribed use of five or more medications – which only increases the expenditure for the UK National Health Service (NHS). It is estimated that over 40% of the NHS annual budget is spent on older adults, equating to ~£46.5 billion. Given the aforementioned demographic predictions, ensuring good health in order to function independently in old age is of paramount importance, as the provision of care services for dependant older adults will become economically unsustainable. Therefore, the creation of interventions capable of attenuating age-related health declines holds the potential to drive substantial human and economic benefits.

Being physically active is one widely accepted method to reduce, or even prevent, many debilitating health conditions. Improvements in muscle strength, bone health, sleep quality and reductions in joint pain and fatigue are a sample of the benefits from being physically active and undertaking a specific exercise programme (Taylor, Cable, Faulkner, Hillsdon, Narici, & Van der Bij, 2004). Furthermore, according to the Department of Health, 50% of all cancers could be prevented by changes in lifestyle towards being more active (The Department of Health, 2011). Specifically in older adults, systematic reviews and meta-analyses have shown that 70-80 year olds involved in 150 minutes per week of moderate to vigorous intensity exercise for 5 years or more, reduce the risk of developing Alzheimer’s disease by 40% (Macpherson, Teo, Schneider and Smith, 2017). Accordingly, the axiom that *‘exercise is medicine’* is well supported in the literature (Sallis, 2008). However, physical health is only one dimension of health and to fully understand health, and how it is influenced, we must consider it from a more holistic perspective.

Therefore, the aims of this chapter are to introduce the subject of biopsychosocial health and provide context for the forthcoming chapters. The background of my thesis questions are discussed through my perspective as a professional health practitioner and review of the existing literature. The key objectives of the thesis are also presented, along with how I intend to achieve these objectives through literature reviews and a series of empirical studies. Finally, an overview of the thesis contents is outlined.

What is biopsychosocial health?

The notion that health is influenced by more than solely biological factors was proposed over 40 years ago (Engel, 1977). Inevitably, losses in physical function can indirectly impact on mental health and lead to social isolation and perceptions of loneliness. Hence, when discussing health, the term *biopsychosocial* is used to refer to the combination of physical, cognitive, psychological, social and emotional dimensions of health (Engel, 1977).

More recent research supports the notion proposed by Engel in 1977, that a comprehensive understanding of one’s health can only be fully appreciated when considered from a biopsychosocial perspective (Alonso, 2004). This is based on the premise that being physically unwell can affect emotional and psychological health, such as reducing mood and self-esteem. (Steptoe, Deaton & Stone, 2015). Furthermore, due to the function restrictions of a physical illness, functional independence can become impaired impacting on social health, often as a result of becoming socially isolated, which in turn can lead to further decline in physical health (Hawton et al., 2011)

However, how the dimensions of health interact is relatively unknown as they are often investigated in isolation, or as a combination of two of the three elements. The benefits of physical activity for mental health, including psychosocial wellbeing have been discussed in the literature (Fox, 1999). Similarly, Curneya (2007) reviewed the literature on exercise interventions during cancer treatment and reports that biological mechanisms are primarily focussed on, with research on psychosocial mechanisms sparse. It has also been suggested that being socially, cognitively and physically active are important lifestyle factors to reduce the rate of cognitive decline and risk of dementia (Fratiglioni, Paillard-Borg and Winblad, 2004). However, how these dimensions of health interact, and the mechanisms underpinning adaptations to overall health is relatively unknown.

From a practical perspective, it is rarely the case that interventions are designed with physical, cognitive and psychosocial dimensions of health in mind. For example, exercise interventions are often designed to improve physical function, however physical exercise can also bestow benefits in cognitive function. Furthermore, if performed in a group, social interaction is enhanced among group members benefiting psychosocial health. Therefore, could a group-based exercise class be thought of a biopsychosocial intervention? Research capable of enhancing knowledge and understanding of the relationship between these biopsychosocial dimensions of health is therefore warranted to inform the creation of innovative and more productive practical interventions.

Professional context

The statistics and projections in regard to the ageing population and declines in health fascinate and frighten me in equal measure. We live in such a technologically advanced world and we live longer than ever before, yet also spend more time in ill health than ever before. I am therefore encouraged by the evidence highlighting that exercise is medicine. As noted by the former Chief Medical Officer, Professor Dame Sally Davies, *“If physical activity were a drug, we’d talk about it as a miracle cure.”* (Davies, 2017).

Move it or Lose it, the company for which I am a Director, specialises in exercise for older people. Working with this demographic, I am aware of the vast spectrum of health and functional ability among older adults. I have seen and worked with 60-year olds with the physical and cognitive function expected of an 80+ year old and 90-year olds who function as if they were 20 years younger. Chronological age does not necessarily correlate with one’s biological age, in terms of functional abilities and hence there is no one size fits all approach that can be applied. I am yet to meet an older person who wishes to lose their independence, however unfortunately many older adults do not know what to do to prevent this, and view it as an unavoidable fate, as age-related declines in health eventually catch up with them. At Move it or Lose it, we strive to ensure older people live active, healthier and happier lives by providing group exercise classes for the over 60s, as well as products to keep them active at home. We work in community, care and NHS settings providing evidence-based programme, called FABS, delivering flexibility, aerobic, balance and strength exercises. Of course, we are one of many organisations aimed at working with older adults, and unsurprisingly many local authorities and government initiatives are centred around helping older people to overcome the barriers they face in the pursuit of maintaining health and independence. Many of these initiatives are aimed at reducing the financial strain on the NHS caused by an ageing nation in poor health.

The health service and state of the nation

The NHS was created over 70 years ago to treat illness, yet the world we live in today is very different to the world in 1948 when the NHS was born. At that time, one of the main causes of death was rheumatic heart disease; an inflammatory disease typically developing in children aged 5 – 15 years old which can be treated by antibiotics (Hawe, 2008). In 2015, ischaemic or coronary heart disease was the leading cause of death in the UK; a condition caused by the build-up of fatty substances narrowing the arteries and preventing blood flow and oxygen delivery to parts of the body, also termed *atherosclerosis*. Atherosclerosis is often the result of unhealthy lifestyle factors such as smoking, poor diet and inactivity leading to high cholesterol and high blood pressure (NHS, 2017). This is an example of the different challenges faced by the NHS today compared to when it was established in 1948 with the aim of improving provision of medication to treat illnesses. However, many modern-day lifestyle related health conditions cannot typically be cured through medication but can be prevented and partially remediated though healthy lifestyle modifications.

This shift from a treatment model to a prevention model represents the greatest challenge facing the NHS since its inception. In relation to the advancing age of the population, the prevention model would attempt to detect declines in health earlier and put interventions into place to attenuate such declines maintaining functional independence for as long as possible. Research can also play an important part in enhancing our understanding of how and why we age, why our health naturally declines and most importantly what practical interventions can be put into place to maximise the benefits for biopsychosocial health.

Thesis overview

I have an interest in technology, research and innovation and I am glad that the NHS has taken the steps to embrace technology within its policy for change. I believe that novel practical applications to enhance health and prolong independence can be developed if these three fields are integrated. Accordingly, the focus for my research lies in field-based practical application and enhancing knowledge that can be applied by practitioners without the need for expensive equipment. In this thesis I present the case for using simple field-based assessments of biopsychosocial function in older adults. This includes the use of simple and accessible technology to demonstrate how this can be utilised efficiently and accurately in the real-world, without the need for a controlled laboratory environment.

I do not believe that I can change the NHS single-handedly, however I am ambitious enough to believe that, through research and application, I can enhance current understanding and the practical implications this can have for NHS patients. Advancing age affects all of us and hence is in everyone's interest to ensure we build a world in which we can enjoy and not endure our old age.

Therefore, my motivation for this thesis is to identify how research, technology and innovation can be implemented into real-world practical interventions to help us live longer happier, healthier lives. Accordingly, there are two broad aims of the thesis, each with more specific objectives that I aim to uncover through my research. Hence the broad and specific aims are as follows:
Thesis aim 1.) Understanding biopsychosocial function and the role of physical activity in older adults,

- To understand the relationship between physical function, cognitive function and psychosocial function in older adults.
- To understand the relationship between levels of physical activity across the life span and biopsychosocial function in later life.
- To understand if physical activity in later life can improve biopsychosocial function in older adults, in the community and primary care settings.

Thesis aim 2.) The evaluation of field-based assessment tools in older adults,

- To use different field-based assessment tools to measure biopsychosocial function of older adults.
- To identify which field-based assessment tools are most effective in measuring biopsychosocial function of older adults.
- To use this evaluation of assessment measures and translate them into impactful practical applications to promote longevity and independence in old age.

These objectives will be achieved by producing four research outputs each one leading from the last to cumulate into final conclusions and practical applications.

Literature review and methodology

I begin the thesis by delving into current knowledge and understanding of the ageing process from a biopsychosocial perspective which is presented in Chapter 2. In addition to the introduction of this chapter, Chapter 2 provides further context for the reader in regard to biopsychosocial influences on function in older adults.

This is then explored further in Chapter 3 which was published as a New Perspective piece in Cogent Psychology, (2017) volume 4, issue 1. Within this chapter I review the existing literature and identify gaps in the knowledge base in regard to the relationship between physical and cognitive function, and the potential novel application for the prevention of falls in older adults.

The process of producing Chapter 3 informed my methodological decision-making for the empirical studies which is presented in Chapter 4. It is of course crucial to carefully consider the most appropriate methodology to achieve the thesis objectives. Therefore, in Chapter 4 I present the case for different research methods i.e. quantitative and qualitative and the systematic decision-making process used for the selection of field-based assessment measures utilised in the empirical studies.

Empirical studies

The empirical studies progress logically in turn, with a common theme of enhancing understanding of biopsychosocial function in older adults (Thesis aim 1) and using simple field-based assessments to measure biopsychosocial function (Thesis aim 2). In the first of three empirical studies, Chapter 5 seeks to investigate the relationship between physical activity levels across the life span on present levels of physical and cognitive function in older adults. This follows the evidence presented in the existing literature in Chapters 2 and 3. Positive relationships were discovered between different life stages and functional abilities which was explored further in Chapter 6. The aim of this study was to identify how attendees of a weekly exercise class compared to normative population data in assessments of physical, cognitive and psychosocial functions, including the ability to complete Activities of Daily Living (ADLs). In line with Thesis aim 2, simple field-based assessment measures were used and evaluated. The analysis of the data collected in Chapter 6 demonstrated the complex nature of the relationship between biopsychosocial functions among healthy community-dwelling older adults. Chapter 7 aimed to further this understanding by assessing adherence to and the effect of exercise in a cohort of patients with Chronic Obstructive Pulmonary Disease (COPD). This study was conducted in a primary care setting enabling evaluation of field-based assessment measures in this environment. This chapter provides insight into the use of field-based assessment measures in different settings to establish biopsychosocial health status in specific population groups.

Discussions, conclusions and reflections

The findings from the three empirical studies are then discussed in detail in relation to the key thesis objectives in the final discussions and conclusions presented in Chapter 8. Here, each study is reviewed with all the key findings culminated and discussed in relation to enhancing understanding of biopsychosocial function of older adults (Thesis aim 1) and using simple field-based assessments to measure biopsychosocial function (Thesis aim 2). A novel explanation of the relationships shared among dimensions of biopsychosocial health is presented, along with a novel and impactful practical application to advance the prevention of age-related decline in biopsychosocial health. Finally, the thesis concludes with my final thoughts, reflections and future directions. Here I present an honest account of completing the thesis, how the findings with influence my future practice and my ambitions for further research.

Therefore, the structure of the thesis is as follows:

Chapter 1 – Introduction to biopsychosocial health and ageing,

Chapter 2 – Changes to function associated with advancing age,

Chapter 3 – Preventing falls in older adults: Can improving cognitive capacity help?

Chapter 4 – Methodological decision-making and experimental design,

Chapter 5 – Do high physical activity levels across the lifespan correlate with high cognitive, and physical function measured in the field in British community-dwelling older adults?

Chapter 6 – The biopsychosocial health of older adults that attend group-based exercise compared to population normative data,

Chapter 7 – The relationship between group exercise adherence and physical function and perceptions of health in older adults with COPD

Chapter 8 – Discussion, conclusions and future directions.

Conclusion

As presented at the start of this chapter, global ageing demographics are increasing. In the UK, this presents the challenge of change for the NHS to prevent modern day health conditions and similarly, through early identification attenuate age-related declines in health. In my opinion, the use of technological innovation holds great potential to enhance the function of older adults and help the NHS move toward a prevention model of care, releasing the financial strains placed on treatment of illness.

In order to explore this notion further, this thesis aims to add to the existing knowledge base of ageing from a biopsychosocial perspective. The thesis will then delve progressively deeper into the subject of influencing factors on biopsychosocial health and function in older adults, to uncover a greater understanding of the relationship and interaction between physical, cognitive and psychosocial dimensions of function. I aim to use simple, field-based assessment measures to identify functional abilities and will discuss the practical utility and application within 'real-world' settings. I will then translate the findings from the thesis to provide a rationale for the potential of a novel practical application to enhance biopsychosocial function in older adults.

A key aim of the thesis is to enhance current understanding of biopsychosocial function in older adults, to inform the design of novel and impactful practical applications to attenuate decline in health. It is therefore important to document what is currently known in regard to the ageing process and natural declines associated to advancing age. Therefore, the next chapter will provide an overview of existing literature and knowledge to provide context for the reader and ensure the subsequent chapters have maximum impact.

CHAPTER 2 – CHANGES TO FUNCTION ASSOCIATED WITH ADVANCING AGE

Introduction – what is ageing?

Before biopsychosocial changes that occur as a result of ageing can be fully appreciated, it is important to understand what ageing is and how in impacts human health. Recent research focussed at the cellular level has provided new insights into explaining ageing. Within the nucleus of every cell in the human body, the chromosomes containing DNA are stored. On the end of each chromosome is a structure called a *telomere* – a nucleoprotein structure designed to protect genetic information and reduce degradation (Tucker, 2017). With advancing age, every cell in the body goes through constant cycles of mitosis –the division and regeneration of cells– to maintain the function of the tissue it forms, be it bone, muscle or organ. Research has shown that each time mitosis occurs, a piece of the telomere is cut away, shortening its length (Tucker, 2017). This persistent shortening of telomeres contributes to biological ageing, and hence, the shorter the telomeres the older the person, biologically (Zglinicki & Martin-Ruiz, 2005).

The shortening of telomeres is a naturally occurring process, however it can be heavily influenced by lifestyle factors. Activities such as smoking, poor diet and sedentary behaviour promote inflammation and increase the rate of telomere shortening (Tucker, 2017). Accordingly, the term *inflammaging* has been coined to describe advancing biological age that accompanies inflammatory lifestyle behaviours (Bartlett et al., 2012). Conversely however, lifestyle activities that protect against inflammation such as being physically active, can reduce the rate of telomere shortening (Tucker, 2017). This means that chronological age and biological age can differ widely among older adults largely dependent on the interactions between genetics and lifestyle. Accordingly, biological age will influence one's level of independence and the ability to complete activities of daily living (ADLs), such as bathing, using the toilet and walking. Enhancing understanding of the biological mechanisms behind ageing such as telomere shortening, and the lifestyle factors that influence this has broadened knowledge of *how* we age and the disparity on levels of function among older adults.

Of course, the ageing process cannot be reversed or stopped fully, and as such changes to all systems and processes within the human body are ultimately inevitable. However, the more we understand about senescence and inflammaging, the causes and underlying mechanisms, the more knowledge we have to create impactful interventions to attenuate or even prevent declines in health as a consequence of advancing chronological age.

This chapter discusses the biopsychosocial changes associated with advancing age, the impact this has on function, and describes the subsequent practical implications for older individuals.

Age-related changes to biological health and the impact on function

The aim of this section is to present current knowledge and understanding of how age-related changes to biological health impact physical function, such as the completion of ADLs. Age-related changes occur across all biological systems (Lakatta, 2002; Sharma & Goodwin, 2006; Iwasaki & Yamasoba, 2015; Lazarus, Lord & Harridge, 2018) and to review each of these systems would be far beyond the scope of this chapter. Therefore, the focus here shall be on the major changes that occur to the musculoskeletal system that directly impact physical function and independence, such as sarcopenia and osteoporosis.

Impact of sarcopenia on health

There has been a variety of definitions of sarcopenia in the literature, most of which include a reduction in muscle mass that occurs with advancing age. In 2009-10, the European Working Group on Sarcopenia in Older People (EWGSOP) defined sarcopenia as *'a syndrome characterised by a progressive and generalised loss of skeletal muscle mass and strength with a risk of adverse outcomes such as physical disability, poor quality of life and death'* (Cruz-Jentoft et al., 2014). Hence, sarcopenia is the result of a reduction in the number and size of muscle fibres, in particular fast twitch fibres (Type II). Accordingly, Type II fibres can decline by as much as 4.7% per decade in men and 3.7% per decade in women from the age of 50; by age 80, as much as 49% of muscle mass can be lost (Mitchell et al., 2012). This inevitably leads to a decline in the ability to exert muscular force, termed *dynapenia,* which results in a loss of strength capacity of 1% to 3.5% per year from the age of 50 to 80 respectively (Seene, 2013). Furthermore, from age 75, strength is lost at an even faster rate of 3-4% per year in men and 2.5-3% per year in women (Mitchell et al., 2012). In line the with the EWGSOP definition of this syndrome, the side effects of sarcopenia have a significant impact on daily function and one's ability to perform ADLs, such as standing from sitting, using the toilet and bathing.

Evidence has demonstrated that 70 to 80-year-olds with the lowest quartile of hand grip strength (measured through hand grip dynamometry), are more likely to be hospitalised than age-matched equivalents with greater hand grip strength (Cawthon et al., 2009).

Poor hand grip strength has also been associated with reduced ADL ability and cognition, as well as a higher risk of death within the subsequent four years, when compared against those with hand grip above the sample mean (Taekema, Gussekloo, Maier, Westendorp, & de Craen, 2010; Laukkanen Heikkinen & Kauppinen, 1995). Similar findings have also been reported for lower limb strength, particularly poor knee extension strength which is related to increased risk of disability and mortality (Yeung, Reijnierse, Trappenberg, Blauw, Meskers & Maier, 2018).

Although one does not die directly from reduced muscle mass per se, strength is heavily implicated in mobility, independence and increased risk of a range of other illnesses which can increase the risk of mortality. For example, sarcopenic individuals are reportedly three times more likely to fall than non-sarcopenic individuals, regardless of age or gender, often resulting in hospitalisation (Landi et al., 2012). Once admitted to hospital muscle strength is lost at a rate of 5% per day of treatment in a hospital bed (National Audit Office, 2016). All these issues ultimately serve to both diminish quality of life and likely contribute to an increasing probability of premature mortality.

More positively, however, sarcopenia has been shown to reduce, or even reverse, through regular engagement in physical activity, and in particular through strength training (Steffl, Bohannon, Sontakova, Tufano, Shiells & Holmerova, 2017; Landi, Marzetti, Martone, Bernabei & Onder, 2014). Regardless of age, strength training stimulates greater muscle fibre recruitment via neural adaptations, leading to an increased capability of the muscle to exert force, resulting in greater muscle strength (Sundstrup et al., 2016). In the lower limbs, muscular strength aids ADLs such as standing from sitting, using the toilet and walking and hence has clear implications on functional independence.

Considering the importance of physical activity in the prevention of muscle atrophy, it is unsurprising that the prevalence of sarcopenia in active community dwelling and independent older adults is lower (1-29%) than those in institutionalised care (14-33%, and up to 68% in men) (Cruz-Jantoft, 2014). The phrase *'move it or lose it'* seems highly applicable to the syndrome of sarcopenia, suggesting that if the muscle is not regularly activated, inevitably muscle mass and strength will decline, which can be debilitating for functional independence and health.

Impact of osteoporosis on health

For the first three decades of life our bones are constantly breaking down, termed *resorbing* and rebuilding, termed *reforming*, as internal structures adapt to the regularly imposed mechanical loads associated with movement (Pearson and Lieberman, 2004). However, from the age of 60 years, hormonal changes result in a net deficit between resorbing and reforming bone tissue leading to demineralisation (Iwamoto, 2013). Consequently, bone tissue becomes more porous, and bone mineral density (BMD) is reduced by 0.002 – 0.006 g/cm^2/year (Warming, Hassager & Christiansen, 2002).

The imbalance between building and breaking down bone tissue therefore increases annually and when BMD reduces to 2.5 standard deviations below the mean for young adults, osteoporosis is diagnosed (Kanis, McCloskey, Johansson, Cooper, Rizzoli & Reginster, 2013). Unsurprisingly, osteoporosis is consequently associated with bone fragility and increased susceptibility to fracture and falls-related injury (Burge, Worley, Johansesn, Bhattacharyya & Bose, 2001). Osteoporosis affects an estimated 5 million individuals in the UK, based on bone mineral density measurements of total hip and total hip or spine (Wade, Strader, Fitzpatrick, Anthony & O'Malley, 2014). Prevalence of osteoporosis is higher in women, with an incidence rate of 27% compared to only 7% in men (Wade et al., 2014).

In terms of everyday functioning, osteoporosis itself is not debilitating. However, should a fall occur the risk of bone fracture is far greater than in non-osteoporotic peers. Furthermore, older adults with osteoporosis have a 2.3% increased risk of re-fracture within one year of the initial fracture (Cauley, 2013). Unsurprisingly, a review of clinical trial studies reported that 26% of older adults suffered a re-fracture within one year (Cauley, 2013). This not only impacts the wellbeing of the older person but also the associated costs of treatment and ongoing care. It is estimated that there will be ~230,000 bone fractures as a result of osteoporosis in 2020, subsequently costing more than £2.1 billion in direct medical care expenses (Burg et al., 2001). This places a significant strain on health services in terms of provision of treatment, hospital and care-home accommodation and care staff. The average length of a hospital stay ranges from 8.2 days for a non-injurious fall and 15 days for a severely injurious fall, at an average cost of £322 per day (NHS Improvement, 2017).

To help reduce this burden, for the health service and for the individual, increased physical activity and reduced sedentary behaviour are recommended as preventative measures to improve bone health (Braun, Kim, Jetton, Kang & Morgan, 2017).

As with muscle, bone responds to mechanical stress by stimulating bone metabolism and inhibiting bone resorption (Iwamoto, 2013); thereby resulting in increasing BMD. Consequently, weight-bearing activities such as walking, running, dancing and jumping are deemed especially beneficial to bone health, due to the mechanical stress imposed during ground contact during these activities (Moreira, de Oliveira, Lirani-Galvão, Marin-Mio, dos Santos, & Lazaretti-Castro, 2014).

Similarly, resistance training is also beneficial to BMD (Iwamoto, 2013), and it has been suggested that low-impact resistance exercises may be more applicable and sustainable for older adults, given their increased likelihood of prior conditions, such as arthritis, which might prevent performance of high-impact exercises (Moreira et al., 2014). Accordingly, available evidence strongly suggests that physical activities which impose mechanical load on bony structures, serve to attenuate losses in bone density and hence reduce the risk of falls-related fragility fractures, and the associated costs and consequences to overall health (Gregg, Pereira & Caspersen, 2000)

Age-related changes to cognition and the impact on function

Cognition and memory have been shown to decline with advancing age, with an accelerated rate of decline from 70 years of age (Resnick et al., 2000). This is unsurprising given the extensive neuro-architectural changes that occur in ageing populations. Notably, for example, brain volume typically diminishes in individuals aged 60 years and over with the greatest amount of atrophy present in those aged over 80 (Resnick et al., 2000). Such structural changes are associated with increased incidence of dementia; a progressive cognitive impairment syndrome and umbrella term for other cognitive disorders such as Alzheimer’s disease (AD) (Arevalo-Rodriguez et al., 2015). Accordingly, dementia is defined as a decline in cognitive, emotional and conative functioning (Gustafson, 1996). Reported cases for dementia across Europe are expected to reach 15.9 million by 2040 and hence poses significant challenges to public health (Norton, Matthews, Barnes, Yaffe & Brayne, 2014). The following section will outline the impact of cognitive decline on the health of the older person, and the associated economic implications, while also reporting the positive mitigating influence physical activity has on cognitive decline.

Impact of cognitive decline on health

As the umbrella term for many cognitive disorders, dementia is often thought of as the only state of cognitive decline, with individuals either being demented or not. Interestingly however, there is a transitional stage of declining cognitive function which has been termed mild cognitive impairment (MCI), and is characterised by an impairment in cognitive functions such as memory, without impacting basic function of completing ADLs (Petersen, Smith, Waring, Ivnik, Tangalos & Kokmen, 1999; Berg, Wallin, Nordlund & Johansson, 2013). There is a large variance in the reported prevalence of MCI in the literature with current estimates suggesting that 22% of people aged 71 years and over have MCI (Plassman et al., 2008). However, prevalence as high as 42% has been reported; this disparity, however, may be due to differing definitions of MCI (Ward, Arrighi, Michels & Cedarbaum, 2012).

Two subtypes of MCI exist, *amnestic*; which relates to episodic memory impairment, and *non-amnestic;* which relates to cognitive impairment of domains other than memory (Sachdev et al., 2015). The onset of either subtype of MCI does not necessarily result in further cognitive decline or transition to dementia, evidenced by reports of individuals living with MCI for seven years or more (Berg et al., 2013). However, when memory, language, reasoning and visuospatial abilities inhibit daily function and the performance of ADLs, dementia will often then be diagnosed (Arevalo-Rodriguez et al., 2015). Unsurprisingly, individuals with amnestic MCI are at an increased risk of developing Alzheimer's disease (AD); a neurodegenerative disorder whereby a progressive reduction in memory and cognitive function is accompanied by neuropsychiatric symptoms such as delusions and changes in behaviour (Baker, Cook, Arrighi & Bullock, 2011).

AD is highly debilitating for everyday functioning and the completion of ADLs, with AD patients often becoming dependent on others (Baker et al., 2011). The costs of treating and caring for AD patients, are estimated to be between £7 billion and £14 billion in the UK (Lowin, Knapp & McCrone, 2001). Given the projections for increases in the ageing population and prevalence of dementia, these figures are likely to increase. However, evidence has emerged to suggest that delaying the onset of AD by as little as 1 year could result in an 11% reduction in worldwide cases by 2050 (Norton et al., 2014). Due to the fact that known risk factors for the onset of AD include diabetes, midlife hypertension, midlife obesity, physical inactivity, depression, smoking and low educational attainment (Norton et al., 2014), interventions to prevent or reduce these risk factors holds significant promise for both public health and the economy.

Impact of physical activity on cognitive function

A meta-analysis conducted by Kramer and colleagues (2005) revealed a significant positive effect of exercise on cognitive function in the ageing population. This research analysed studies published between 1966 and 2001, that had assessed the cognitive function of older adults (aged >55 years) before and after a physical exercise intervention. The study revealed that aerobic training combined with strength and flexibility training had a greater positive effect on cognition than aerobic training alone (Kramer et al., 2005). More recent research supports this finding and suggests that participation in aerobic and strength exercise, at any life stage, exerts a positive effect on delaying or even reversing cognitive decline (Northey, Cherbuin, Pumpa, Smee & Rattry, 2017).

Cognitive decline can be highly debilitating for older adults, causing a loss of independence through the onset of dementia. However, many of associated risk factors can be reduced through physical activity and exercise; thereby benefiting the longevity of independent daily functioning of the older person while also exerting positive economic implications for the health service. Further review of the effect of physical activity on cognitive function and cognitive training on physical function is discussed in the next chapter.

Age-related psychosocial changes and impact on function

Humans are a social species whose evolutionary success was heavily dependent on group-based affiliations and collaborations (Cacioppo, Hawkley, Norman & Berntson, 2011). Recent research has shown how important social interaction and social relationships can be for physical health and mental wellbeing (Holt-Lunstad, Smith & Layton, 2010). As an example, in older adults, social isolation is associated with increased inflammation, and compromised immunity and sleep quality; all of which can contribute to higher rates of morbidity and mortality (Cacioppo et al., 2011). The following section outlines the impact social relationships, and similarly the lack of them, can have on physical and psychosocial dimensions of health.

Impact of social isolation on health

A lack of social integration can affect one’s psychological state and result in loneliness, of which there are two types: *social loneliness* and *emotional loneliness* (Luanaigh & Lawlor, 2008).

Each form of loneliness can occur independently, however, as is usually the case in older adults, the loss of one's life partner results in emotional loneliness which tends to consequently result in social loneliness through social isolation. Similarly, the loss of any significant figure, such as a friend, can also increase the likelihood of social isolation and emotional loneliness and have a detrimental impact on psychological wellbeing, often leading to a state of depression (Alpass & Neville, 2010). Some authors have reported that this can increase the risk of mortality, potentially through negatively impacting immune function (Holwerda et al., 2012; Luanaigh & Lawlor, 2008).

Social isolation and resulting perceptions of loneliness have also been linked to other negative health outcomes such as poor sleep, hypertension, abnormal stress responses and the increased risk of developing cognitive impairments. Subsequently, prevalence of AD significantly increases in lonely individuals (Wilson et al., 2007; Cacioppo et al., 2002a, 2002b; Steptoe, Owen, Kunz-Ebrecht & Brydon, 2004). The negative implications to health and wellbeing from poor psychosocial status is therefore evident and of considerable concern, given that over 1 million older adults in the UK report perceptions of loneliness (Bolton, 2012). Reducing the amount of socially isolated individuals therefore could have significant implications on health-related quality of life for older adults, and the financial strain currently imposed on the health and social care system (McNally, Nunan, Dixon, Maruthappu, Butler & Gray, 2017).

Impact of social relationships on health

Being socially connected however, can serve to attenuate many of the health risks associated with social isolation. Consequently, a large scale meta-analytic review with over 300,000 participants demonstrated that the odds of survival increase by 50% in people with strong social affiliations (Holt-Lunstad Smith & Layton, 2010). In other words, an individual with strong social relationships is likely to live longer than an individual with weaker social relationships. Although this may sound trivial, the authors also reported that as a predictor of mortality, strong social relationships are equal to smoking cessation and surpass that of obesity and physical inactivity (Holt-Lunstad et al., 2010). It therefore seems clear that social relationships are a crucial factor for longevity and overall biopsychosocial health.

Importantly, being physically active has been reported to attenuate health declines associated with loneliness and to induce psychosocial benefits, such as reducing depression, and elevating mood (McAuley, et al., 2000; Kritz-Silverstein, Barrett-Connor & Corbeau, 2001; Arent, Lander & Etnier, 2000).

According to Pederson and Saltin (2015), there are a number of possible mechanisms for this, one of which is increased levels of brain derived neurotrophic factor (BDNF) released in response to physical exercise. Elevated BDNF promotes hippocampal volume; thereby offsetting the hippocampal atrophy typically associated with depressed individuals (Duman, 2005).

Other theoretical mechanisms of health benefits through social relationships comes from social support whereby the relationship helps to '*buffer'* stressors, through informational, emotional or tangible support; thereby moderating the behavioural or neuroendocrine responses to illness, or stressful events (Holt-Lunstad et al., 2010). Furthermore, the main effects model suggests that social relationships act to protect biopsychosocial health status through healthy behaviours and self-care. In other words, healthy behaviours are typically conformed to within social networks through the provision of meaningful roles and life purpose, which also benefits self-esteem (Holt-Lunstad et al., 2010; Cohen, 2004).

Highlighting the influence of social networks on healthy ageing, previous research has illustrated that cognitive decline in community-dwelling older adults is lower for both males and females that undertake regular social engagement with relatives and the community (Zunzunegui, Alarado, Del Ser & Otero, 2003). Such social activities may also involve physical activity, for example walking to a meeting place and thereby reducing sedentary behaviour which can be so harmful to health (Tremblay, Colley, Saunders, Healy & Owen, 2010). Such benefits can be extended further if, for example, social relationships are formed through an exercise class, whereby physical and cognitive benefits of the exercise are also induced (Barnett, Smith, Lord, Williams & Baumand, 2003; Northey et al., 2017).

The importance of social relationships is often overlooked in regard to health, however research has identified just how important social relationships are in relation to overall health and wellbeing. Biopsychosocial health encompasses physical, cognitive, psychological, social and emotional dimensions which seem to all interact with each other. When age-related changes to more than one dimension of biopsychosocial health lead to functional decline, often the result is what is known as *frailty*.

Frailty

The term 'frail' is often associated with older adults which accordingly has been described as a "*geriatric syndrome, reflecting multisystem dysfunction and in which individuals are able to dynamically transition between severity states*" (Dent, Kowal & Hoogendijk, 2016, pp. 3). Furthermore, a commonly reported side effect of frailty is a vulnerability to adverse events and the inability to recover from them (Turner & Clegg, 2014). The onset of frailty can occur gradually and naturally or be brought on by acute illness, injury or psychological stress. In this case, due to the vulnerable nature of fail individuals, the onset of further decline and morbidities can occur quite rapidly, and result in the need for medical care and treatment.

The worldwide incidence of frailty is reportedly 5.8% - 35% among over 65s and represents a global health concern in light of population projections of 1.4 billion over 60s by 2030 and 2.1 billion over 60s by 2050 (Department of Economic and Social Affairs: Population Division, United Nations, 2017; Chen, Chang & Lin, 2017). One of the main reasons for this concern is the associated care costs of frail individuals. Due to the multisystem dysfunctional nature of frailty, individuals often have several prescribed medications, termed polypharmacy, require frequent GP and/or hospital appointments, and in some cases need assistance at home or inevitably and eventually become institutionalised in a care home. It has been reported that providing care for these individuals costs local authorities in England £8.8 billion per annum (McNally et al.,2017). Ironically, prescribing several medications to help combat functional decline associated with frailty, has been reported as *high-risk prescribing*, and can contribute to the onset of frailty in community-dwelling males aged 70 and over (Gnjidic et al., 2012). It would therefore seem that interventions aiding the prevention of the onset of frailty, as opposed to the pharmaceutical treatment of it would prove more cost-effective for the health service and benefit the health of the individual.

In addition to the costs of care, frail individuals are more likely to suffer an injurious fall due to multisystem dysfunction leading to multiple morbidities and the resultant polypharmacy – a known risk factor for falls (Richardson, Bennett & Kenny, 2015). In addition to this, frailty has been reported to increase the rate of cognitive decline, and consequently frail individuals have a higher risk of cognitive impairment and dementia than non-frail counterparts (Clegg, Young, Iliffe, Rikkert & Rockwood, 2013).

Arguably, the most debilitating side effect of frailty is one's loss of independence. It has been reported that frail individuals have reduced activity levels and a poor quality of life compared to none-frail individuals (Chen et al., 2017). This could be for several reasons, not least the decline of physical health but also the negative impact on psychosocial wellbeing, with increased levels of anxiety, depression and reduced levels of social activities (Dent & Hoogendijk, 2014). This therefore leads to a downward spiral of declining biopsychosocial health, resulting in the dependence on others to aid the performance of ADLs.

However, there is emerging evidence that the vulnerability associated with frailty can be stabilised or even decreased through appropriate exercise and nutrition (Turner & Clegg, 2014). Group-based and home-based exercise programmes have been reported to improve functional ability and mobility in frail elderly individuals (Clegg et al., 2013). Such exercise interventions primarily focus on physical function, with strength and balance training highlighted as areas of particular importance, however exercise will also benefit cognitive function (Clegg et al., 2013; Northey et al., 2017). With regard to nutrition, vitamin D has been identified as a key vitamin for frail individuals because it has been demonstrated to improve neuromuscular function and increase bone formation reducing the likelihood of fracture, particularly if combined with calcium supplements (Avenell, Gillespie, Gillespie & O'Connell, 2009). Vitamin D can be obtained through direct sunlight exposure, thus has been pseudonymised by some authors as *"the sunshine vitamin"* (Holick, 2018). However dietary supplementation is reportedly more effective for increasing vitamin D levels in deficient individuals (Wicherts, Boeke, van der Meer, van Schoor, Knol & Lips, 2011).

Conclusion

It is clear that as chronological age advances, so too does biological age. However, the environment one lives in, and the lifestyle choices one makes can dramatically influence health status and consequent biological age through aggregating inflammation in the body, termed inflammaging (Bartlett et al., 2012).

Health decline is a natural ageing process through the shortening of telomeres, but this can be accelerated through unhealthy lifestyle. Conversely, physical activity can prevent inflammaging and aid the maintenance of functional health status. Physical exercise is repeatedly highlighted to reduce inflammaging and benefit function through attenuating decline of sarcopenia, osteoporosis, dementia and ultimately frailty and loss of independence (Northey et al., 2017; Turner & Clegg, 2014).

Furthermore, being socially active should be considered as important as being physically active for biopsychosocial health given the associated benefits of social relationships (Holt-Lunstad et al., 2010; Farrence, et al., 2016).

Nonetheless, declines in biopsychosocial health can result in frailty and loss of independence. Therefore, knowing how much healthier physically and socially active older adults are compared to population normative data would add to the existing evidence base of the importance of exercise interventions to improve the health of the older adult population. These Interventions are needed to help older people be more physically active, prevent the onset of frailty and remain independent for longer.

However, provision and access to physical activity interventions is not always possible, hence research to broaden understanding on improving function in the absence of physical activity is warranted. This is what will be discussed in the next chapter.

CHAPTER 3 – PREVENTING FALLS IN OLDER ADULTS: CAN IMPROVING COGNITIVE CAPACITY HELP?

The previous chapter outlined the benefits of physical activity and exercise in attenuating the decline in biopsychosocial health of older adults, including the onset of frailty and loss of independence. As previously mentioned, frail individuals are more likely to be cognitively impaired and suffer from injurious falls than non-frail individuals (Richardson et al., 2015; Clegg et al., 2013). Consequently, this can have significant implications for the individual's biopsychosocial health and result in high associated healthcare costs. Recent research has shown links between cognition and walking gait from which novel and impactful fall prevention interventions could be developed. The following chapter is based on a previously published peer-reviewed paper:

Robinson, J. E. and Kiely, J. (2016). Preventing falls in older adults: Can improving cognitive capacity help? *Cogent Psychology*, 4(1), doi/abs/10.1080/23311908.2017.1405866

Introduction

It is well known that in order to achieve and maintain physical health, one must partake in regular physical activity. With regard to promoting health and preventing disease in older adults (65 years and over) The American College of Sports Medicine (ACSM) and American Heart Association (AHA) recommends 30 minutes of moderate-intensity aerobic activity five times a week, or 20 minutes of vigorous-intensity aerobic activity three times a week, in addition to muscle-strengthening exercises at least twice a week (Nelson et al., 2007). In addition to this, a meta-analysis of studies published between 1966 and 2001 revealed a significant positive effect of physical exercise on cognitive function in older adults (Colcombe & Kramer, 2003). The authors reported cognitive task performance improved by an average 0.5 standard deviations following physical exercise. Similarly, the psychosocial benefits of physical exercise have also been reported in the literature (Taylor, Cable, Faulkner, Hillsdon, Narici & van der Bij, 2007).

However, whether a bi-directional relationship exists between cognitive and physical functions is less clear, with few available publications evident within the relevant literature. However, there is emerging evidence of a link between executive brain functions and walking gait, which holds potential for a novel approach to enhancing physical function through cognitive training.

Accordingly, the aims of this chapter are to:

1. Present current knowledge on physical and cognitive exercises, and the potential functional interaction between them,
2. Review emerging evidence, specifically in older adults, relating to cognition, cognitive training and walking gait,
3. Suggest a conceptual framework explaining why cognitive training might improve walking gait.

Current Knowledge: Physical exercise for physical and cognitive function

Adults over 50 years of age represent the most sedentary segment of the adult population, with 88% of over 65s living with at least one chronic health condition (King, Rejeski & Buchner, 1998). Older people do, however, positively respond to physical activity. Accordingly, both low (40-60% VO2max) and high intensity aerobic exercise (75%VO2max) have been demonstrated to increase endurance capacity, by 12% and 20-30% respectively in older adults (Lakatta, 1993). Further, studies have demonstrated that aerobic endurance training can lead to reduced body fat, fat mass and waist-to-hip ratios in 60-70-year-old men and women (Kohrt, Obert & Holloszy, 1992). Moreover, resistance training in older adults has been shown to increase muscle strength and bone density, therefore potentially reducing falls risk and the subsequent risk of fracture following a fall (Taylor et al., 2004).

As well as improving physical function, physical exercise has also been shown to positively affect cognitive function. This has been demonstrated in both children (Sibley & Etnier, 2003) and adults (Moonen, van Boxtel, de Goost & Jolles, 2008), as well as across the human lifespan (6-90 years) (Etnier, Salazar, Landers, Petruzzello, Han & Nowell, 1997). In a recent study, cognitive function in older adults aged 50 years and over was reported to improve, after aerobic and resistance-based exercise programmes of at least moderate intensity (Northey, Cherbuin, Pumpa, Smee & Rattray, 2017). Thus, illustrating the importance of physical exercise for the development and maintenance of cognitive function in childhood and adult life. Importantly for older adults, regular participation in physical exercise has also been shown to attenuate cognitive decline (Fox, 1999), and has repeatedly been reported to reduce risk of cognitive impairment such as dementia (Barha, Galea, Nagamatsu, Erickson & Liu-Ambrose, 2017).

One potential reason for this apparent protective effect is through aerobic exercise promoting the secretion of brain-derived neurotropic factor (BDNF), a protein that encourages the growth of new neurons termed *neurogenesis* and formation of new synapses termed *synaptogenesis*. Furthermore, lower concentrations of BDNF are associated with Alzheimer's disease, Parkinson's disease, depression, anorexia and many other diseases (Adlard, Perreau, Pop & Cotman, 2005).

However, not all studies investigating the influence of BDNF on cognition have been positive. This discrepancy is thought to be due to the different form of BDNF tested across studies, as the precursor molecule, pro-BDNF is neurotoxic, which is later converted into the neuroprotector, mature BDNF (Barha et al., 2017). Nonetheless, regardless of whether BDNF is the primary driver for morphological and structural changes to cognitive function in response to exercise or not, the benefits of physical exercise in the prevention of cognitive morbidities is clear (Taylor et al., 2007).

Strength, or resistance training seems to promote different responses to aerobic training; resulting in greater increases in levels of insulin-like growth factor 1 (IGF-1) (Kramer, Colcombe, McAuley, Scalf, & Erikson, 2005). Together, IGF-1 and BDNF interact to fulfil a neuro-protective function, preserving neuronal micro-architectures from progressive structural deterioration; thereby facilitating the preservation of higher-order cognitive processes (Kramer et al., 2005; Cassilhas et al., 2007). Following aerobic training, such changes are less pronounced, thereby proposing different mechanisms through which aerobic and resistance training mediate cognitive enhancements (Barha et al., 2017). These differing mechanisms therefore suggest that both aerobic and resistance training are important to drive the cognitive enhancing effects of physical exercise (Northey et al., 2017).

It is also evident that physical exercise promotes psychosocial benefits, such as reduced levels of depression (Kritz-Silverstein, Barrett-Connor & Corbeau, 2001), enhanced mood (Arent, Lander & Etnier, 2000) and reduced feelings of loneliness (McAuley, Blissmer, Marquez, Jerome, Kramer & Katula, 2000). It is thought that the increased opportunities for social interaction presented, for example by attending an exercise class, are potential reasons for these psychosocial benefits (For further review see Taylor, et al., 2007 and Duman, 2005).

Current Knowledge: Cognitive exercise for cognitive function

Just as the body adapts in response to regular physical stimuli, the brain adapts to regular cognitive stimuli through robust neuroplasticity (Fernandez & Goldberg, 2009; Anguera et al., 2013). Such stimulation can be applied through adequately challenging, structured and focussed cognitive training (Gates & Valenzuela, 2010; Fernandez & Goldberg, 2009). Such cognitive training demands that the participant attempts to solve novel cognitive challenges, targeted to specific dimensions of cognitive function, such as attention, working memory and processing speed. Accordingly, such cognitive challenge requires the participant to stimulate specific functional brain networks on multiple occasions; thereby promoting positive neurogenesis and synaptogenesis (Perrey, 2013).

Previous research has illustrated that cognitive training for older adults can drive the maintenance and enhancement of cognitive function (Anguera et al., 2013; Gates & Valenzuela, 2010). A systematic review by Keuider and colleagues (2012) examined 38 studies of computerised cognitive training methods with older adults between 1984 and 2011. The studies were split into three categories: classic cognitive training; to train specific aspects of cognition individually; neuropsychological software; designed to enhance multiple cognitive domains with a variety of tasks; and video games; involving manipulating 'on-screen' images to achieve a goal (Keider et al., 2012). All three types of training improved cognitive abilities, with the authors concluding that computer-based interventions are less labour intensive than paper-and-pencil methods and, importantly, that being technology savvy is not a requirement in order to reap the associated benefits (Keider et al., 2012).

These findings are of importance as cognitive decline is a common feature of ageing, particularly with regard to processing speed, working memory and inductive reasoning (Singer, Verhaeghen, Ghisletta, Lindenberger, & Baltes, 2003). Crucially, cognitive training targeting these functions has been shown to improve self-efficacy, and preserve independence in older adults (Wolinsky et al., 2009). Openness to experience —thinking creatively and enjoying intellectual pursuits— also declines with age, but has been shown to increase following a period of cognitive training (Jackson, Hill, Payne, Roberts & Stine-Morrow, 2012). Accordingly, as with physical exercise, it appears that participating in cognitive training not only improves functional cognitive abilities, but also indirectly benefits psychosocial health in older adults.

Emerging Evidence: Cognitive training for cognitive and physical function

Motor stabilisation is central to proficient movement execution (Skoyles, 2008). Uniquely within the animal kingdom, human's predominant locomotive gait is bipedal in nature; thereby posing unique stabilisation challenges, requiring continuous skeletomuscular adjustments and multi-level neural control to maintain posture and preserve on-going gait stability (Skoyles, 2008; Hausdorff, 2007). Crucially, these adjustments require cognitive processing and demand uptake of neural resources to anticipate destabilising perturbations and initiate remediating limb movements in advance of destabilisation occurring (Melzer, Benjuya & Kaplanski, 2001; Skoyles, 2006; Hausdorff, 2007). Therefore, it is clear that walking not only requires muscular activations, but also demands higher-order neural processing capacity s (Hausdorff, 2007). As such, cerebral cortical processing abilities and movement stability are closely linked (Skoyles, 2006).

Executive Function

Executive function refers to high-order cognitive processes that control, integrate and organise cognitive abilities to achieve goal-orientated tasks, such as decision-making and problem-solving (Segev-Jacubovski, Herman, Yogev-Seligmann, Mirelman, Giladi & Hausdorff, 2011; Fernandez & Goldberg, 2009). Recent evidence has suggested a close relationship exists between executive function and walking gait (Ijmker & Lamoth, 2012).

Walking is often thought of as an automatic task in young adults, requiring no cognitive effort (Smith-Ray, Hughes, Prohaska, Little, Jurivich, & Hedeker, 2013), whereas in the early and late phases of life it is visibly less automated requiring greater conscious effort. The complex processing essential to anticipatory movement control to maintain a stable gait demands dedication of an inevitably limited reservoir of higher-level cortical resources, not fully developed in the young, and in a state of decline in the old (Lacquaniti, Ivanenko, & Zago, 2012). Under normal walking conditions, gait pattern is relatively rhythmical due to the natural bilateral coordination of α-motoneurons, controlled by spinal neuronal networks activating on both sides of the body in synchronisation (Ivanenko, Poppele & Lacquaniti, 2006; Lacquaniti et al., 2012). When task constraints become unpredictable, and the consequence of error is high —for example when traversing icy or broken surfaces— additional attentional capacity is required to effectively process sensorimotor information. The autonomous motor program is therefore competing with high level cortical capacity, or executive functions, to safely navigate the demanding environmental conditions.

As individual safety is instinctively paramount, gait stability is prioritised to maintain an upright posture (Schabrun, van den Hoorn, Moocroft, Greenland & Hodges, 2014), and so the timing of muscle activation is altered to counteract perturbations and thus gait pattern becomes less rhythmical (Ivanenko et al., 2013; Skoyles, 2008).

Additionally, in persons with cognitive impairments such as, for example, Alzheimer's disease, deterioration of physical abilities, such as walking, decline in tandem with cognitive capacity, (Witter, Websters & Menz, 2010), Many community-dwelling activities such as walking through a crowd of people depend on the successful execution of executive functions. Problem solving and decision making ensure a safe route through the crowd, working memory ensures information can be manipulated in real-time, inhibition filters distractions and mental flexibility allows the brain to quickly switch between functions (Fernandez & Goldberg, 2009; Smith Ray et al., 2013). All this needs to take place in tandem with the execution of motor function to allow the person to walk, regulate gait fluctuations (Decker, Cignetti & Stergiou, 2013) and reduce the risk of falling through maintaining stability (Mirelman et al., 2012).

Linking executive function and physical function

In the ageing brain, neural connections begin to deteriorate from 40 years of age (Fernandez and Goldberg, 2009). Authors have demonstrated an age-related decline in executive functions such as working memory (Buckner, 2004) and processing speed (Park, 2000). Multi-tasking performance, which requires executive functions such as mental flexibility and attention, also declines with age (Anguera et al., 2013; Segev-Jacubovski et al., 2011). However, age-related cognitive decline can be attenuated through regular stimulation. Research has demonstrated that being cognitively active delays the onset of cognitive morbidities such as mild cognitive impairment, dementia and Alzheimer's disease (Wilson et al., 2010). It is thought the stimulation of different brain regions builds a resilience to decline; likely to be due to its promotion of neurogenesis and synaptogenesis (Fernandez & Michelon, 2011).

Moreover, declines in executive function have been demonstrated to present more than just reductions in cognitive function. For example, older adult fallers perform more poorly in computerised tests of executive function than their non-faller counterparts (Hausdorff, Doniger, Springer, Yogev, Giladi, and Simon, 2006). Similarly, older adult fallers with poor working memory overestimate their reach capacity by 16% compared to only 2% in older adult fallers with good working memory (Liu-Ambrose, Ahamed, Graf, Feldman and Robinovitch, 2008).

Further, in persons with dementia a reduction in walking gait velocity has been reported (Ijmker and Lamoth, 2012). Such findings emphasise the point that cognitive and motor functions may compete for limited neural resources, and that this competition may impede performance in one, or both outcomes.

Dual-Tasking

An implication of cognitive deterioration, within the older adult population is increased falls risk. One key contributing factor to falls risk appears to be declining attentional capacity. This impacts the ability to maintain the necessary focus to complete one or more tasks simultaneously known as dual tasking (Segev-Jacubovski et al., 2011). Dual-tasks often occur in community-dwelling daily living, such as walking, while completing a second cognitively demanding task (Segev-Jacubovski et al., 2011; Muir et al., 2012). In this situation, the competition for resources within the cerebello-cerebral circuitry may lead to a deterioration of concurrent performance; thereby increasing the risk of falling (Skoyles, 2008; Schabrun, et al., 2014). Furthermore, age-related deteriorations to the brain regions located in the prefrontal cortical areas, which facilitate executive function, are reported to influence the risk of falling (Herman, Mirelman, Giladi, Schweiger & Hausdorff, 2010).

In a novel study, walking while reading and typing text on a mobile phone, slowed walking gait, incurred postural changes and caused deviations from walking in a straight line (Schabrun, et al., 2014). In this context, the cognitive task (reading or typing text) competed with walking for limited neural resources, and consequently walking gait was impaired. Accordingly, the two tasks were unable to be accurately executed simultaneously, as both draw upon the same high-order cortical resources; thereby forcing task prioritisation of the more cognitively complex task leading to a subsequent deterioration in performance (Segev-Jacubovski et al., 2011), which the authors claim may impact the safety of the individual (Schabrun et al., 2014).

This effect has been further demonstrated by researchers asking participants to walk while performing cognitively stimulating tasks, such as counting backwards from 100 in ones or sevens (Muir, Speechley, Wells, Borrie, Gopaul & Montero-Odasso, 2012). Inevitably this dual-task resulted in reduced gait velocity and increased stride time gait variability; indicating that gait became unstable, thereby increasing the likelihood of a fall (Muir et al., 2012).

In older adults with mild cognitive impairment or Alzheimer's disease, there is a much greater reduction to gait velocity than those with normal cognitive function (35% and 39% vs. 15% respectively) and increases in stride time gait variability exceed the fall-risk threshold (Muir et al., 2012). Such findings highlight the increased risk of falling when cognition is in a state of decline: a risk which is exacerbated when attempting to complete more than one cognitively demanding task simultaneously.

However, it is important to acknowledge that a deterioration of gait in the aged can also be due to physical ailments such as arthritis, joint pain and diminished range of motion; subsequently leading to gait and balance disorders which influence gait variability and stride length (Salzman, 2010). Clearly, changes to executive function will not bring about transformations to peripheral tissue structures such as joints and musculature. Instead, the intention here is to present the emerging evidence of a link between cognitive capacity (and in particular executive function) and walking gait, and suggest how cognitive training may provide a novel solution to enhancing walking competence as illustrated in Figure1.

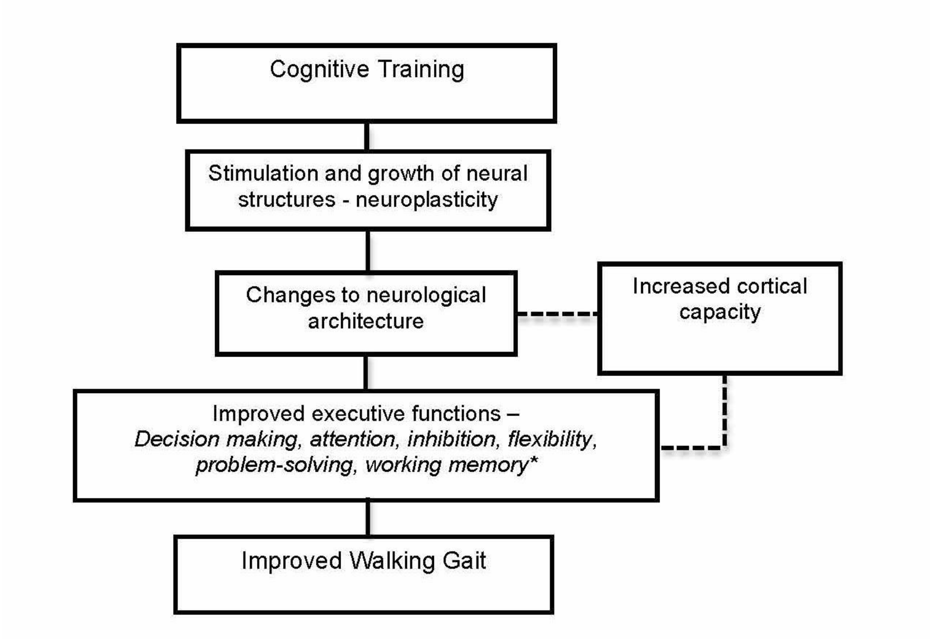


Figure 1. Suggested hierarchical pathway to improve walking gait following a cognitive training programme. Adapted from Fernandez & Goldberg, (2009); Segev-Jacubovski et al., (2011).

Can executive function be improved?

Despite age-related cognitive decline often proving detrimental to health, studies have demonstrated that older adults can improve cognitive capacity, through specific training. A recent study by Saposnik and colleagues (2011) demonstrated that virtual reality gaming, which taxed decision-making and processing speed, enhanced motor function in stroke patients. In this context, the assumed mechanism is that the games drive neurological change which improved motor function (Saposnik et al., 2011). Essentially, in this context, the game worked as a form of cognitive training stimulating neurogenesis and synaptogenesis as the brain plastically remodelled neural micro-architectures. Similarly, playing a custom-designed video game improved the multi-tasking abilities of older adults (65-80 years old) to greater levels than those found in 'untrained' 20-year-olds (Anguera et al., 2013). One hour per day, three times a week for one month playing the multi-tasking game enhanced cognitive abilities which the authors claim is due to the robust plasticity of the ageing brain (Anguera et al., 2013).

Intriguingly, recent research suggests that dimensions of walking performance (specifically gait velocity and balance), can be improved in older adults, consequent to computerised cognitive training programmes (Verghese Mahoney, Ambrose, Wang & Holtzer, 2010, Smith-Ray et al., 2013). Ten weeks of computerised visual, spatial memory and decision-making games slowed the decline of walking speed and balance in a cohort of older adults on average 83 years of age (Smith-Ray et al 2013). The authors attributed the results to the nature of the training, which focused on elements of executive function. Similarly, Verghese and colleagues (2010) reported a statistically significant improvement in walking speed (0.68 ± 0.20 vs 0.77 ± 0.18 $m.s^{-1}$) in 10 sedentary older adults following an 8-week computerised cognitive training intervention. The authors suggested the improvements to mobility were resultant of the targeted intervention which led to improved attention and executive function (Verghese et al., 2010).

These findings hold even greater significance when considered alongside the increased likelihood of mortality at walking speeds less than 0.82 $m.s^{-1}$ (Stanaway et al., 2011). Furthermore, the Advanced Cognitive Training for Independent and Vital Elderly (ACTIVE) study —the largest cognitive intervention study to date (n = 2802)— has demonstrated that training induced improvements to cognitive abilities, such as memory, reasoning and processing speed, are maintained for up to 24 months (Ball et al., 2002).

Such findings demonstrate the robustness of the aging brain and highlight the important role cognitive training can play in maintaining cognitive and physical function in the ageing population should it be applied in a structured and specific manner.

Conclusion

Studies have outlined the importance of physical exercise for physical, cognitive and psychosocial function (Nelson et al., 2007; Colcombe & Kramer, 2003; Duman, 2005). Similarly, cognitive training has also been shown to be beneficial to cognitive and psychosocial health (Anguera et al., 2013; Gates & Valenzuela, 2010). These outcomes are advantageous in terms of attenuating age-related declines to biopsychosocial wellbeing. However, approximately 50% of community-dwelling older adults aged 85 and over will fall each year. Crucially, those with a cognitive impairment are twice as likely to suffer a fall (Iinattiniemi, Jokelainen & Luukinen, 2009). This not only impacts individuals, but also has huge economic implications with fall related treatment costing the UK NHS ~£1 billion per annum (Davis, Robertson, Ashe, Liu-Ambrose, Khan & Marra, 2010).

The uniqueness of human bipedal gait demands high level neural processing to preserve motor stabilisation. Previously it has been suggested that cognition and gait mastery share cerebello-cerebral circuitry (Skoyles, 2008). Recent evidence has emerged within the literature suggesting a link between executive function, walking gait and the risk of falls (Ijmker & Lamoth, 2012). Subsequently, it has been suggested that improving executive function is likely to reduce the risk of falls (Segev-Jacubovski et al., 2011).

One potential method of improving executive function in older adults is via computerised cognitive training, which has also reportedly elicited benefits to walking gait and balance (Verghese et al., 2010; Smith-Ray et al., 2013). However further research is needed to broaden understanding of the relationship between executive functions and walking gait. Furthermore, the utility of computerised training to augment cognitive capacity may, following the rationale and evidence presented here, prove a novel intervention capable of indirectly reducing falls risk in the ageing population. The following chapter is the first in a series of empirical investigations designed to use simple, field-based assessments measures to broaden understanding of biopsychosocial health in older adults.

CHAPTER 4 - METHODOLOGICAL DECISION-MAKING AND EXPERIMENTAL DESIGN

Introduction

The previous chapters have presented demographic statistics outlining how the population is ageing, the natural biological changes that occur with advancing age and the issues these pose to biopsychosocial function and levels of independence. To take this information a step further, a series of empirical studies are needed to achieve the key thesis objectives;

Thesis aim 1.) Understanding biopsychosocial function and the role of physical activity in older adults,

- To understand the relationship between physical function, cognitive function and psychosocial function in older adults.
- To understand the relationship between levels of physical activity across the life span and biopsychosocial function in later life.
- To understand if physical activity in later life can improve biopsychosocial function in older adults, in the community and primary care settings.

Thesis aim 2.) The evaluation of field-based assessment tools in older adults,

- To use different field-based assessment tools to measure biopsychosocial function of older adults.
- To identify which field-based assessment tools are most effective in measuring biopsychosocial function of older adults.
- To use this evaluation of assessment measures and translate them into impactful practical applications to promote longevity and independence in old age.

As demonstrated previously, much of the existing research in this field has been conducted using expensive, technologically advanced equipment within laboratories or other highly-controlled environments. However, field-based measures have a high degree of practical application and hence pose a greater degree of practical utility, which aligns with the thesis aims. There is a likely degree of ‘trade-off’ however, between measurement validity and measurement simplicity i.e. the field-based assessment measures might be accessible but not as accurate as equipment available in a laboratory setting.

Therefore, identifying the most accessible but ecologically valid field-based assessment measures required a decision-making process to tailor the methodological design in accordance with achieving the thesis objectives.

Methodological decision-making

Given that the focus of the thesis is centred around biopsychosocial health, three key dimensions of health would need to be assessed:

1. Physical function, i.e. the implications of age-related changes to physical health,
2. Cognitive function, i.e. the implications of age-related changes to cognitive health,
3. Psychosocial function, i.e. the implications of age-related changes to psychological, emotional and social health.

Each of these dimensions need to be explored further and various assessment measures considered, which are detailed below. Amidst each of these decisions was the consideration of choosing qualitative or quantitative assessment.

Quantitative vs qualitative data

When deciding which form of assessment to use, it is important to understand the type of outcome that is desired. Quantitative assessments produce numeric outcomes through measurement of variables, whereas qualitative assessments would require extrapolating evidence from written or verbal language (Field, 2009). Both have advantages and disadvantages and consequently it was necessary to decide which type of outcome would most readily align with the thesis aims.

Quantitative measures often provide instant feedback that is objective and can be easily monitored to measure progress over time. Whereas the nature of qualitative methods produce a more open-ended approach to the research design resulting in detailed subjective data (Bryman, 2006). As such it has been reported that within quantitative design the researcher and the participants remain independent, whereas in qualitative research, an empathic relationship between researcher are participant is advantageous (Yilmaz, 2013).

Considering the core thesis objectives of using simple, field-based measures with a high degree of practical application, the use of quantitative assessment measures were considered to be favourable.

Similarly, to make comparisons with previous related research, quantitative assessment would be advantageous as the majority of assessment measures used in previous research are in this form. Hence, if quantitative data collection was to be used, the specific assessment measures for each study needed align with the specific research question and aims, centred around the key objectives of the thesis.

To aid this decision, previous literature as discussed in Chapters 2 and 3, were examined to provide insight into previous and existing research methods.

Assessment measures

Previous literature and search engine databases (e.g. PubMed) were used to identify assessment measures for the empirical studies detailed in Chapters 5, 6 and 7. There are a wealth of measures available to determine the required dependent variables, however it was imperative measures were only considered that were suitable for older adults. This was to comply with Thesis aim 2 and the translation of any positive findings into impactful practical applications. With this in mind, a shortlist of potential assessment measures was compiled for consideration to enable a systematic decision-making process based on the following criteria:

- Field-based and simple practical application,
- Appropriateness of the outcome measured,
- Evidence of validity and reliability.

How each of the considered assessment measures faired against these criteria is presented in Table 1, with further explanation provided below.

Table 1. Summary of evaluation of assessment measures for different dependant variables.

Dependant variable	Assessment Measure	Practical application	Outcome measure(s)	Validity	Reliability
Physical function	Timed Up and Go	Field-based, minimal equipment required, quick to administer (<1min/participant).	Functional mobility. Falls risk.	Area Under the Curve = 0.58, *p* = .17 (Hofheinz & Mibs, 2016)	ICC .92 (95% CI=.86–.95) for intrarater measurements and .91 (95% CI=.86–.94) for interrater measurements. (Nordin et al., 2006)
	Timed Up Go Dual-Task	Field-based, minimal equipment required, quick to administer (<1min/participant).	Functional mobility. Ability to complete Activities of Daily Living (ADLs).	Moderate AUC of 0.65, $p < .05$. Valid for identifying falls risk (Hofheinz & Mibs, 2016)	Test-retest reliability ICC = .76 (95% CI=.60–.86) ($p < .01$). (Yang et al., 2016).
	Short Physical Performance Battery	Field-based, minimal equipment required, relatively quick to administer (~5min/participant).	Lower limb function and mobility.	Significantly related to self-report health status ($p < 0.05$) (Gomez et al., 2013).	Test-retest reliability r = .89 (95% CI: 0.83, 0.93) and r = .83 (95% CI: 0.73, 0.89) (Freire et al., 2012).
	OptopJump March In Place protocol	Field-based, OptoJump hardware and software plus laptop required, ~5-10min/participant to administer.	Dynamic balance control.	OptoJump equipment high association to force platform r = .98-.99 (Ruggiero et al., 2015).	OptoJump equipment high test-retest reliability, ICC = .82-.86 (.70 - .92) (Ruggiero et al., 2015).
	30s Sit To Stand	Field-based, only requires a chair and stopwatch, quick to administer (30 sec per participant).	Lower limb strength.	Criterion validity, r = .77 (CI .64-.85) compared to weight adjusted leg press (Jones at al., 1999)	Interrater reliability r = .89 (95% CI = .84-.97) (Jones et al. 1999)

Cognitive function	Lumosity Brain Performance Tests	Field-based, requires a laptop, internet and access to Lumosity BPT. Requires 30-40min per participant to complete.	Executive functions: processing speed, decision-making, problem-solving.	Association to pen and paper test version ranged from r = .47 to .71 (p < 0.05 – 0.01).	Test-retest scores for all assessments range from r = .38 to .83.
	Mini Mental State Examination	Field-based, requires MMSE paperwork to complete test. Specialist training required to implement and interpret results. Takes ~5-10min/participant to administer.	Cognitive impairment.	Strongly associated to Dementia Rating Scale r =.87 (p<0.001) (Aarslsand et al., 2004).	Moderate test-retest reliability r = .45-.50 over 1-year period (Mitrushina & Satz, 1991).
	Stroop colour-word test	Field-based, requires test paperwork but easily acquired. No specialist training required to implement or interpret results. Takes ~5min/participant to administer.	Executive functions; attention, decision-making.	Healthy control vs MS patients p < 0.05, Cohen's d = 0.37 (Lapshin et al., 2013).	Test-retest reliability range r = .55-.77 over 1 and 2-week period (Franzen et al. 1987).
	Trail Making Test	Field or laboratory based. requires test paperwork but easily acquired. No specialist training required to implement or interpret results. Takes ~5min/participant to administer.	Executive functions; attention, decision-making, flexibility.	Moderately associated to the DEX questionnaire r = .37, p < 0.01 (Burgess et al., 1998).	Strong test-retest reliability range r = .76 - .89 (Wagner et al., 2011).

	Raven's Standard Progressive Matrices	Field-based, requires RSPM paperwork to complete test. No specialist training required to implement or interpret results. Takes ~15-20min/participant to administer.	Eductive cognitive ability, problem solving.	Moderately associated to other cognitive assessments in older adults, *r* = .54 - .55 (*p* < .001) (Deary et al., 2004).	test-retest reliability, r = .83 in adults 50+ years, r = .98 to 1.00 in UK based populations (Raven, Raven and Court, 2000).
Social Wellbeing	UCLA 3-item Loneliness Scale	Field-based, short questionnaire. No specialist training required to implement or interpret results. Takes <5min/participant to administer.	Perceptions of loneliness.	Related to other measures of social relationships *r* = -.54, *p* < 0.001 and depression *r* = .45, p < 0.001 (Russel, 1996).	Test-retest reliability *r* = .73 (Russel, 1996).
	De Jong Gierveld Loneliness Scale	Field-based, 6-item questionnaire. No specialist training required to implement or interpret. Takes ~5min/participant to administer.	Perceptions of loneliness.	6-item scale highly related to 11-item scale, *r* = 93 - .95 (De Jong Gierveld et al., 2006).	6-item scale Cronbachs α coefficients .70 - .76 (De Jong Gierveld et al., 2006).
	Campaign to End Loneliness Measurement Tool	Field-based 3-item questionnaire. No specialist training required to implement or interpret results. Takes <5min/participant to administer.	Perceptions of loneliness.	No data available.	No data available.
	Single item questions	Field-based, very quick to administer and no	Perceptions of loneliness.	Low to moderate validity compared to validated	Strong reliability scores r = .72 - .82 (Milton et al., 2010).

		specialist training required.		questionnaires (*r* = .33 - .53) (Milton et al., 2010).	
Activity Levels	Current and Past Activity Questionnaire	Field-based self-report questionnaire. No specialist training required to implement or interpret results. Takes ~5-10min/participant to administer.	Historical and current physical activity levels.	Low to moderate associated to daily activity measured by accelerometers, *r* = .38 and 7-day activity records, *r* = .64 (Orsini et al., 2008).	Test-retest ICC .69 for current activity and .75 - .81 for activity at age 50, and .73 - .75 for activity at age 30 (Orsini et al., 2007).
	CHAMPS	Field-based 41-item self-report questionnaire. No specialist training required to implement or interpret results. Takes ~20min/participant to administer.	Current physical activity levels.	Moderately associated to accelerometer data *r* = .38 - .40, (p < .001) (Hekler et al., 2012).	Test-restest reliability for activity of varying intensity ranged from ICC = .66 - .70 (Hekler et al., 2012).
	Global Physical Activity Questionnaire	Field-based or laboratory based, face-to-face interview. Requires specialist training to implement and interpret. Takes ~30min/participant to administer.	Current physical activity levels.	Moderately associated to accelerometer data *r* = .48 for moderate to vigorous physical activity (Cleland et al., 2014).	10-day test-restes reliability ranged from .83 - .96 and 3 -month reliability was .53 - .83 (Herrmann et al., 2013).
Perceptions of health	Health Confidence Score	Field-based 4-item questionnaire. Can be self-reported or interviewer led. No specialist training required to implement or interpret results. Takes	Confidence in own health management.	Moderately correlated to other validated scales, *r* = .49, number of medications, *r* = -.29 and age, *r* = .22	Strongly related to My Health Confidence score (*r* = 0.76, *p*<0.001) (Benson et al., 2018).

		<1min/participant to administer.		(Benson, et al., 2016).	
	Traffic Light Metric	Field-based questionnaire using depiction of a traffic light. No specialist training required to implement or interpret results. Takes <1min/participant to administer.	Perceived mental wellbeing. Perceived physical wellbeing.	No data available.	No data available.

Measuring physical function

There are many attributes of physical function that can be measured in the field. When focussing on the function of older adults the most common dependant variables among existing literature include flexibility, strength, balance and walking gait (Stathokostas, Little, Vandervoort & Paterson, 2012; Jantunen et al., 2017). Objective assessment measures are often used to capture physical function performance for which many different assessments exist. Identifying those with a high degree of practical utility and validity would be an important process.

Timed Up and Go and dual-task Timed Up and Go

The Timed Up and Go (TUG) is a validated measure of functional mobility and related to falls risk and level of independence (Shumway-Cook, Brauer and Woollacott, 2000; Nordin, Rosendahl & Lundin-Olsson, 2006). It is a very quick and easy to administer test and highly practical due to no specialist equipment being needed– only a chair, tape measure and cone or marker– as stipulated by some authors (Podsialdo & Richardson, 1991). It requires the participant to stand from a seated position, walk 3m to a marker, turn 180° and walk back to the chair, turn 180° for a final time and return to a sitting position. The time it takes to complete this is recorded as a performance measure, with slower times indicating poorer functional mobility and a higher risk of falling (Bohannon, 2006). The TUG has been extensively used in previous literature and has normative data from large samples, as reported in Table 2.

Table 2. Normative data for the TUG

Age range	Normative sample size	Mean TUG time (95% CI)
60-99 years	4395	9.4 (8.8-9.1)
60-69 years	176	8.1 (7.1-9.0)
70-79 years	798	9.2 (8.2-10.2)
80-99 years	1102	11.2 (10.0-12.7)

Source: Adapted from Bohannon (2006)

In the study by Hofheinz and Mibs (2016), receiver operating characteristics were used to demonstrate the validity of the TUG to detect falls risk in community-dwelling older adults. However, the TUG with a cognitive dual-task was reported to be more accurate at predicting falls risk than the TUG without a dual-task (Hofheinz and Mibs, 2016).

The dual-task version of the TUG involves completing the course as described above whilst also completing a cognitive task simultaneously, such as counting backwards from 100 in multiples of three or seven (Muir, Speechley, Wells, Borrie, Gopaul and Montero-Odasso, 2012). This assessment measure is of particular interest as to perform dual-tasks, executive functions such as mental flexibility and attention are required (Segev-Jacubovski et al., 2011). As with the normal TUG version, the dual-task version is quick to administer and does not require any specialist equipment. Both the TUG and dual-task TUG require the use of a stopwatch which has potential for human error in starting and stopping the timer at exactly the right moment. Despite this limitation however, the TUG has been reported as a valid and reliable test for quantifying functional mobility (Podsialdo & Richardson, 1991). As displayed in Table 1, inter-rater and intra-rater measurements have shown excellent reliability of the TUG to as a measure of activities of daily living (ADL) ability (Nordin et al., 2006), and the test-retest reliability of the TUG dual-task has been reported as very good (ICC = .76, $p < 0.01$) (Yang, He, Yiu and Pang, 2016).

Short Physical Performance Battery

The Short Physical Performance Battery (SPPB) is a measure of physical independence using three assessments of physical function 1.) balance, 2.) timed 4m walk and 3.) time to complete five sit to stand repetitions (Freire, Guerra, Alvarado, Guralnik & Zunzunegui, 2012). Each function is scored out of a possible three points, the higher the score the greater the level of physical independence. It is therefore commonly used with older adults both community-dwelling and in care. It can be conducted in the field, requires no specialist equipment and is relatively quick to administer, although there are three separate assessments. It does have high practical application as it is related to lower limb mobility and functional ability to perform ADLs (Guralnik et al., 2000). The SPPB has good levels of test-retest reliability when assessing older adult populations (Freire et al., 20012; Guralnik et al., 2000), and is significantly related to self-reported health status (Table 1.) (Gomez, Curcio, Alvarado, Zunzunegui, & Guralnik, 2013).

OptopJump March In Place (MIP)

The OptoJump MIP protocol is an alternative option to traditional measures of balance and mobility. It uses the OptoJump 1-meter system (Microgate, Bolzano, Italy). This involves two 1m sensor bars fitted with an optical measurement system that detects and calculates interruptions to transmitting LEDs between bars.

The bars are connected to a laptop computer with OptoJump software (OptoJump Next, Version 1.3.20.0, Microgate, Bolzano, Italy) which translates the information from the bars into meaningful data.

The MIP protocol utilises the OptoJump system and requires the participant to march on the spot in between the two 1m bars set parallel to each other, at three intensity levels; slow (60 bpm), medium (90 bpm) and fast (120 bpm). The intensity is set by a metronome. Three trials of 30 seconds at each intensity level for each participant with data for step time recorded, and synchronicity with the metronomic beat calculated. The greater the level of synchronization between the step and metronome, the greater the dynamic control ability of the individual. The OptoJump system is a practical field-based measure that can quickly and easily provide objective data. The specialist OptoJump equipment (hardware and software) is needed however, and completing the three trials can be more time consuming than other assessments, such as TUG.

As the March In Place protocol is a novel assessment, consequently no specific validity or reliability data exists at the time of writing. However, the OptopJump equipment has been used in a variety of settings including elite sports training and testing (Avram et al., 2011; Malone, 2014) and walking gait analysis in older adults (Lienhard, Scheinder & Maffiuleti, 2012). The equipment has therefore been verified as a valid and reliable field-based measurement tool (Table 1) (Ruggiero, Dewhurst, and Bampouras, 2015).

30s Sit to Stand

The 30 seconds sit to stand test involves rising from a seated position to standing before lowering back to a seated position repeatedly for 30 seconds. The number of repetitions completed within the 30 second time is recorded making it a very simple, quick and field-based assessment measure. Furthermore, as presented in Table 1, the 30 second sit to stand test has been demonstrated as a valid and reliable measure of lower limb strength in older adults (Jones, Rikli, & Beam, 1998).

Measuring cognitive function

Many different assessments of cognitive function have previously been used in the literature.

The most commonly used four considered here are the Mini Mental State Examination (MMSE) (Ijmker & Lamoth, 2012; Herman, Inbar-Borovsky, Brozgol, Giladi & Hausdorff, 2009; Wittwer, Webster & Menz, 2010), the Stroop colour-word test (Van der Elst, Van Boxtel, Van Breukelen & Jolles, 2006), Trail Making Test A and B (TMT A and B) (MacPherson et al., 2017); and the Ravens Progressive Matrices (Raven, Raven & Cort, 2000; Wongupparaj, Kumari & Morris, 2015). Traditionally, the only version of these assessments would be paper and pen, however many assessments are now also available as a computerised version. Hence a further part of the decision-making process was to consider computerised versus pen and paper assessment, or indeed would it be necessary to use both.

Lumosity Brain Performance Tests (BPT)

Lumosity.com (Lumos Labs, San Francisco, California, USA) is the number one brain-training software programme on the Internet with 95 million members worldwide ("Discover What Your Mind Can Do", n.d.). It provides computerised training programmes designed to improve elements of executive function such as attention, flexibility, working memory and problem solving. Many of the games are based on traditional cognitive assessments such as the Stroop colour-word test and the Trail Making Test. It is also conducting the Human Cognition Project (HCP) which aims to:

"…create and validate training tools that aim to improve core cognitive abilities and assessment tools to measure cognitive performance, advance the pace of cognitive science research, and expand the understanding of the human brain" ("Lumosity's Human Cognition Project", n.d.).

Part of the project is concerned with healthy adults and ageing which in conjunction with the aims above align well with the thesis aim to broaden understanding of biopsychosocial function of older adults, including cognitive function The Brain Performance Tests (BPT) provide a battery of nine computerised cognitive assessments measuring a range of executive functions. Computerised assessment measures may prove to be advantageous in the field as they can provide instantaneous feedback, unlike paper and pen assessments which requires scores to be calculated manually. Furthermore, the BPT have a moderate to high association to pen and paper versions ranging from r = .43 to r = .71, with low to high test-rests reliability (Table 1) (Morrison, Simone, Ng, and Hardy, 2015).

Mini Mental State Examination

The MMSE is an evaluation of cognitive impairment and is often used to diagnose dementia and its severity. It consists of a 30-item questionnaire which takes approximately 10 minutes to complete and assesses attention, concentration, memory, language, visuoconstructional skills, calculations and orientation (Donoghue et al., 2012). The lowest scores out of 30 considered the most severe cases of dementia (Wittwer et al., 2010). The specific questionnaire form is required to conduct the assessment and specialist training is required to interpret the results .The MMSE is a valid measure of global cognitive function and it is strongly associated with the Dementia Rating Scale (r = .87, p < .001) (Aarsland et al., 2004). Although it is field-based and relatively quick to administer, it appears to provide a greater indication of cognitive dysfunction, rather than cognitive function. There is also no computerised version of the MMSE.

Stroop colour-word test

The Stroop colour-word test is a psychological assessment tool (Van der Elst, Van Boxtel, Van Breukelen and Jolles, 2006), and has been used to assess EF many times since its creation by Professor John Ridley Stroop in 1935. It involves comparing an individual's performance by way of time to complete a basic reading task of colour names with a similar task in which the colour names are printed in different coloured ink. The difference in performance is sometimes referred to as '*the Stroop interference effect'* (Van der Elst et al., 2006).

The test requires EF such as attention, decision-making and processing speed. Various forms of the test have been developed in both paper and pen and computerised versions. The test is relatively quick to administer but requires a one-to-one setting with the researcher and the participant and the only data output is the time taken to complete the test – the performance level of each EF would not be measured. In relation to the pen and paper version, it has been demonstrated as a reliable measure of executive function with moderate to strong test-retest reliability of r = .55 - .77 over a 1- and two-week period (Franzen, Tishelman, Sharp, & Friedman, 1987). Various computerised versions are available on the internet however the reliability of these versions is not well established in the literature and hence considered not to be valid for research purposes.

Trail Making Test

The TMT is a commonly used neuropsychological test (Ashendorf, et al., 2008), which involves EF such as planning and attention, specifically in Part B of the assessment (Ijmker and Lamoth, 2012). In Part A, it requires the participant to draw a line between randomly spaced apart numbers in sequence, e.g.1, 2, 3, 4 up to 10. In Part B the line is drawn between alternating numbers and letters in sequence, e.g.1, A, 2, B, 3, C, 4, D up to 10, J. The participant is timed to complete both tests, with faster times considered superior. Despite high test-retest reliability (Wagner Helmreich, Dahmen, Leib, & Tadic, 2011), associations to other validated assessments are moderate to poor (Table 1) (Burgess, Alderman, Evans, Emslie, & Wilson, 1998). This test can be done with paper and pen and as a computerised version, with the advantage of the computerised version giving instant feedback. It is relatively quick to administer, however, similar to the Stroop test, the only outcome variable for analysis would be the recorded time of each Part, and individual cognitive function performance would not be highlighted.

Ravens Standard Progressive Matrices

The Raven's Standard Progressive Matrices (RSPM) can be considered as a test of fluid intelligence (Schweizer, Goldhammer, Rauch & Moosbrugger, 2007), which involves the eductive component of cognitive ability. According to Raven, Raven and Court (2000) eductive ability is:

"…the ability to forge new insights, the ability to discern meaning in confusion, the ability to perceive, and the ability to identify relationships. Since perception is primarily a conceptual process, the essential feature of eductive ability is the ability to generate new, largely non-verbal, concepts which make it possible to think clearly." (pp. SMP1, Raven Manual: Section 3, 2000).

The test requires the participant to solve incomplete patterns of increasing difficulty by choosing one of eight possibilities that could complete the pattern. As with the BPT, as there is a series of assessments, it does take longer to complete than the TMT or Stroop tests. The number of correct answers represents the level of cognitive performance, previously reported as a highly reliable and moderately valid measure of cognitive function (Raven, Raven & Court, 2000; Deary Whalley & Crawford, 2004) (Table 1). It can be completed by traditional pen and paper or on a computer.

Measuring psychosocial function

The subject of psychosocial function is vast when considering psychological, emotional and social health. There are many variables that could be measured using a wide array of assessments, often via self-report questionnaire.

It was therefore important to ensure the methods chosen to measure psychosocial function remained simple to administer and could be applied in the field. In order to provide insight into the relationship and interaction between biopsychosocial functions it was thought that a focus on social isolation and loneliness would be applicable. This was due to the impact these can have on other aspects of health, such as physical function, as discussed in Chapter 2. Hence the following loneliness-related questionnaires were considered.

UCLA 3-item Loneliness Scale

The UCLA 3-item Loneliness Scale is a self-report questionnaire with three questions, as follows: "*How often do you feel that you lack companionship", "How often do you feel left out", "How often do you feel isolated from others".* Each answer is coded as 1 – hardly ever, 2 – some of the time or 3 – often. Scores are then calculated and compared to a scale of 3 – 9, with 3 being the least lonely and 9 the most lonely.

It is very quick to complete given its short length making it highly applicable in real-world situations, such as with exercise groups. Despite its brevity however, it has been shown in the literature to be a valid and reliable measure of loneliness (Table 1.). The UCLA 3-item Loneliness Scale was used in the English Longitudinal Study of Ageing with 12,000 older adults (Victor et al., 2016) allowing its use with smaller sample sizes to be comparable to national samples.

De Jong Gierveld Loneliness Scale

The De Jong Gierveld Loneliness Scale focuses is also a self-report questionnaire on emotional and social loneliness and was designed to be used with older people. There are 6- and 11-item versions, both of which are strongly related in their ability to discern perceptions of loneliness (Table 1). The 6-item has greater practical utility as it is quicker to complete and is no less as valid than the 11-item version.

With the 6-item version, three questions are focused on emotional loneliness and three questions are focused on social loneliness. The questionnaire has positively and negatively worded questions, the latter of which may prove difficult to ask.

The analysis of responses from individuals is rather convoluted with possible responses being ‘yes’, ‘more or less’ and ‘no’ with score of 1, 1, 0 respectively for the three emotional loneliness questions, which is inverted to 0, 1, 1 respectively for the social loneliness questions. This is due to the positive and negative wording used in the questions. Therefore, the most lonely would score a six and least lonely would score a three. Despite being a robust questionnaire, the nature of the questions and mean it may not be a practically valid questionnaire for use in the field.

Campaign to End Loneliness Measurement Tool

The Campaign to End Loneliness Measurement Tool is a short 3-item questionnaire. that is field-based and quick to administer. It has five possible responses for each question (*“strongly disagree”, “disagree”, “neutral”, “agree”, “strongly agree”, “don’t know”*) which increases the response choice placing greater demand on the decision-making process than few choices would. Despite claims of its strong validity and reliability, no supporting data can be found (Robertson et al., 2012) however, the tool is new and has not been extensively used. It therefore may not be sensitive to changes over time, with the potential to under report feelings of loneliness due to only using positive words.

Single-item scales

Single-item scales are a commonly used measure (Pinquart & Sorenson, 2001) despite potential for bias by asking direct questions about loneliness, as often participants are not always willing to admit to loneliness (Victor, Scambler, Bond, & Bowing, 2012). It is also difficult to capture the specific aspect of loneliness in one question and so results could be misleading, particularly if asking about loneliness over a time period. However, evidence does suggest that even single questions can demonstrate strong validity and reliability (Milton et al., 2010) (Table 1). They can be administered quickly and easily in the field and do not require any specialist training or materials.

Measuring physical activity levels

There are many ways to measure physical activity levels including questionnaires, activity trackers or self-report activity diaries (Sylvia, Bernstein, Hubbard, Keating & Anderson, 2014). The use of questionnaires to measure activity levels is the most common method in the existing literature. Questionnaires allow for a range in variables to be collected and are cost-effective and have a high degree of practical utility (Sylvia et al., 2014). They also allow for historical activity levels to be reported, whereas other methods, such as activity trackers and diaries, only capture current activity levels. Therefore, questionnaires appear be the most applicable assessment measure for the purpose of the thesis' empirical studies, however identifying which questionnaire to use would be an important decision. Three commonly used questionnaires are discussed below.

The Current and Past Physical Activity questionnaire

The Current and Past Physical Activity questionnaire (Orsini et al., 2007) was used to establish this activity levels across the lifespan. It is a self-report multiple-choice questionnaire and provides information of physical activity levels at 15 years, 30 years, 50 years of age and in the last year. This does however place significant demand on long-term memory in order to report historical physical activity levels as accurately as possible. Despite this demand, the questionnaire has been reported as a valid and reliable method to measure current and historical physical activity (Table 1) (Orsini et al., 2007). As a self-reported measure, it can be easily conducted in the field taking approximately 10 minutes to complete, hence giving it a relatively high degree of practical utility.

The Community Healthy Activities Model Program for Seniors

The Community Healthy Activities Model Program for Seniors (CHAMPS) Questionnaire is a 41-item self-report questionnaire based on activities completed in the past four weeks. The questionnaire asks if an activity was completed, how many times it was completed and how many hours were spent completing it. This questionnaire demonstrated moderate validity to accelerometer data and strong test-retest reliability within the population group (Hekler et al., 2012). However, it is a lengthy and time-consuming questionnaire, which subsequently limits its practical utility. Similarly, as it only identifies activity levels in the past four weeks, it would require monthly updates to establish any change in activity patterns. Nonetheless, it would still not establish activity levels beyond the month preceding the first time the questionnaire was completed.

The Global Physical Activity Questionnaire

The Global Physical Activity Questionnaire (GPAQ) from the World Health Organisation is a comprehensive physical activity questionnaire. It is a 16-item questionnaire and asks a range of questions including questions relating to work, travel and recreation. It is a robust and well used questionnaire. However, this assessment requires 30 minutes with a trained specialist to implement and interpret, thereby limiting its practical utility. Furthermore, although it is suitable for older adults, it is not specifically tailored for that demographic, hence questions relating to current work-related activities are likely not applicable. Also, the questions only relate to the present and not the past so historical activity levels are not captured.

Perceptions of health

Health Confidence Score

The Health Confidence Score (HCS) is a 4-item self-report questionnaire designed to measure a patient's confidence in their ability to manage their own health. It uses depictions of smiley faces with associated descriptions; '*Strongly Agree', 'Agree', 'Neutral'* and '*Strongly Disagree'* as responses to four questions – '*I know enough about my health*', '*I can look after my health'*, '*I can get the right help if I need it'* and '*I am involved in decisions about* me'.

The HCS is a field-based measure which is relatively quick to administer, requiring no specialist training or equipment. It is also moderately related to other validated questionnaires and is a reliable indicator of patient confidence (Benson et al., 2016; Benson et al., 2018). However, it does not provide information on health status and how an individual perceives their health, only their level of confidence in self-managing their health.

Traffic Light Metric

The Traffic Light Metric is a simple 2-item questionnaire designed to identify how an individual perceives physical health and mental health. It asks the questions '*How do you feel in your body?*' and *'How do you feel in your mind?*' and uses an illustration of a traffic light so that individuals respond as either red, amber or green (Appendix 6). There are no verbal descriptions associated to the colours of the traffic light to avoid any potential bias of positively or negatively worded cues which may influence the individual's perception, which has been reported as a limitation of psychosocial questionnaires (Robertson et al., 2012).

Instead, the colours of roadside traffic lights are used, where red means *'stop'*, amber means *'get ready'* and green means *'go',* which is an internationally known metaphoric system (Girard, 2011). Thereby if the participant selects 'red' for mental health but green for physical health, it suggests their perception of their mental health is that it is stopping them i.e. they are having a bad day, but physically they feel fine and ready to go. The Traffic Light Metric therefore functions in the same manner as the validated HCS but replaces coloured smiley faces with the symbolic colours of a traffic light. The use of traffic lights as a metaphoric system is widely applied in education and on dietary information in the UK, and has demonstrated validity through a high understanding of its associated meaning (Girard, 2011; Scarborough et al., 2015)

The Traffic Light Metric is used before and after an intervention in order to understand the impact of that intervention on an individual's perception of physical and mental health. The colours of the traffic light are associated to a number so that responses can be quantified (i.e. red = 1, amber = 2 and green = 3). This makes the Traffic Light Metric a quick and simple assessment measure with high practical utility. Although no published data exists supporting its validity and reliability, it has been used in a vocational setting by more than 350 older adults with long term health conditions.

Taking the above assessment measures into consideration, the next section outlines the design of each experimental study.

Empirical study design

The final assessment measures were decided for each experimental study, which would create three empirical studies and a work-based evaluation project. The series of experimental studies were designed to answer a specific research question, with each study aiming to build upon the findings of the preceding study. Hence the overview of each experimental study is presented below, with the rationale for each chosen assessment measure.

Empirical Study 1

Research Question: *How do previous and current activity levels influence physical and cognitive function in older adults?*

In order to answer this research question, the following assessment measures were chosen:

- The Current and Past Physical Activity questionnaire
- The OptoJump March In Place protocol (MIP)
- The Short Physical Performance Battery (SPPB)
- Lumosity Brain Performance Tests (BPT)

The above assessment measures were chosen to measure activity levels throughout the lifespan and how this relates to physical and cognitive function in later life. Of the assessment measures evaluated, the Current and Past Physical Activity questionnaire was the only questionnaire to capture historical physical activity data across the lifespan, hence justifying its selection in this study.

The MIP and SPPB will provide a measure of physical function and the BPT will provide a measure of cognitive function. The MIP requires marching on the spot, simulating a walking gait pattern, which has previously been related to cognitive function (Ijmker & Lamoth, 2012). Hence, the MIP was chosen to explore whether the outcomes from this measure were related to the BPT outcomes. The SPPB has been widely used with older adults and has a high test-retest reliability of physical function (Table 1). Therefore, the MIP and SPPB were chosen to identify any potential relationships with participant activity levels and physical function. Correlating the outcomes from these assessment measures to the activity levels of the participants will help further develop current understanding of the role of physical activity across the lifespan, and on the biopsychosocial function of older adults in line with Thesis aim 1.

Furthermore, the BPT and MIP were chosen to explore the practical utility of novel, computer-based measures in the field. This can be evaluated to contribute to Thesis aim 2; the evaluation of field-based assessment tools in older adults and translation into impactful practical applications. All the measures are suitable for older adults and have evidence of validity and reliability as presented in Table 1. With regard to the outcome of the study, it is hypothesised that the most active participants will have greater physical and cognitive function.

Empirical Study 2

Research Question: *Does attending an exercise class regularly improve biopsychosocial function above reported normative values in community-dwelling older adults and can this be measured in the field?*

In order to answer this research question, the following measures were chosen:

- Timed Up and Go (TUG)
- Timed Up and Go dual-task (TUG DT)
- Ravens Standard Progressive Matrices (RSPM)
- UCLA 3-item Loneliness Scale

The chosen assessment measures will determine physical and cognitive function and levels of social interaction of participants who regularly attend a group exercise class. The TUG and TUG DT will measure physical function and discern the impact of an additional cognitive task whilst performing the physical task. This will provide greater depth in understanding of how physical and cognitive function are related and translate to the ability to perform ADLs. To assist in this, the RSPM will provide a measure of cognitive function which is hypothesised to be greatest in those that perform well in the TUG and TUG DT. The UCLA 3-item Loneliness Scale will provide a measure of social wellbeing which can be used to determine if perceptions of loneliness are related to other biopsychosocial functions.

Participant scores can then be correlated with normative scores for each assessment, hence available normative data is important for these assessment measures. It is for this reason that the RSPM was chosen as the cognitive function measure in this study over the BPT used in Study 1. Furthermore, the use of a pen and paper assessment can be evaluated in the field for practical utility, aligning with Thesis aim 2. Also, comparing the assessment scores of regular exercisers to normative data will develop current understanding of the impact of physical activity on biopsychosocial function in later life, aligning with Thesis aim 1. It is hypothesised that the participants attending the exercise class would have higher levels of function that normative scores.

Empirical Study 3

Research Question: *Can improvements in biopsychosocial function over 12 weeks be measured in clinical settings using simple field-based measures in patients with Chronic Obstructive Pulmonary Disease?*

In order to answer this research question, the following measures were chosen:

- Timed Up and Go (TUG)
- 30 second sit to stand (STS)
- Traffic Light Metric

To contribute to Thesis aim 1, these assessment measures were chosen to enhance understanding of the role of physical activity on the biopsychosocial health of older adults with Chronic Obstructive Pulmonary Disease (COPD).

The TUG and STS have been chosen to measure physical function as both measures have previously been demonstrated as valid and reliable (Table 1). Both the TUG and STS are relatively quick to administer in the field and do not require any specialist equipment. On a practical level, especially when working with groups, time-efficient assessments are needed in order to collect data without compromising the delivery of the exercise intervention. It is therefore important to evaluate the practical utility of these assessment measures in line with Thesis aim 2.

The Traffic Light Metric will measure the health perceptions of the participants, which will give an indication of whether the participant perceives their physical and mental health to have improved. Collected before and after each exercise session, this builds a profile for each participant of how health perception might change over the 12-week intervention. Based on the criteria for assessment selection, the Traffic Light Metric is the most appropriate assessment measure for this study as the intervention was aimed at improving health and consequently measuring participant perception of health was needed. In contrast the HCS would only measure confidence in the self-management of health which was not a dependent variable in this study.

Furthermore, in line with Thesis aim 2, the evaluation of the chosen assessment measures will provide practically applicable information on their efficacy as field-based measures of biopsychosocial function and perceptions of health in older adults with COPD.

Rationale for assessment measures

In addition to answering the specific research question for each of the empirical outputs, the assessment measures used in the experimental studies were chosen as they have been shown to be suitable for older adults, field-based, simple to administer, valid and reliable as highlighted in Table 1.

One key criterion for the assessment measures was the ability to perform them in the field. Not only does this reduce logistical issues with coordinating participants to travel to unfamiliar locations, such as a laboratory for example, but it also increases the repeatability and practical utility of the assessments. As stated under Thesis aim 2, it was important that any significant findings have practical implications which could subsequently be translated into impactful practical applications, hence administering the assessments *in-situ* was a priority.

Table 3. Summary of assessment measures chosen for empirical studies.

Assessment Measure	Outcome measured	Study used in
Timed Up and Go (TUG)	Functional mobility. Falls risk.	2 & 3.
Timed Up and Go, dual task (TUG DT)	Functional mobility. Ability to complete ADLs.	2
OptoJump March In Place protocol (MIP)	Dynamic balance control	1
Short Physical Performance Battery (SPPB)	Lower limb function and mobility	1
30s sit to stand (STS)	Lower limb strength	3
Ravens Standard Progressive Matrices	Eductive cognitive ability. Problem solving.	2
Brain Performance Tests (BPT)	Executive functions e.g. processing speed, decision-making, problem solving.	1
UCLA 3-item Loneliness Scale	Perceptions of loneliness.	2
Current and Past Activity Questionnaire	Current and historical physical activity levels.	1
Traffic Light Metric	Perceived physical and mental wellbeing.	3

The chosen assessment measures, as presented in Table 3 all have the ability to be administered in the field, often with inexpensive and easily accessible equipment. This is important not only for practical repeatability, but also because they require straightforward instructions which is an important consideration when working with older adults. This also helps the assessments to be time efficient as they do not require long explanations of the assessment protocol and what is expected of the participant, and the data is collected within a short time frame. Furthermore, the inclusion of the March In Place protocol has the potential to demonstrate the practical utility of using field-based technology to measure physical function, as opposed to laboratory based equipment.

Cognitive function across each experimental design was determined by either a battery of nine computer-based Brain Performance Tests (BPT) devised by Lumosity (Lumos Labs, CA, USA) or a paper and pen version of the RSPM (Raven, Raven & Court, 2000). The decision to use computerised tests of cognitive function (Lumosity BPT) was taken based on the growing body of evidence, shown in Chapter 3, that computerised brain training can lead to improvements in motor function, most notably walking gait. Hence, it was logical to apply this evidence to evaluate the practical utility of computer-based assessments in participants aged over 60 years.

It was also important for the second empirical study that normative data were available for the assessment measures used in order to answer the research question. For this reason, the paper and pen version of the RSPM would be used as it was far more accessible to have multiple paper copies of the test, compared to multiple computers, and there is also no normative data available for the computerised version (Williams & McCord, 2006). This also allows for comparison and critiquing of the use of computerised versus paper and pen assessment of cognitive function in the field with older adults, to determine which is the most efficient and practically applicable, as per Thesis aim 2.

The three questionnaires chosen (UCLA 3-item Loneliness Scale, Current and Past Physical Activity questionnaire and the Traffic Light Metric) are all readily available and easily implantable in the field and, with the exception of the Traffic Light Metric, have been demonstrated as reliable assessments (Russell, 2010; Orsini et al., 2007). These questionnaires would also allow the aforementioned research questions for each empirical study to be answered, particularly the Current and Past Activity Questionnaire, as the other questionnaires considered did not collect historical data.

Conclusion

In order to achieve the thesis objectives, and to further the evidence and knowledge presented in the previous chapters, a series of empirical studies have been developed. The systematic decision-making process for assessment measures has been outlined which forms an important part of each study design. Each assessment measure has been selected to maximise the potential outcomes of the empirical studies in relation to Thesis aim 1 and Thesis aim 2.

The assessment measures chosen are all applicable in the field and the forthcoming chapters will document how successful these measures are in establishing biopsychosocial functions in older adults. Ensuring a greater understanding biopsychosocial function in older adults (Thesis aim 1) and the determining the practical utility of the assessment measures (Thesis aim 2) to achieve this underpin the thesis, as this will drive the potential for further impactful interventions to promote longevity and functional independence in old age.

The next chapter will therefore present the first of the three empirical studies, followed by the subsequent study outputs as follows;

Chapter 5 – Do high physical activity levels across the lifespan correlate with high cognitive and physical function measured in the field in British community dwelling older adults?
Chapter 6 – The biopsychosocial health of older adults that attend group-based exercise compared to population normative data
Chapter 7 – The relationship between group exercise adherence and physical function and perceptions of health in older adults with COPD

CHAPTER 5 - DO HIGH PHYSICAL ACTIVITY LEVELS ACROSS THE LIFESPAN CORRELATE WITH HIGH COGNITIVE AND PHYSICAL FUNCTION MEASURED IN THE FIELD IN BRITISH COMMUNITY DWELLING OLDER ADULTS?

Introduction

In Chapter 3, the benefits of physical exercise on physical and cognitive function are discussed which has been well documented in the relevant literature (Lakatta, 1993; Kohrt, Obert & Holloszy, 1992; Etnier, Salazar, Landers, Petruzzello, Han & Nowell, 1997; Colcombe & Kramer, 2003; Taylor, Cable, Faulkner, Hillsdon, Narici & van der Bij, 2004). However, in order to take advantage of these benefits to function one must be physically active on a regular basis. The UK Chief Medical Officer produces physical activity guidelines for adults and older adults recommending 150 minutes of moderate intensity activity or 75 minutes of vigorous activity per week, along with strength and balanced focused activity at least twice a week. According to the guidelines, achieving the recommended amount of physical activity results in improved health and a reduced risk of morbidities such as Type 2 diabetes and cardiovascular disease by 40% and 35% respectively (CMO Physical Activity Guidelines, 2019).

Interestingly, there are no guidelines for the maintenance or enhancement of cognitive function. As previously mentioned in Chapter 3, lower concentrations of BDNF are associated with cognitive morbidities such as Alzheimer's disease and Parkinson's disease (Hillman, Erickson & Kramer, 2008). In contrast, human studies report elevated levels of BDNF following exercise and, in rodents, this has been shown to mediate neuroplasticity and consequently enhance learning and memory consolidation (Barha et al., 2017; Hillman et al., 2008). It is therefore suspected that elevated levels of BDNF in humans could facilitate similar effects. Therefore, given the reported benefits of physical activity on cognitive function, to maintain cognitive health in older adulthood, it is assumed that one must meet the physical activity guidelines. Unsurprisingly, exercise throughout the lifespan is reportedly an important contributor for the maintenance of cognitive functions (Etnier et al., 1997).

As previously mentioned in Chapter 3, a relationship may exist between cognitive and physical function, or more specifically, executive function and walking gait, suggesting that a decline in the former is expressed in the latter (Ijmker & Lamoth, 2012). Should physical activity be related to function, it would be expected that individuals who are physically active, currently or historically, perform better in tests of physical and cognitive function.

However, older adults are reportedly the least physically active population group in the UK (Sport England, 2016) hence, does being active across the lifespan hold any benefits for function in later life? Given that low functioning older adults are more likely to suffer a falls-related injury, which costs the UK NHS ~£2 billion per annum (Public Health England, 2016), some UK-based investigations in this field appear warranted (Scuffham, Chaplin & Legood, 2003).

Much of related literature investigating the function of older adults reports the use of a variety of technologies such as accelerometery (Lamoth et al., 2011; Ijmker & Lamoth, 2012), laboratory-based equipment (Taylor et al., 2012; Schabrun et al., 2014), long walkways of sensor mats (Item-Glatthorn & Maffiuletti, 2014) and force-sensitive insoles (Herman et al., 2010). These methods are expensive and often require specialist expertise, equipment and training to administer and are therefore neither readily accessible, nor always possible, in practical settings. In order to gain a greater understanding of function in an applied setting, field-based assessment measures that are simply implemented are required. Furthermore, establishing whether these field-based measures will successfully record physical activity levels and physical and cognitive function of older adults has important practical implications.

Accordingly, in line with Thesis aim 1, the primary aim of the present study was to provide greater understanding of the relationship between levels of physical activity across the life span on physical and cognitive function in older, community-dwelling British adults. Furthermore, in line with Thesis aim 2, a secondary aim was to use simple field-based assessment measures of biopsychosocial function capable of providing data that could be translated into practically implementable applications.

Specific Methodology

Participants

Seventeen community dwelling older adults (*n* = 13 female) living independently agreed to participate in the study (mean age 68±2years). Participants were excluded if they had acute illness, history of brain surgery, unable to walk unaided or had a psychological or neurological disease. All participants gave informed consent for inclusion in the study, which was approved by University of Central Lancashire BAHSS Ethics Committee (unique reference number BAHSS 217 2nd phase).

Assessment Measures

Cognitive Function

Cognitive function was determined by a battery of nine computer-based Brain Performance Tests (BPT) devised by Lumosity (Lumos Labs, CA, USA).

The BPT measured the participants executive functioning via specifically designed computer-based games, including working memory, problem solving, flexibility, processing speed and attention. Details of the BPT can be seen in Table 4

Table 4. Brain Performance Test used to measure a variety of cognitive functions.

Test Name	Description	Cognitive Function
Arithmetic Reasoning	Two numbers appear on screen, side by side. The larger of the two numbers should be selected as quickly as possible by using the keyboard arrow keys, responding to the question *"Determine which side is larger?"* left or right. The number options become progressively harder by becoming equations testing mental arithmetic. Selection time along with the number of correct scores is recorded.	Processing speed, decision making.
Digit Symbol Coding	A series of symbols appear on screen, each with a number associated to it. Symbols are shown at random. The number on the keyboard that corresponds to the symbol of the screen should be selected as quickly as possible. Reaction time is measured, along with correct/incorrect scores.	Processing speed, decision making.
Trial Making A	Twenty-two numbers are displayed on screen, in a random order. The aim is to click (using the computer mouse to navigate) on each number in numerical sequence, i.e. 1, 2, 3… The time taken to complete the test is recorded.	Attention
Trial Making B	As above, only with 12 numbers and 12 letters also displayed. The sequence selected should reflect one number followed by one letter, i.e. 1, A, 2, B, 3, C…The time taken to complete the sequence is record.	Attention
Memory Span	A group of circles are displayed on screen, in the colour blue. They flash for approx. one second in orange, in a random sequence. The aim is to remember the sequence and select the circles in the correct order. The test becomes progressively harder by adding more circles to the sequence. If two consecutive errors, are committed in one sequence the test will end. The number of correct sequences is recorded for analysis.	Working memory, processing speed.
Reverse Memory Span	As above, however the sequence must be selected in reverse order. The test becomes progressively harder by adding more circles to the sequence. If two consecutive errors i.e. wrong circle selected, are committed in one sequence the test will end. The number of correct sequences is recorded for analysis.	Working memory, processing speed.
Wordy Equations	A series of mathematical equations are displayed on screen, one at a time, in words i.e. "*two plus two = ?"* The aim is to type the answer into an answer box on screen, using the computer keyboard number keys. The test lasts 45 seconds with the number of correct answers recorded.	Problem solving, processing speed.
Matrix	A grid with a graphical pattern is displayed on screen, with part of the pattern missing. The test requires selecting one of eight possibilities that could complete the pattern, and adapted as a computerised version of Ravens Standard Progressive Matrices (Raven, Raven & Court, 1998). This test is also reported to measure fluid intelligence (Schweizer, Goldhammer, Rauch & Moosbrugger, 2007).	Attention, decision making and problem solving.
Go/No Go	A picture of a randomly selected fruit is displayed on screen. Instructions to only "Go" when this particular fruit is displayed are given. Then, a series of pictures displaying different fruit are briefly shown on screen. The keyboard space bar key must be pressed as quickly as possible when the instructed fruit is displayed, any other fruit must be ignored. Essentially, a choice reaction time test, with time taken to react being recorded and the mean time of 10 trials given as results. The number of errors is also recorded.	Attention and processing speed.

For participants unaccustomed to using computers the researcher was present to provide instructions and assist when required. Before each trial, a practice go was allowed. This was to help the participant understand how to complete the computerised assessments, however only one practice attempt was permitted as not to incur a learning effect. The researcher would be present during the practice go to ensure the participant was completing the test correctly and left the room when the actual test began. Participants worked through all nine BPT in their own time until all tests were completed.

All assessments were completed online via the internet which allowed the results to be collected and stored on a central database held by Lumosity (Lumos Labs, CA, USA). These were later forwarded to the researcher for analysis.

The BPT provide three main outputs; the raw score, scaled score and percentile score. With a focus on determining the relationship between cognitive test scores and other assessment scores, the raw score –the number of correct responses or the time taken to complete the assessment– was taken forward for analysis. None of the other assessments in the study use scaled or percentile scores, hence the raw score was considered the most appropriate data to establish any potential relationship.

Physical Function

Physical function was assessed through two assessments, the March in Place (MIP) and the Short Physical Performance Battery (SPPB).

March in Place

The MIP assessment measures ground contacts made when marching on the spot in relation to an audible beat. For this, the participant is required to march on the spot in-between two adjacent OptoJump parallel sensor bars (100cm x 8cm), which contain 96 light-receiving diodes separated by 1 cm, located 3mm above floor level. The diodes in each sensor bar line up opposite each other and detect when the light between them is broken, which is captured on a computer containing dedicated software for data processing, at a sampling rate of 100Hz (OptoJump Next, Version 1.3.20.0, Microgate, Bolzano, Italy).

The software also allows for a metronomic beat to be played, made audible via the laptop computers speakers.

The metronome was played at three levels; slow (60 bpm (MIP60)), medium (90 bpm MIP90)) and fast (120 bpm MIP120)), giving three trials of 30 seconds for each participant to march on the spot. Each ground contact is measured by the OptoJump software, the timing of which can be compared against the metronomic beat. For example, for MIP60, there are 60 beats per minute, equating to one ground contact per second (one every beat). The average ground contact time in seconds from each trial was calculated and taken forward for analysis.

The instructions of the test were explained to each participant prior to the first trial and the participant was asked if this had been understood before beginning the trial. This included, the time of the trial, where to stand in relation to the OptoJump system, how to step between the bars, to *"match the beat with your walk as best you can"* and how to step out from between the OptoJump bars. A physical demonstration was also given before the first trial for each participant. The metronomic beat was then played and participants were asked if this was audible before commencing. The trial then began when the participant was ready. When the trial ended the participant stepped out from the bars, walked around to the start position and this was repeated for trials two and three.

Short Physical Performance Battery

The Short Physical Performance Battery (SPPB) consists of three assessments of physical function;1.) balance, 2.) timed 3-meter walk and 3.) five sit to stand repetitions. Each assessment is scored out of a possible three points, with higher scores indicating greater levels of physical independence.

To conduct the timed 3-meter walk test, a tape measure was placed on the floor to determine the three-meter distance. The participant was then asked to stand at edge of the start of the tape measure. The researcher then demonstrated walking the course. The participant was then asked to walk at their normal pace *"as if walking down the street to go to the shops",* in accordance with SPPB guidelines (Freire et al., 2012). Then a *"ready, begin"* instruction was given to indicate the start of the test which was timed manually using a digital stopwatch (iPhone 4s, Apple, CA). Two trials of the test were conducted, the fastest time was carried forward for analysis.

To assess balance, three positions were used; 1.) feet side by side, 2.) semi-tandem, and 3.) full tandem. In the first position the participant stands with feet side by side, touching on the medial edge.

The participant was asked to stand in the position for up to 10 seconds. If completed, the participant moved one foot forward slightly into the second position so that the side of the heel of the front foot touches the big toe of the other foot.

Again, the participant was asked to stand for 10 seconds. The final position was to move one foot in front of the other, so that the heel of that foot was touching the toes of the other foot. The participant was asked to stand in the position for 10 seconds.

Each balance test was conducted in accordance with SPPB protocol guidelines. The researcher demonstrated each position before asking the participant to do so. The researcher would then take up a position to the side of the participant, holding their arm gently to allow the participant to get into position without loss of balance. The researcher would then say, *“are you ready”?* and upon an answer of *“yes”* from the participant, would say *“ready, begin”*. The researcher would then let go of the participants arm and start the stopwatch (iPhone 4s, Apple, CA). After 10 seconds the researcher would say *“stop”* and, stop the stopwatch and the test would end. If the participant had lost balance before 10 seconds had elapsed, the time at which balance was lost was recorded for analysis.

The sit to stand test involved the participant sitting and rising from a chair five times, as quickly as possible. The participant was instructed to fold arms across the chest and maintain the position throughout the test. If the participant could not complete five rises from the chair in without using arms, the test ended. Once the test had been demonstrated and explained to the participant, the cue *“ready, begin”* was used to start the test. The five sit to stands were timed using the same stopwatch as the walking gait and balance tests (iPhone 4s, Apple, CA). The test ended when the participant was in a full standing position following the fifth rise from the chair, or when it was signalled that no more rises form the chair were possible, and the elapsed time was taken forward for analysis.

Previous and Current Physical Activity Level

The Past and Current Physical Activity questionnaire (Orsini et al., 2007) was used to establish this metric. It is a self-report multiple-choice questionnaire, which the participants completed independently. The researcher was present but only to answer queries the participants had when completing the questionnaire.

The questionnaire uses multiple choice answers to questions relating to levels of activity in different categories such as when at school or work, at home and during leisure time.

The answer options are descriptive e.g. *less than 1 hour per week*. Therefore, in order to quantify the responses, metabolic equivalent intensity levels (METs) were used, in accordance with Ainsworth et al. (2000).

This gave a numeric value to the activity which could then be calculated for each participant. Higher values therefore represented higher levels of physical activity. A copy of the questionnaire can be seen in Appendix 1.

Statistical analysis

In line with the study aims, the relationship shared between physical and cognitive function and physical activity levels were analysed. Furthermore, the assessment measures of physical and cognitive function were also analysed to enable greater evaluation of the tools used to establish biopsychosocial function in the field.

All data was tested for parametricity. As no violations were found, multiple analyses were conducted to determine the relationship between variables using Pearson's correlation coefficient (*r*). The correlation coefficients were assessed according to the following scale of magnitude: ≤ 0.1, trivial; >0.1-0.3, small; >0.3-0.5, moderate; >0.5-0.7, large; >0.7-0.9, very large; and >0.9-1.0, almost perfect (Hopkins, Marshall, Batterham & Hanin, 2009). All statistical analyses were conducted on SPSS v22 for Windows.

Results

The first part of the data analysis explores the relationships between physical activity levels and physical and cognitive function. Pearson's correlation coefficient (*r*), values, the number of participants (*n*), statistical significance value (*p*) and relationship magnitude are reported in accordance with Field (2009).

Table 5. Correlation matrix and significance values for self-reported physical activity levels and March in Place trials.

		Activity @ 15	Activity @ 30	Activity @ 50	Activity last year	MIP 60	MIP 90	MIP 120
Activity @ 15	*r*	—	.739**	.081	-.084	-.041	-.039	.178
	p	—	.001	.756	.748	.876	.882	.494
Activity @ 30	*r*		—	.468	.077	-.221	-.267	-.012
	p		—	.058	.770	.394	.299	.964
Activity @ 50	*r*			—	.551*	-.296	-.260	-.142
	p			—	.022	.249	.314	.585
Activity last year	*r*				—	-.195	-.098	.051
	p				—	.454	.707	.846
MIP 60	*r*					—	.868**	.281
	p					—	.000	.274
MIP 90	*r*						—	.390
	p						—	.122
MIP 120	*r*							—
	p							—

*Correlation is significant at the 0.05 level (2-tailed). **Correlation is significant at the 0.01 level (2-tailed).

There were no statistically significant relationships between the March in Place and activity level questionnaire scores. The magnitude of the relationships ranged from trivial to small correlations (Table 5).

In contrast, test scores did present significant relationships with each other. Activity at the age of 15 demonstrated a large significant relationship with activity at age 30. Activity at age 50 demonstrated moderate statistically significant relationship with activity in the last year. March in Place 60 shared a very large significant relationship with March in Place 90. However, all other test scores reported a magnitude of relationship ranging from trivial to moderate (Table 5).

Physical activity levels and cognitive function relationships

Table 6. Pearson correlation and significance values for self-reported physical activity levels and Brain Performance Test scores.

		BPT 1	BPT 2	BPT 3	BPT 4	BPT 5	BPT 6	BPT 7	BPT 8	BPT 9
Activity @ 15	*r*	-.018	-.564*	.087	.436	-.124	.129	-.551*	-.205	-.308
	p	.948	.028	.759	.104	.660	.646	.033	.464	.264
Activity @ 30	*r*	.053	-.703**	.156	.536*	-.135	-.101	-.542*	-.180	-.404
	p	.850	.003	.578	.039	.631	.720	.037	.520	.135
Activity @ 50	*r*	.030	-.376	.318	.317	-.526*	-.351	-.345	-.362	-.234
	p	.915	.167	.249	.250	.044	.199	.208	.184	.401
Activity last year	*r*	.029	-.208	.095	.240	-.119	.234	-.176	-.125	-.251
	p	.919	.458	.737	.390	.672	.401	.530	.658	.366

*Correlation is significant at the 0.05 level (2-tailed). **Correlation is significant at the 0.01 level (2-tailed). BPT 1 = Wordy equations; BPT 2 = Digit Symbol Coding; BPT 3 = Trail Making Test A; BPT 4 = Trail Making Test B; BPT 5 = Memory Span; BPT 6 = Reverse Memory Span; BPT 7 = Grammatical Reasoning; BPT 8 = Progressive Matrices; BPT 9 = Go/No Go.

The magnitude of relationships shared between the physical activity levels and cognitive function ranged from trivial to very large (Table 6). Digit Symbol Coding (BPT 2) and Grammatical Reasoning (BPT 7) both reported large significant correlations with activity levels at age 15.

Digit Symbol Coding (BPT 2) and Grammatical Reasoning (BPT 7) both also reported very large and large significant correlations with activity levels at age 30 respectively. Activity levels at age 30 also shared a large significant relationship with TMT B (BPT 4).

The only BPT to show any correlation with activity at age 50 was Memory Span (BPT 5) where a large significant relationship was reported.

Activity in the last year and BPT scores shared only non-significant trivial to small relationships (Table 6).

Evaluation of assessment measures

The second part of the data analysis explores the relationships shared between the assessment tools used.

When analysing the relationship between the assessments of physical function (MIP and SPPB) the correlations reported non-significant values (*p* > 0.05), with magnitudes ranging from trivial to small (Table 7).

Table 7. Pearson correlation and significance values for the physical function assessment tools and the cognitive function assessment tools.

		SPPB	BPT 1	BPT 2	BPT 3	BPT 4	BPT 5	BPT 6	BPT 7	BPT 8	BPT 9
MIP 60	*r*	-.130	.191	.334	.000	-.184	-.276	.256	.086	.238	-.003
	p	.620	.496	.223	.999	.511	.320	.357	.761	.392	.992
MIP 90	*r*	-.124	.048	.198	-.035	.105	-.232	.118	.070	.272	-.014
	p	.636	.866	.480	.902	.710	.405	.677	.804	.327	.959
MIP 120	*r*	.004	-.021	.473	.089	.154	-.194	.262	.363	-.067	-.030
	p	.987	.940	.075	.753	.583	.488	.345	.184	.811	.915

*Correlation is significant at the 0.05 level (2-tailed). **Correlation is significant at the 0.01 level (2-tailed).

SPPB = Short Physical Performance Battery; BPT 1 = Wordy equations; BPT 2 = Digit Symbol Coding; BPT 3 = Trail Making Test A; BPT 4 = Trail Making Test B; BPT 5 = Memory Span; BPT 6 = Reverse Memory Span; BPT 7 = Grammatical Reasoning; BPT 8 = Progressive Matrices; BPT 9 = Go/No Go.

Pearson correlation analysis of the MIP scores with each of the nine BPT reported non-significant correlation values, with magnitudes ranging from trivial to moderate (Table 7). The strongest relationship reported was a moderate relationship between MIP 120 and Digit Symbol Coding (BPT 2).

Table 8. Correlation matrix of Brain Performance Tests (BPT).

		BPT 1	BPT 2	BPT 3	BPT 4	BPT 5	BPT 6	BPT 7	BPT 8	BPT 9
BPT 1	*r*	—	.237	-.287	-.461	.122	.258	-.153	.178	-.385
	p	—	.395	.300	.083	.664	.354	.586	.526	.156
BPT 2	*r*		—	.136	-.564*	-.035	.345	.733**	-.050	.214
	p		—	.629	.029	.903	.208	.002	.861	.444
BPT 3	*r*			—	.362	-.707**	-.197	.196	.046	.477
	p			—	.185	.003	.481	.484	.871	.072
BPT 4	*r*				—	-.282	-.268	-.335	-.029	.030
	p				—	.309	.334	.223	.917	.916
BPT 5	*r*					—	.417	.077	.114	-.048
	p					—	.122	.786	.685	.864
BPT 6	*r*						—	.046	-.175	-.220
	p						—	.870	.532	.430
BPT 7	*r*							—	.112	.464
	p							—	.692	.081
BPT 8	*r*								—	.414
	p								—	.125
BPT 9	*r*									—
	p									—

*Correlation is significant at the 0.05 level (2-tailed). **Correlation is significant at the 0.01 level (2-tailed).

Each of the BPT reported correlation magnitudes with each other ranging from trivial to very large (Table 8). Trial Making Test A (BPT 3) and Memory Span (BPT 5) reported a very large and significant relationship. Digit Symbol Coding (BPT 2) significantly correlated with both Trial Making Test B (BPT 4) and Grammatical Reasoning (BPT 7), demonstrating a large and very large relationship, respectively.

Discussion

The aims of the present study were to provide greater understanding of the relationship between levels of physical activity across the life span on physical and cognitive function in community-dwelling British older adults. A secondary aim was to use simple field-based assessment measures of biopsychosocial function that could translate into practical applications.

The findings of the study are presented below in two sections in relation to Thesis aim 1, enhancing understanding of biopsychosocial relationships and Thesis aim 2, the evaluation of field-based assessment of biopsychosocial function.

Enhancing understanding of biopsychosocial relationships

Physical activity and physical function

The participants of the present study have demonstrated being more physically active either in early adulthood or late adulthood. This is represented by a large and statistically significant relationship between self-reported levels of physical activity at 15 and 30 years of age and a moderate statistically significant relationship between activity levels at 50 years of age and those of the last year (Table 5). Despite the reported importance of maintaining high physical activity levels for greater physical function in older age (Stenholm et al., 2015; Hall et al., 2017), these findings suggest a *'peak'* in physical activity levels across the lifespan.

Being more or less active in early or late adulthood does not seem to have influenced the physical function of the older adult participants (mean age 68 ±2 years). The relationship between self-reported physical activity levels across the life span and the physical function measures are reported in Table 5. However, with the exception of the relationship between the March in Place (MIP) 120 trial and activity at 15 years of age, all correlations were negative values, suggesting that higher physical activity levels at any age relate to greater physical function in older age, as measured by the MIP. Although not statistically significant, this supports the perspective that physical activity throughout the lifespan is beneficial to physical function in later life **(**Manini & Pahor, 2009). However, this cannot be stated with a large degree of certainty given the magnitude of the relationships and small sample size used (n = 17), hence there is a higher risk of type II error, leading to the acceptance of a false null hypothesis (Faber & Fonseca, 2014; McLeod, 2019). There is also a possibility of memory bias when completing the questionnaire, in that the participants are being asked to recall historical activity levels of up to ~50 years ago. However, the questionnaire has been reported as a valid and reliable method to measure current and historical physical activity as displayed in Table 1 (Chapter 4) (Orsini et al., 2007).

Similar findings have been reported in much larger studies. For instance, a study of 1,149 participants suggested that higher levels of physical activity across the lifespan are associated with reduced decline in physical function and a lower incidence of disability and mortality in older age (Stenholm et al., 2016). This finding is corroborated by Hall and colleagues (2017) who report that greater levels of physical activity are associated with better physical function performance tests of mobility, strength, balance and endurance in all age groups (30 – 90+ years) (Hall et al., 2017).

It therefore seems clear that being physically active at any life stage will bestow benefits to physical function in later life. However, to maximise these benefits remaining active across the lifespan is recommended.

Physical activity and cognitive function

Interestingly, physical activity levels in the first three decades of life appear related to cognitive performance in later life. This is demonstrated by the large, statistically significant relationships shared between activity at age 15, BPT 2 and BPT 7 (Table 7). Furthermore, activity at age 30 shared a very large, statistically significant relationship with BPT 2 and a large, statistically significant relationship with BPT 4 and BPT 7 (Table 7).

These findings are supported in the literature where high physical activity levels in early life have been shown to benefit cognitive functions, such as information processing speed, in older age (Dik, Deeg, Visser & Jonker 2003). Processing speed is one of the cognitive functions measured in BPT 2 and BPT 7, however interestingly, the study by Dik and colleagues (2003) found the influence of regular physical activity to only benefit males, whereas 76% of the participants in the present study were female. The differing modes of assessment i.e. paper and pen versus computerised assessments, could be attributable for this contrasting finding. It is also plausible that education and socioeconomic status may also be a factor which was not accounted for in the present study.

A further contradictory finding from the present study reports a significant relationship of activity levels at age 50 with BPT 5, the Memory Span assessment. Research reports shrinkage of 0.5% - 1% per year in grey matter mass from the age of 60 years, which correlates with reduced memory performance (Macpherson, Teo, Schneider & Smith, 2017). Interestingly, with the exception of BPT 1 and BPT 9, the remaining seven BPTs share a moderate to large relationship with the level of physical activity at age 50 (Table 8.) This suggests that the participants self-reporting as physically active during the more recent years of their lives have benefited cognitive function.

A systematic review by Santos-Lozano and colleagues (2016) has demonstrated that 150 minutes per week of moderate to vigorous physical activity can lower the risk of Alzheimer's disease by 40% in 70-80-year olds. Therefore, despite no set guidelines for the maintenance of cognitive function, following the CMO guidelines for physical activity would appear to benefit physical function, as supported by the reported literature.

Accordingly, further supporting literature has identified exercise to aid prevention of age-related cognitive decline and neurodegenerative diseases (Hillman et al., 2008; Northey et al., 2017). In the present study, it therefore seems likely that being physically active has benefited the participants cognitive function, given the magnitude of the relationships between physical activity level at age 50 and seven of the nine BPT. However with a mean age of 68(±2) years, it is possible that the participants can more accurately recall activity levels at age 50 (an average of 18 years ago) compared to activity at age 30 and 15 (an average 38 and 53 years ago, respectively). Furthermore, there were only 17 participants in the present study representing a small sample size. Hence potential memory bias and small sample size suggest the need for further research with larger cohorts to test the robustness of these assessment measures and consequent findings.

Evaluation of field-based assessment tools to measure biopsychosocial function

Assessment of physical function

Both physical function assessments were successfully completed in the field. Despite requiring some specialist equipment i.e., the OptoJump sensor bars and software, the MIP was simple to set up and the nature of the test was quickly understood by the participants. As each trial lasted for 30 seconds this is a relatively quick assessment to administer and does not require specialist knowledge or training.

Similarly, the SPPB was simple to set up and requires no specialist equipment. The three tests were easily understood by each participant, and completion of the full battery of tests takes a similar duration to the MIP. The main difference between the two assessments is the space needed, given one of the tests in the SPPB is a 3m timed walk. Hence, when space is limited, which can often be the case in the field, this test is not possible, however the MIP has no such issue.

Another difference between the two assessments is data output. The scoring system for the SPPB is 0 – 3, whereas for the MIP, it can be any number reported to two decimal places. This is due to the nature of the assessments and suggests that the SPPB is not as sensitive to differences in physical function as the MIP among a community-dwelling group. In the present study many of the participants scored highly on each test component of the SPPB, with some scoring maximum points across the three components. Hence, there was little variance among scores (mean±SD = 11.24±0.66).

Whereas, due to the sensitivity of the technology, the MIP reported highly variable data with each participant reporting a different score. This variety of scores is likely due to the natural fluctuations in gait pattern when marching on the spot. (Hausdorff, 2007).

Hence, when comparing the outcomes of both assessments, no statistically significant relationships were found. The magnitude of the relationship shared between all three MIP trials and the SPPB scores were trivial (Table 7). This suggests that, despite both assessments measuring physical function, it appears that they cannot be used interchangeably as a high score in either the SPPB or MIP would not necessarily translate to a high score in the other. This represents an important finding for practitioners, as different assessments of physical function can produce different results. Choosing an assessment appropriate for the desired outcome and the participant is therefore of significance.

Previous research has reported the reliability and validity of the SPPB to measure physical function in a community-dwelling group of older adults aged 65 – 74 years (Freire, Guerra, Alvarado, Guralnik & Zunzunegui, 2012), hence it is a highly applicable field-based assessment of gross physical function. However, if a test of greater sensitivity is required, the MIP would present the practitioner with a more detailed picture of an individual's level of physical function.

Furthermore, with the MIP there is also the added challenge of staying 'in place' and not deviating too much from the centre of the two parallel OptoJump sensor bars, whilst also maintaining the rhythm of the metronome. This requires cognitive functioning through a complex process of sensory input, information processing, task prioritisation and motor output (Hausdorff, 2007; Skoyles, 2008). Reportedly, executive functions such as information processing, processing speed and attention utilise the same brain regions as locomotion (Segev-Jacubovski et al., 2011; Muir et al. 2012; Herman et al., 2010). Hence it would be logical to hypothesise that the MIP scores would be related to the BPT scores, however this was not the case with all tests of correlation reporting non-significant trivial to moderate relationships (Table 7).

It is possible that computer literacy affected participant scores of the BPT and hence the reported values were not 'true' reflections of functional ability. However, this is unlikely given previous research has suggested being 'computer savvy' does not impact performance of computerised cognitive assessment (Kueider et al. 2012).

Assessment of cognitive function

The battery of nine computerised assessments measured cognitive functions including processing speed, decision making, attention, working memory and problem solving. The assessments gave mixed data outputs including raw scores, scaled scores and percentile scores from each BPT. In the present study, the raw scores were taken forward for analysis which included the time taken to complete the assessment or the number of correct answers. It is important for any practitioner to understand the nature of the outputs an assessment measure provides, hence when using computerised assessments with different outputs it is important to maintain consistency.

In regard to practical utility, the time taken to complete all nine BPT was ~60 minutes with those who were less computer literate taking longer to familiarise with the tests and use of the computer mouse or keyboard. Once completed, the results of each assessment were then sent to Lumosity to be processed before being returned to the researcher for analysis, in agreement with the Human Cognition Project (HCP) terms of involvement. Despite one of the benefits of computerised assessment being instant feedback of participant performance, in this case it was delayed. This limits the practical application of the BPT, however, in circumstances outside the HCP this would not occur. This strengthens the use of these computerised assessments as field-based measures of cognition. Nonetheless, 60 minutes dedicated to assessment is not always feasible in the field and hence, a shortened version of the BPT would be advantageous.

Assessment of physical activity levels

The Past and Current Physical Activity questionnaire has previously demonstrated its reliability in measuring physical activity levels over a life span (Orsini, Bellocco, Battai, Pagano & Wolk, 2007). The questionnaire was relatively simple to complete, however despite being a self-report questionnaire, some participants required assistance from the researcher due to ambiguous instructions on the questionnaire, which could be construed as a limitation.

It is easy to complete in the field with paper and pen however it was rather time consuming to complete, hence if practitioners working with large groups might seek a shorter questionnaire. Quantifying scores using METs was also rather time consuming and complicated reducing its applicability if used with large groups. However, this does allow the questionnaire to be quantified and not only provide descriptions of activity level.

Where historic activity levels are required the Past and Current Physical Activity Questionnaire combined with METs provided a quantifiable indication of physical activity level across the lifespan. This method of analysis has led to the discovery of peak activity levels in early or late adulthood. Therefore, to enhance the practical utility and the reliability of this method of data analysis, inter-rater and intra-rater reliability testing with a larger sample size to that of the present study is warranted.

Conclusion

The present study aimed to provide greater understanding of the relationship between levels of physical activity across the life span on physical and cognitive function in community-dwelling British older adults. This was achieved using simple field-based assessment measures of biopsychosocial function with the aim of evaluating the practical utility of such measures.

It was identified that British older adults tend to exhibit greater activity levels either in early life, (<30 years of age) or in later life (>50 year of age). The relationship between the amount of physical activity undertaken at different life stages and physical function in older age (mean±SD = 68±2years) was trivial to small. However, the direction of this relationship suggests that higher physical activity levels at any age relate to greater physical function in older age. Although the sample size of the present study was small, larger scale studies also support this conclusion (Stenholm et al., 2016; Hall et al., 2017).

Interestingly, being physically active in the first three decades of life shares a much larger relationship with cognitive function in later life than was demonstrated for physical function. Processing speed ability in later life seems to particularly benefit from high levels of physical activity in early life. In addition, being physically active in later life has greater benefits for memory than any of the other cognitive functions measured. These findings suggest that physical activity levels throughout life are related to a range of cognitive functions in older age.

Using field-based assessment measures to test physical and cognitive function is possible with some tests demonstrating greater practical utility than others. The SPPB and MIP are simple and relatively quick assessments to employ making them practically applicable in the field. However, practitioners should be aware of the outcomes of these assessments and remain consistent in the choice of assessment, as it has been demonstrated that they are not interchangeable.

The BPT and Past and Current Physical Activity questionnaire are worthy assessments, however the time taken to complete them can limit their usefulness in the field. Similarly, the method used in the present study to quantify the questionnaire results warrants further validation.

Hence, a shortened version or similar shorter assessment measures may be desired by practitioners should reporting cognitive function and historic self-reported physical activity levels be required.

Overall, older adults have self-reported as being either more active in the first 30 years of live or from 50 years of age onwards. There appears to be some benefits in being more physically active at different life stages, but those who are more active in recent years do not significantly outperform less-active peers in field-based assessments of physical and cognitive function. Nonetheless, remaining as active as possible and ideally meeting the CMO physical activity guidelines throughout the lifespan would be advised to maximise the benefits of physical and cognitive function in older age.

Further research is needed to delve deeper into the relationship between physical activity levels and physical and cognitive function. Furthermore, given the impact of social relationships on health, as reported in Chapter 2, how are social relationships related to physical and cognitive function? Hence, the following experimental study attempts to provide a greater understanding of the relationship between biopsychosocial functions in older adults and the use of field-based assessments to measure such functions.

CHAPTER 6 – THE BIOPSYCHOSOCIAL HEALTH OF OLDER ADULTS THAT ATTEND GROUP-BASED EXERCISE COMPARED TO POPULATION NORMATIVE DATA

Introduction

The findings of the previous chapter demonstrated that activity levels across the lifespan were highest either before 30 years of age or after 50 years of age. As evidenced by the literature reported in Chapter 2, regular activity in later life is a fundamental means of attenuating many manifestations of age-related decline, such as sarcopenia (Steffl et al., 2017). Subsequently, regular activity holds the potential to serve as a key strategy to promote and prolong physical independence.

Related to this is the ability to perform activities of daily living (ADLs) which are an essential requirement for independent function (Covinsky et al., 2003). ADLs include activities such as bathing, rising from a chair, dressing, using the toilet and walking. Unfortunately, many age-related declines in physical and cognitive function typically inhibit the ability to perform ADLs and is typically coupled with morbidity and reductions in health-related quality of life (Costa, Badia, Chow, Lipton & Wardley, 2008).

In a recent study of 14,767 emergency hospital admissions of adults aged 50 and over, 83% had three or more morbidities, known as multi-morbidity, which is related to an increased length of stay in hospital (J. M. Lord, personal communication, September 14, 2018). Prevalence of multi-morbidity increases with advancing age and is associated to disability, functional decline, and increased healthcare costs (Marengoni et al., 2011). It is estimated that multi-morbidity accounts for two million unplanned emergency hospital admissions per year and 68% of hospital emergency bed days, with 10% of these staying for longer than two weeks (Imison, Poteliakhoff & Thompson, 2012).

Often, multi-morbidity will reside as both physical and cognitive decline and unsurprisingly, is often also associated with frailty and an increased risk of falling (Pfortmueller, Lindner & Exadaktylos, 2014). It is estimated that a third of over 65s and half of those aged 80 and over fall at least once per year (Pfortmueller et al., 2014). As identified in Chapter 3, cognition plays an important role in stabilising a bipedal walking gait and hence a decline in specific executive functions can increase the risk of falling (Hausdorff, 2006; Ijmker & Lamoth, 2012). In addition to the physical impact of a fall, psychosocial health can also suffer. Previous research has reported that 40% of older adults are clinically depressed after a fall (Means, O'Sullivan & Rodell, 2003).

This, combined with the fear of suffering another fall, can often lead to social isolation and loneliness, which can be as harmful to health as smoking 15 cigarettes per day (Holt-Lunstad et al., 2010). It is estimated that in England 1.2 million people aged 65 and over are chronically lonely which is associated with a significant decline in health-related quality of life (Marmot et al., 2016).

Fortunately, there is a wealth of literature supporting the value of physical activity and exercise to offset these debilitating age-related declines in biopsychosocial health. For example, a large-scale systematic review and meta-analyses recently confirmed that physical activity protects against the onset of sarcopenia and improves and protects the ability to perform ADLs (Steffl et al., 2017). Furthermore, being physically active is also associated with a higher sense of achievement, improved self-efficacy and enhanced self-esteem; all of which are associated with higher levels of health-related quality of life (Elavsky et al., 2005). Similarly, as reported in Chapter 3, older adults who regularly participate in physical exercise are less likely to exhibit cognitive decline and hence have a reduced risk of cognitive impairments, such as dementia (Fox, 1999; Barha, Galea, Nagamatsu, Erickson & Liu-Ambrose, 2017). Consequently, it seems clear that being physically active in older age positively contributes to the maintenance of biopsychosocial health, functioning and independence.

Automaticity is a term used to describe a skill or activity that requires low levels of attentional resources (Paul, Ada & Canning, 2005). Therefore. the amount of attention required to complete the activity dictates how automated the performance of that activity is. For example, walking is a fundamental and highly practiced ADL which, in healthy adults, has a high automaticity (Paul et al., 2005). However, super-imposing concurrent cognitive tasks upon habituated physical activities, such as walking, serves to challenge the allocation of cognitive resource such as attention. Consequently, dual-tasks have previously been used as an experimental paradigm to investigate attentional limitations (Wulf, McNevin & Shea, 2001; Richer & Lajoie, 2019). Previous research has calculated the effect of dual-tasking on the automaticity of walking as a percentage with a maximum score of 100% indicating no decrement in walking performance (Paul et al, 2005). Previous literature reports that in healthy young adults walking performance of ≥90% shows normal automaticity levels, but this may be lower in older adults due to age-related declines in physical and cognitive functions (Paul et al., 2005).

One means of assessing an individual's functional ability is to compare their test scores to normative values. Normative values are typically based on chronological age and/or gender and provide a generic benchmark of expected functional performance based on previously collected data. Based on the rationale provided thus far, it is hypothesised that older adults regularly attending an exercise class, would perform well in tests of physical, cognitive and social function, and thus ADL ability.

Subsequently, to further understanding of relationships that may exist between biopsychosocial functions of older adults, the primary aim of the present study was to measure the physical, cognitive and social function of regular group-based exercise attendees and compare this to normative data. This would assist with achieving Thesis aim 1, while a secondary aim of this study was to evaluate the use of simple field-based assessment measures to adequately establish dimensions of biopsychosocial function in older adults, in line with Thesis aim 2.

Methods

Participants

Twenty-one community dwelling older adults (18 female; 3 male) living independently volunteered to participate in the study (mean age 80±6.5 years). Participants were excluded if self-reported an acute illness, history of brain surgery, a psychological or neurological disease or were unable to walk unaided. Two participants were unable to complete the full assessment protocol. One participant was removed from the data analysis due to a diagnosis of mild dementia, thereby violating the inclusion criteria. Hence data analyses were conducted on 18 participants.

All participants were recruited from a group-based community exercise class aimed at improving flexibility, aerobic capacity, balance and strength. Sessions last for one hour and all exercises can be done seated, standing with chair support or free standing. All participants had been attending the class once per week regularly for at least 12 months. All participants gave informed consent for inclusion in the study, which was approved by University of Central Lancashire BAHSS Ethics Committee (unique reference number BAHSS 217 2nd phase).

Assessment Measures

Each participant completed four assessments including: one assessment of physical function, one assessment of cognitive function, one assessment of perceived social relationships and one assessment of ADL ability. In line with the secondary aim of the study, each of these assessments used simple field-based assessment measures.

Physical function

Timed Up and Go

To complete the Timed Up and Go (TUG) each participant starts sitting in a standard armchair, back against the back rest of the chair and resting his/her arms in one's lap. The participant is then required to stand up from the chair, walk to a marker that is 3 meters away, turn 180° around the marker, walk back to the chair, turn 180° for a final time, and sit down in the chair. The test ends when the patient's buttocks touch the seat. Participants were instructed to *"walk at your normal pace*".

The test was explained to the participant while seated in the chair. Once the participant confirmed they were ready to begin the test, the researcher verbally cued the start of the test by counting down *"3, 2, 1, go",* upon which the participant began to stand and the stopwatch was started. The researcher stopped timing as soon as the participant made contact with the chair when returning to a seated position. The chair used had no arms so the participant could not push up to aid standing. The legs of the chair were secured against a wall to ensure the chair did not move during the test. A digital display stopwatch (Apple iPhone 6s, Apple, CA, USA) was used to time the test in seconds. The participant was given two attempts at the test, separated by a minimum of 20 seconds, until the participant was ready to go again. The best of the two times was be taken forward. The normative data used as a base of comparison for this investigation was reported by Bohannon (2006), following a meta-analysis of 21 studies representing 4395 participants aged 65 and over.

Cognitive function

Ravens Standard Progressive Matrices

The paper and pen version of the Raven's Standard Progressive Matrices (RSPM) test was used to measure the eductive component of cognitive ability, as defined in Chapter 4 (pg 47). Participants were given a question sheet with five sets, A – E, each with 12 questions of increasing difficulty. Participants recorded their answers on a specifically designed answer sheet (Pearson Inc., TX, USA) which, upon completion of the test could be peeled back to reveal a carbon copy of the participants marked answer on a set of correct answers. This procedure aided analysis allowing the researcher to tally up the correct answers for each section quickly. The participants completed as many questions as they could in their own time. The results were analysed in accordance with Raven, Raven & Court's (2000) guidelines. Scores are reported as arbitrary units (AU). A copy of the question sheet is presented in Appendix 4. The normative data used as a base of comparison was reported by Raven et al. (2000) and provides a representative sample of adult Britons.

Perceived social relationships

UCLA 3-item Loneliness Scale

The UCLA 3-item Loneliness Scale is a self-report questionnaire with three questions, as follows: "*How often do you feel that you lack companionship", "How often do you feel left out", "How often do you feel isolated from others".* Each answer is coded as 1 – hardly ever, 2 – some of the time or 3 – often. Scores are then calculated and compared to a scale of 3 – 9, with 3 being the least lonely and 9 the most lonely.

Participants were given the questionnaire on paper to complete in their own time to avoid any external influencing factors, such as peer pressure. Completed versions of the questionnaire were then collected by the investigator for analysis. A copy of the question sheet is presented in Appendix 2. The normative data used as a base of comparison was collected as part of the Office for National Statistics *Omnibus Survey* and represents 999 respondents aged 65 or over, as reported by Victor, Scrambler, Bond, and Bowling (2005).

ADL ability and independence

Timed Up and Go Dual-Task

To establish the influence of cognition on ADL ability, such as walking and consequently a level of independence, the dual-task TUG (TUG DT) was used. This consisted of the same TUG test as described above with the addition of a second cognitively demanding task. For this, participants were asked to verbally count backwards in subtractions of 3 from a randomly assigned number between 50 and 100. This is similar to cognitive dual-tasks previously reported in the literature (Springer et al., 2006; Taylor et al., 2013).

The participants began counting after standing from the chair and ceased counting when they returned to a sitting position. Participants were instructed to verbalise as many numbers as they could while maintaining a normal walking pace, and to try to not prioritise either counting or walking. The time taken to complete the test i.e. from standing up to returning to sitting, was recorded for analysis.

Difference in time to complete TUG and TUG DT

The time difference to complete the TUG and TUG DT was calculated via subtraction. Using the automaticity index an estimate of the impact of the dual-task on walking performance was derived. This was achieved by expressing the time differences as a percentage, using the following equation:

$$\frac{TUG}{TUG\ DT} \times 100$$

Subsequently, the percentage scores were used to determine the impact of the dual-task on the automaticity of walking for each participant.

Statistical analyses

All data was tested for parametricity. A Kolmogorov-Smirnov test reported the TUG data as normally distributed, (D(19) = 0.16, p = 0.20), however all other data sets were all significantly non-normally distributed, reporting a significance value of $p \geq .05$. As such, Kendall's tau (τ), a non-parametric bivariate correlation was used to establish the relationship between each assessment measure. The correlation coefficients were assessed according to the following scale of magnitude: ≤0.1, trivial; >0.1-0.3, small; >0.3-0.5, moderate; >0.5-0.7, large; >0.7-0.9, very large; and >0.9-1.0, almost perfect (Hopkins et al., 2009).

In order to compare the study population to normative values in physical, cognitive and social function a Wilcoxon Signed Ranks Test was used due to the non-parametric nature of the data. Data is reported as z-scores (z) with effect sizes (r) based on the following magnitudes of small; +/- 0.1 – 0.3, medium; +/- 0.3 – 0.5 and large; +/- 0.5 – 1.0 (Cohen, 1988, 1992). The level of significance was set at $p < .05$. All statistical analyses were conducted on SPSS v22 (IBM SPSS Statistics, Version 22.0, Armonk, NY: IBM Corp).

Results

Descriptive statistics and test results are reported in table 9 and correlation values are reported in table 10.

Table 9. Mean and SD participant descriptive statistics and assessment measure results.

	Age	TUG (s)	TUG DT (s)	Diff. (s)	% Diff	UCLA	RSPM
Mean	79	9.46	11.32	1.86	84	4	43
SD	7	1.6	3.0	2.2	12	1.1	4.5

Relationships between biopsychosocial functions, ADL ability and independence

Table 10. Correlation and significance values for all biopsychosocial functions, ADL ability and independence.

		Physical (TUG)	Cognitive (RSPM)	Social (UCLA)	ADL (TUG DT)	TUG DIFF
Physical (TUG)	τ	-	-.266	.262	.626**	.146
	p	-	.121	.160	.000	.382
Cognitive (RSPM)	τ	-.266	-	-.336	-.085	.036
	p	.121	-	.078	.621	.832
Social (UCLA)	τ	.262	-.336	-	.163	-.134
	p	.160	.078	-	.382	.470
ADL (TUG DT)	τ	.626**	-.085	.163	-	.520**
	p	.000	.621	.382	-	.002
TUG DIFF	τ	.146	.036	-.134	.520**	-
	p	.382	.832	.470	.002	-

TUG = Timed Up and Go; RSPM = Raven's Standard Progressive Matrices; UCLA = UCLA 3-item loneliness questionnaire; TUG DT = TUG dual-task; TUG DIFF = difference in time recorded to complete TUG and TUG DT. **$p < 0.05$

Table 10 reports a small and non-significant relationship between TUG and the RSPM, UCLA and the TUG DIFF. However, the relationship shared between the TUG and the TUG DT was large and significant.

The RSPM reported a moderate but non-significant relationship with the UCLA 3-item loneliness questionnaire. The relationship shared with the other assessment measures was small and non-significant (Table 10).

The TUG DT had a large and statistically significant relationship with both the TUG and the TUG DIFF. The TUG DIFF was not significantly related to any other assessment measure reporting only small to moderate associations, which was also the case for the UCLA 3-item loneliness questionnaire.

Comparison to normative values

Table 11. Wilcoxon Signed Ranks Test results for physical, cognitive and social scores versus normative values

	z	**Positive Ranks**	**Negative Ranks**	**Tied Ranks**	***p***	***r***
Physical (TUG)	-3.57	17	1	0	.000	-0.49
Cognitive (RSPM)	-1.17	6	10	2	.241	-0.16
Social (UCLA)	-3.71	17	1	0	.000	-0.51

Z = *z*-score; positive ranks = scores below the norm; negative ranks = scores above the norm; tied ranks = scores the same as the norm; *p* = significance value; *r* = effect size.

The participants demonstrated significantly greater physical functionality, as exhibited by faster TUG times (*Mdn* = 9.7 sec) compared to age-matched normative controls (*Mdn* = 12.7 sec). Similarly, perceptions of loneliness (UCLA) were significantly lower in the study participants (*Mdn* = 4) than age-matched normative data (*Mdn* = 6). However, the study participants' cognitive function (RSPM) (*Mdn* = 44) was not significantly greater than age-matched normative data (*Mdn* = 45).

Discussion

The primary aim of the study was to identify the relationships between biopsychosocial functions in older adults regularly attending a group-based exercise class. A secondary aim was to use simple field-based assessment measures to accomplish the primary aim. The findings of the study are presented below in two sections, as they relate to the stated key thesis objectives:

1.) enhancing understanding of biopsychosocial relationships

2.) the evaluation of field-based assessment of biopsychosocial function.

Enhancing understanding of biopsychosocial relationships

The strongest relationship was between physical function (TUG) and ADL ability (TUG DT). This suggests that physical function is a key indicator of ADL ability and independence, which is supported in previous research (den Ouden, Schuurmans, Brand, Arts, Mueller-Schotte & van der Schouw, 2013).

Interestingly, the mean automaticity score for the study participants was 84% which is just under the previously reported value of 87% for healthy older adults undergoing the same TUG DT (i.e. counting backwards in 3s) (Shumway-Cook et al., 2000; Paul et al., 2005). The participants in the Shumway-Cook (2000) study were community-dwelling with a mean age of 78±6.0 compared the present study's community-dwelling participants with a mean age of 79±7.0.

An advance in average age of one year resulted in a 3% difference in dual-task walking performance. Previous literature suggests that automaticity scores lower than 90% indicate an increased risk of falling, with lower scores signalling greater falls risk (Paul at al., 2005). This therefore suggests that despite exercising regularly, the present study participants could be more likely to fall than previously reported community-dwelling older adults of similar age. A comparison of scores shows the Shumway-Cook et al. (2000) participants, with no history of falls, completed the TUG and TUG DT in 8.4s and 9.7s respectively, compared to the present study participants' 9.5s and 11.0s respectively (Table 9).This difference in scores is small, yet practically significant and contradicts the findings presented in Table 11 suggesting the present study participants have outperformed the physical function of age-matched controls. Thus demonstrating the cautious approach needed when comparing to normative values.

Nonetheless, the lack of relationship found in the present study between TUG (physical function) and RSPM (cognitive function) supports previous research where cognitive function was measured by the MMSE in older adults dependent in ADLs (Nordin et al 2006). Hence it is possible that the cognitive measure used here (RSPM) and the MMSE are not measures of attention, but serve instead as global measures of cognitive ability, which are not related to ADL ability. Conversely however, more recent research with community-dwelling older adults has demonstrated an association between TUG performance and multiple cognitive domains including global cognition, memory and processing speed (Donoghue et al., 2012). Interestingly, of the two measures of global cognition used in the study by Donoghue and colleagues (2012), the MMSE was not as significantly associated to TUG performance as was the Montreal Cognitive Assessment. This variability in outcomes, even when measuring the same function, highlights the importance of assessment measure selection and the significant implications this has for practitioners.

In the present study, cognitive function (RSPM) shared a moderate negative relationship with social function (UCLA) (Table 10). However, reports in the literature have demonstrated that higher levels of social engagement in older adults are associated with increased cognitive function (Krueger et al., 2006). Furthermore, a longitudinal study of older adults' behaviours demonstrated that engaging in more social activities resulted in increased performance in cognitive tests (Glei et al., 2005). Accordingly, on a practical level, the social nature of the exercise class is thought to contribute to the moderate relationship between cognitive and social function demonstrated in the present study. However, the lack of statistical significance found suggests further investigation is needed to confirm this postulation.

Comparison to normative data

The high degree of social activity among the study participants is also demonstrated by the Wilcoxon Signed Ranks test. Compared to normative perceptions of loneliness using the UCLA 3-item Loneliness Scale, the study participants were significantly less lonely, as illustrated by a large effect size (Table 11). When comparing assessment results to normative data, one must always consider potential confounding variables, such as the demographics of the two samples, to ensure a justified comparison of means. However, the authors who compiled the normative data used here state that the characteristics of the sample provides a broad representation of community-dwelling older adults living in Great Britain (Victor et al., 2005).

Subsequently, it may be appropriate to interpret these results as suggestive in that older adults regularly attending group-based exercise classes (an estimated 14% of the elderly population) perceive themselves as less lonely than the general population of older adults (Ellison & Lewis, 2017).

Unsurprisingly, regular attendance at an exercise class resulted in physical function scores, as measured by TUG, that were significantly higher than normative data with a medium effect size (Table 11). However, although considered valid normative reference values, the data published by Bohannon (2006) did not included a British sample. Instead it includes samples from North America, Europe, Australia, Asia and the Middle East. This does demonstrate the international acceptance of the TUG as an assessment measure of physical function, yet may, however, decrease the ecological validity of the present findings for a British population.

As for cognitive function, measured via RSPM, the majority (55.5%) of study participants recorded a cognitive score above the normative data, however this was not statistically significant and the effect of the difference was small (Table 11). This might be due to 33.3% of the study participants scoring below the normative data and 11.1% scoring equal to normative data (Table 11).

There is therefore no obvious effect of attending a group-based exercise class on improved cognitive function. However, as many previous studies have reported, regular exercise does improve cognitive function, although the specific mode of exercise undertaken may be a confounding variable (Northy et al., 2017). In order to benefit cognitive function, prior research suggests that exercise must be of moderate to vigorous intensity (Northey et al., 2017). Research observations suggest the intensity of the exercise class the study participants attend was low to moderate, however this was not quantified. Therefore, future research more precisely quantifying perceptions of exercise intensity, and evaluating the potentially varied impact of exercise modes on cognitive function, would greatly benefit current theoretical understanding.

It is also important to consider potential methodological limitations in respect to study design and use of various normative reference values. Given the lack of relationships identified, alternative assessment measures to examine the relationship between physical and cognitive function to those used here (i.e. TUG, TUG DT, RSPM) would provide further understanding to the efficacy of field-based measures to identify biopsychosocial relationships.

Normative data is useful for field-based work and to provide relevant reference comparisons for practitioners. However, it is difficult to find consistent normative data as the data is often collated from different sources using different population groups. Accordingly, the utility of demographic information should also be considered to offset the potentially confounding variables such as age, gender, education, nationality and physical activity levels of the participants used to create the normative data. Furthermore, as with Study 1 (Chapter 5), due to the small sample size (n = 18), there is an elevated risk of Type II error in the present study (Faber & Fonseca, 2014; McLeod, 2019). Subsequently, although practically informative, these findings should be carefully weighed in light of these limitations.

Evaluation of field-based assessment tools to measure biopsychosocial function

The TUG is a simple and effective assessment measure that is quick to administer and provides a valid and reliable indication of physical function and mobility. The TUG is used internationally and published normative data can be used as reference values when assessing physical function in the field. One potential limitation, however, is human error in the timing of the start and stop of the stopwatch. However, adhering to a standardised protocol can minimise this risk, and high interrater and intrarater reliability values have been previously reported (Nordin et al., 2006).

Adding a cognitive dual-task to the TUG (TUG DT) did create a large and significant difference to the participants' reported times (Table 10). Previous research has reported the TUG DT to be associated to independent ADL ability and falls risk (Segev-Jacubovski et al., 2011; Hofheinz & Mibs, 2016). By establishing the automaticity of the dual-task, the attentional demand of that task can be calculated (Paul et al., 2005). It therefore appears to be a practically useful assessment, especially if used in conjunction with the single task TUG, to identify functional ability in older adults.

As for measuring cognitive function, the pen and paper version of the RSPM was simple to administer in the field and participants were able to independently complete the assessment without any confusion or the need for excessive supervision. This has significant ramifications for practitioners working with groups in the field. Furthermore, the specific question and answer papers (Pearson, London, UK) make collating the results quick and easy, which is an important consideration in a time-limited practical setting. Instantaneous results would be an advantageous feature of computerised assessments, however the paper and pen alternative demonstrated high practical utility.

The paper and pen version is also moderately associated to other cognitive assessments of older adults, (r = .54 - .55, p < .001) (Deary et al., 2004), and has high test-retest reliability, (r = .83) in adults aged over 50 years (Raven, Raven and Court, 2000).

The UCLA 3-item Loneliness Scale is a short and simple questionnaire suited to field-based assessment. The collected data is simple to quantify and feedback can be provided quickly. Data can also be compared to a national sample which is advantageous for research purposes. There are reported limitations, such as only using negative wording. However, there are a number of practically useful characteristics of the scale which potentially outweigh this limitation, and good levels of validity and reliability have been reported (Russel, 1996). Hence, this questionnaire was a successful field-based assessment of perceived loneliness in in older adults.

Practical implications

The findings of the present study demonstrate that attending an exercise class regularly, including seated and standing exercise, can enhance biopsychosocial function of community-dwelling older adults.

Within the group results, there were some interesting individual results. For example, some individuals demonstrated good physical function (TUG), poor cognitive function (RPSM), but good ADL ability (TUG DT). In contrast, some individuals recorded poor physical function (TUG), poor ADL ability (TUG DT) but above average cognition (RPSM). These observations are suggestive of a potentially highly individualistic relationship between biopsychosocial functions. These results serve to highlight the importance of field-based biopsychosocial assessment in gaining holistic insights into the needs of older adults; thereby facilitating the provision of impactful practical applications capable of promoting prolonged health and independence in old age.

With regard to practical implications, adopting a holistic approach to improving biopsychosocial health is required, as improvements in physical function do not necessarily translate to subsequent improvements in cognitive and/or social function and vice versa. Hence despite previous demonstrations of relationships between various dimensions of biopsychosocial function (Ijmker & Lamoth, 2012; Farrance et al., 2016; Smith-Ray, et al., 2013; Verghese et al., 2010), the present study suggests this relationship is clearly complex and warrants further investigation to better understand the underlying mechanisms of these relationships.

Conclusion

The present study demonstrates that it is possible to measure the biopsychosocial function of older adults using simple field-based assessment measures. And by doing so, further understanding of the relationships of biopsychosocial functions have been established. These assessment measures have demonstrated that physical function, as measured by TUG is a key indicator of ADL ability and independence, as measured by the TUG DT, supporting previous findings (Steffl et al., 2017). However, associations between physical function (TUG) and cognitive function (RSPM) and social perceptions (UCLA) were small and non-significant.

Furthermore, physical function (TUG) and social perceptions (UCLA) of the participants were significantly greater than those of aged-matched normative controls. However, this was not the case for cognitive function (RSPM). Subsequently it seems that attending group-based exercise classes, as an older adult, has significant benefits for physical and social health. However, the intensity of the exercise and unique individual exhibition of biopsychosocial functions seem to be an important, yet currently under-explored, consideration.

Further research, utilising larger sample sizes and investigating different modes and intensities of exercise, and their subsequent influences on aspects of biopsychosocial functions would benefit current conceptual understanding. Hence in the next chapter, the effect of adherence to exercise in is investigated. Field-based assessment measures of biopsychosocial function are used to evaluate the practical utility of such measures in clinical settings.

CHAPTER 7 – THE RELATIONSHIP BETWEEN GROUP EXERCISE ADHERENCE AND PHYSICAL FUNCTION AND PERCEPTIONS OF HEALTH IN OLDER ADULTS WITH COPD

Introduction

The previous empirical studies have identified the practical utility of simple field-based assessment measures of biopsychosocial health in older adults in a community setting. In this chapter, similar field-based assessment measures are utilised to determine the biopsychosocial health of patients with Chronic Obstructive Pulmonary Disease (COPD).

COPD is an umbrella term for lung conditions such as emphysema and chronic bronchitis, leading to breathlessness, a persistent cough with phlegm and frequent chest infections (Overview: Chronic Obstructive Pulmonary Disease, n.d.). There are over 1.5 million diagnosed cases of COPD in England (Public Health Outcomes Framework, 2017), with 4.5% of people aged 40 and over living with diagnosed COPD (Chronic obstructive pulmonary disease (COPD) statistics, n.d.).The prevalence of COPD has been increasing steadily over the last decade, with the highest number of cases in the North East, North West and Scotland (Chronic obstructive pulmonary disease (COPD) statistics, n.d.). Within Birmingham City and the West Midlands prevalence is higher than national average according to Public Health England statistics as shown in Table 12.

Emergency admissions related to COPD typically cost a Clinical Commissioning Group (CCG) £2,288 per patient, not including ongoing costs of medication. Hence it is advised that patients undertake pulmonary rehabilitation, which has been shown to improve their physical condition (Puhan, Gimeno-Santos, Scharplatz, Troosters, Walters & Steurer, 2011). It is reported to cost £199-249 per patient to instigate pulmonary rehabilitation (PR) for resources and staff. This cost includes the nurse, physiotherapist, instructor and venue hire costs with adherence levels at around 50% (NHS Scotland, 2011; Hayton et al., 2013).

This is an expensive and time-consuming process that often leads to readmission of patients who do not complete the PR programme. Given the prevalence of COPD, the services to enhance COPD patient's quality of life need to be highly cost-effective and time efficient. Improving the pulmonary rehabilitation service offered could help improve adherence levels and consequently reduce treatment and admission costs as a result (Cecins, Geelhoed & Jenkins, 2008).

Therefore, this chapter documents the evaluation of a potentially novel and effective pulmonary rehabilitation programme, developed within a professional capacity. This followed a successful 12-week pilot study commissioned and financed by Birmingham and Solihull CCG (known formerly as Birmingham CrossCity CCG). The programme was rolled-out across 49 different GP surgeries across the city of Birmingham and surrounding areas such as within the Northfield Alliance, Kingstanding Local Commissioning Group (LCG) and North East LCG. The commissioning of the programme was a result of cost-effective interventions with this population group, and the capability to measure them effectively in the field being a priority to the NHS, due to the incidence and financial implications of COPD.

Table 12. Prevalence of COPD by Clinical Commissioning Group (CCG) and value vs the national benchmark

Area	Number of cases*	Value**
England	*1,509,108*	*2.91*
Birmingham Cross City CCG* **	25,613	3.43
Birmingham South and Central CCG* **	18,076	3.16
Sandwell and West Birmingham CCG	7,657	3.44
Redditch and Bromsgrove CCG	4,217	2.47
Solihull CCG* **	7,759	3.33

*Data from Public Health England, fingertips.phe.org.uk
**Indicates above or below national benchmark
***Since the time of writing these CCGs have merged to form one CCG; Birmingham and Solihull CCG.

Therefore, the primary aim of this study, as per Thesis aim 1, is to broaden understanding of the influence of physical activity on biopsychosocial function of older adults by measuring the effect of adherence to a 12-week exercise programme. A secondary aim, as per Thesis aim 2, is to evaluate the practical utility of field-based assessment measures to determine biopsychosocial function in a clinical setting.

Method

Participants and recruitment

Three hundred and thirty-five COPD patients with a mean(±SD) age of 62(±12) years were recruited for the programme. Patients attending less than two weeks of the programme were excluded form analysis. Hence, the total sample size taken forward for analysis was 169 participants. The most common reason for absence to the programme was illness and/or medical appointments All patients eligible for the programme were written to by their GP surgery to inform them of the programme. Patients then self-referred into the programme on a voluntary basis. Eligibility criteria included medical diagnosis of COPD and aged 50 years and above. All participants completed a Physical Activity Readiness Questionnaire (PARQ) prior to undertaking any physical exercise and were safe to exercise in the professional opinion of their respective GP. A copy of the PARQ can be seen in Appendix 5.

The programme

Patients completed a 45-minute group-based exercise class once per week for 12 weeks, including flexibility, aerobic, balance and strength exercises, following a warm up and proceeding a cool down. All exercises could be adapted and performed seated, standing with support or free standing. Classes also included games for social interaction and cognitive stimulation. After each class patients were invited to stay for a 15-minute discussion on a health topic and enjoy a cup of tea or coffee. The instructor would start the discussion and then encourage patients to contribute and share thoughts and experiences with the group. This was to inform the group of lifestyle behaviours and educate the group on topics such as how to stay active at home, staying hydrated, medication use, alcohol and smoking. A ‘homework’ style task was also given each week to educate and encourage building activity into everyday life. This included heel raises at the sink or leg raises whilst watching television. The discussion topics and homework tasks were planned for each week to maintain consistency across all the locations the programme took place. Physical function and mental wellbeing were monitored regularly throughout the 12 weeks

Assessment of physical function

The 30 second sit to stand test (STS) was completed each week as part of the exercise class as a measure of lower limb strength. The 30 second sit-to-stand test involves standing up from a chair and sitting down again as many times as possible in 30 seconds.

The class instructor would demonstrate and verbalise the sit to stand technique before each test.

Patients would be asked to count their own repetitions as the instructor indicated start and stop of the 30s using a stopwatch. After the test, the instructor would collect the test scores from each participant, giving a maximum of 12 possible scores i.e. one per week.

Every two weeks, the TUG was used following the same protocol as has been explained in previous chapters. The principle researcher would complete this assessment on a one-to-one basis with the patients on weeks 2 4, 6, 8, 10 and 12. The STS and TUG assessments were chosen as measures of physical function as they can be implemented in the field with no specialist equipment. There use has also been supported in previous literature with COPD populations (Al Hadaad et al., 2016; Puhan et al., 2012).

Assessment of perceptions of health

Patient perceptions of mental and physical health was measured bi-weekly alternating with the TUG on weeks 1, 3, 5, 7, 9 and 11. For this, the Traffic Light Metric was used that quickly and efficiently gives insight into the patient's perceptions of physical and mental wellbeing. The metric was developed following successful pilot testing which indicated that self-report questionnaires with lots of text were not user friendly for this population group leading to skewed subjective data results. Hence, the Traffic Light Metric is a visual aid whereby the colour selected reflects the patient's perception.

For example, patients were asked in plain English, *"How do you feel in your body"?* and *"How do you feel in your mind"?* Patients would then select either red (1), amber (2) or green (3) from the traffic light to reflect this. No set description of the colour is given to not influence the perception of the patient, only the symbolic representation of the colour related to a traffic light where red equals *stop*, amber equals *get ready* and green equals *go*. Each colour also had an associated number, indicated in parentheses, to enable quantification and analysis of colours selected. On the days the Traffic Light Metric was used, the patient was asked to provide a score before the exercise class and after the exercise class. Therefore, two scores are given for perceptions of physical wellbeing and mental wellbeing. A copy of the Traffic Light Metric can be seen in Appendix 6.

Self-report evaluation

A self-report evaluation was also conducted after the final session to provide insight into the patient's perceptions of the intervention. The evaluation asked patients to choose whether they '*Strongly Disagree', 'Disagree', 'Agree', 'Strongly Agree*' to the following five questions:

1. I have enjoyed the exercise classes
2. The exercise classes have improved my quality of life
3. I am able to be more active now, than before I started the classes
4. I feel my COPD has improved since starting the classes
5. The classes have given me more control over my COPD

Answers were collated and calculated as a percentage of the total sample. A copy of the evaluation form can be seen in Appendix 5

Statistical analysis

To understand whether the FABS class had improved biopsychosocial functions, pre-intervention and post-intervention comparisons of means were performed on all dependent variables i.e. physical function measures (TUG and STS) and perceptions of health (Traffic Light Metric). A Shapiro-Wilks test of normality highlighted significant differences ($p < 0.05$) among group means for the TUG and 30 second sit to stand scores. Hence to compare group means, a non-parametric MANOVA was performed, with univariate contrasts and a Games-Howell *post-hoc* test. For this, participants were categorised into three groups; 1.) high adherers, $n = 63$ (attending 8-12 weeks), 2.) moderate adherers, $n = 60$ (attending 5-7 weeks) or 3.) low adherers, $n = 46$ (attending 2 - 4 weeks) in order to decern if adherence had an impact on function. Furthermore, to evaluate the field-based assessment of physical function, Kendall's tau (τ), was used to establish the relationship between each assessment. The correlation coefficients were assessed according to the following scale of magnitude: ≤0.1, trivial; >0.1-0.3, small; >0.3-0.5, moderate; >0.5-0.7, large; >0.7-0.9, very large; and >0.9-1.0, almost perfect (Hopkins et al., 2009).

The Traffic Light Metric data did not violate assumptions of parametricity and hence a paired samples *t*-test was performed to compare perceptions of wellbeing before and after the class for both body and mind (DV), pre- and post-intervention (IV). As it was only intended that perceptions of health in response to the intervention were measured, only full data sets for the Traffic Light Metric from high adherers that completed 12 weeks of the intervention (n = 24) were taken forward for analysis to avoid an adherence bias. To establish the size of the effect, effect sizes (*r*) were based on the following magnitudes; small, +/- 0.1 – 0.3; medium, +/- 0.3 – 0.5 and large, +/- 0.5 – 1.0 (Cohen, 1988, 1992).

For all analyses, the level of significance was set to the level $p < 0.05$. All statistical analyses were conducted on SPSS v22 for Windows (IBM SPSS Statistics, Version 22.0, Armonk, NY: IBM Corp).

Results

These results reflect 31 12-week intervention programmes from 49 GP surgeries. Data is expressed as mean(±SD).

Changes in physical function

The 30 second sit to stand

Using Pillai's trace, there was a significant effect of adherence on the 30 second sit to stand scores, $V = 0.28$, $F(4, 302) = 12.39$, $p < .01$. Separate univariate ANOVAs revealed this was non-significant for pre-intervention times, $F(2, 151) = .08$, $p > .05$, but it was significant for post-intervention times, $F(2, 151) = 20.76$, $p < .01$. The Games-Howell *post-hoc* analysis identified this pre-post score difference was dependent on group, by revealing that the post intervention scores for high adherers and moderate adheres were significantly different to the low adherers/control group, both $p < .01$.

High adherers and moderate adherers improved lower limb strength over the 12-weeks by a group mean increase of nine repetitions (high adherers mean pre score = 8.7(± 3.7), post = 16.6(± 6.5), moderate adherers mean pre score = 8.8(± 2.7), post = 16.6(± 6.0)). Meanwhile, the low adherers/control group did also improve but only by one repetition (group mean pre score = 8.5(±3.8), post = 10.1(± 4.0).

Timed Up and Go

Using Pillai's trace, there was a significant effect of adherence on the TUG times, V = 0.24, $F(4, 332) = 11.18$, $p < .01$. Separate univariate ANOVAs revealed this was non-significant for pre-intervention times, $F(2, 166) = 2.29$, $p > .05$, but it was significant for post-intervention times, $F(2, 166) = 11.86$, $p < .01$. The Games-Howell *post-hoc* analysis identified this pre-post times difference was dependent on group, by revealing that the post intervention scores for high adherers and moderate adheres were significantly different to the low adherers/control group, both $p < .01$.

High adherers and moderate adherers improved functional mobility over the 12-weeks by a group mean decrease of 3.18 seconds for high adherers (mean pre score = 12.9s (±5.4s), post = 9.7s (±3.7s)), and a decrease of 2.05 seconds for moderate adherers (mean pre score = 11.5s (±3.9s), post = 9.5s (±3.8s)). Meanwhile, the low adherers/control group did also improve but only by 0.35 seconds (group mean pre score = 13.5s (±5.6s), post score = 13.2s (±5.4s)).

Correlation coefficient analysis

Figures 2 and 3 illustrate the relationship between the physical function assessment measures, pre and post the 12-week intervention.

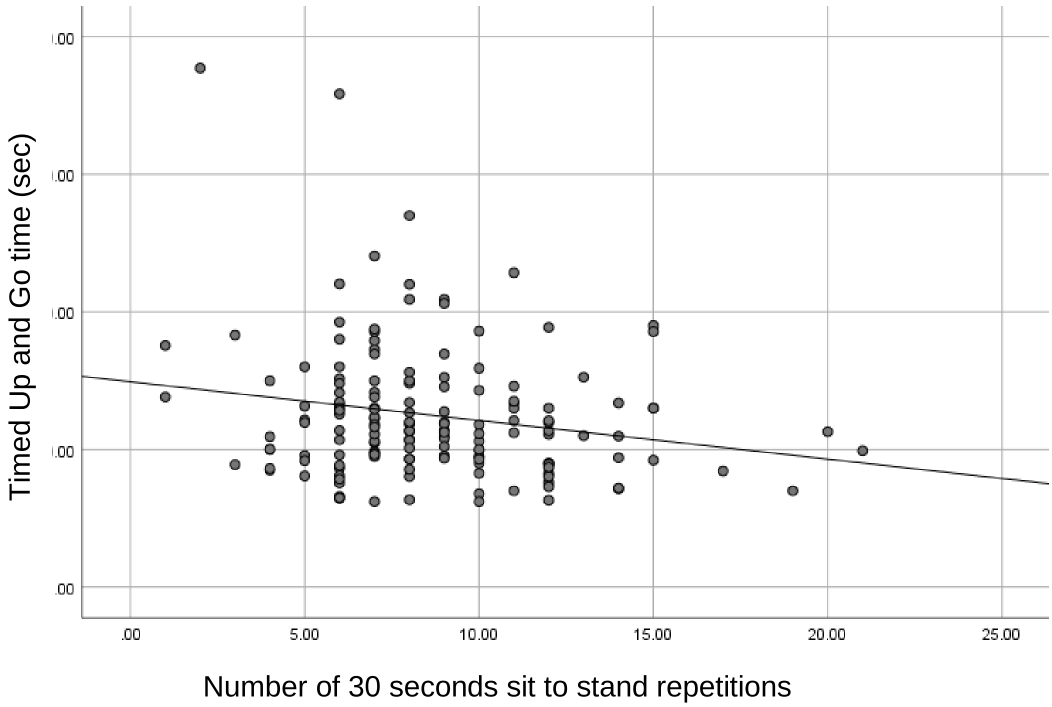


Figure 2. Pre-intervention scatter plot of 30 second sit to stand and TUG scores for all groups.

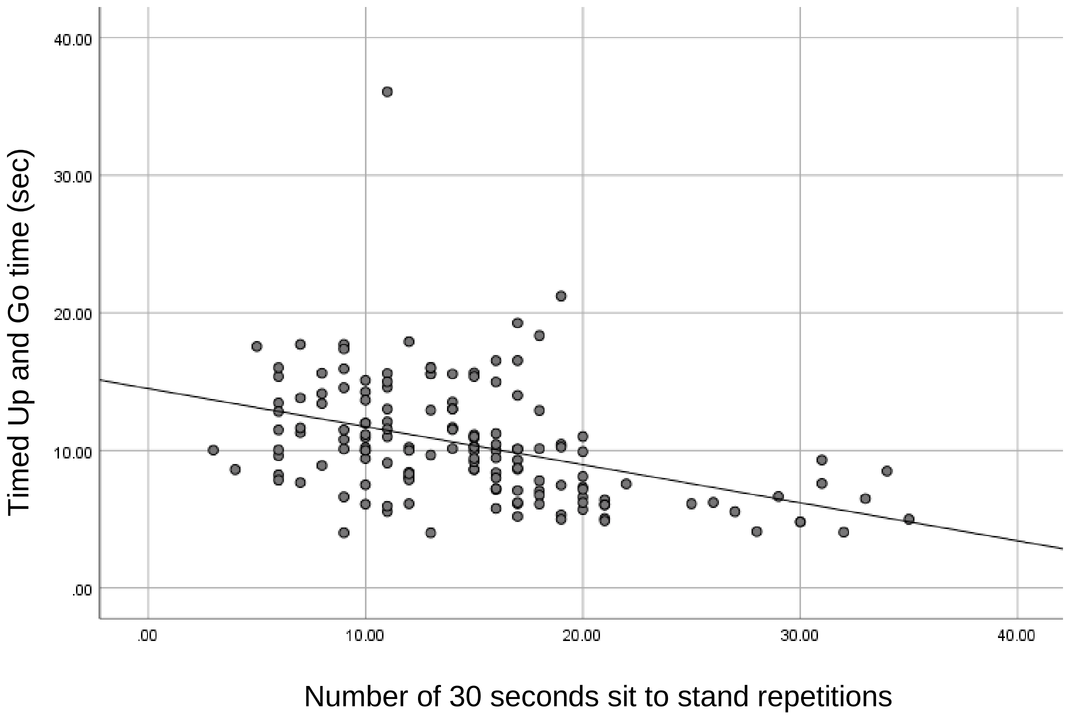


Figure 3. Post-intervention scatter plot of 30 second sit to stand and TUG scores for all groups.

The relationship illustrated by the scatter plots is in a negative direction, suggesting that lower sit to stand scores are related to slower TUG times. However, follow up analyses report that the relationship shared between the physical function assessment measures pre-intervention were small and non-significant (τ = -.105, *n* = 169, *p* = .06).

The post-intervention results also demonstrate a negative direction and represent a moderate relationship that is significantly different (τ = -.344, *n* = 169, *p* < .001).

Changes in patients' perceptions of health - Traffic Light Metric

Physical health before the class

Furthermore, statistical analyses of the pre- and post-intervention data demonstrate that on average, participant's perception of their physical health improved choosing less red before the class in week 12 (*M* = 0.92, *SE* = .60) compared to week 1 (*M* = 3.58, *SE* = .68). This was a significant difference *t*(22) = 2.95, *p* = .007, representing a large effect, *r* = 0.53. Choices of amber before the class also reduced pre-intervention (*M* = 3.5, *SE* = .97) to post-intervention, (*M* = 2.08, *SE* = .65), but this was non-significant, *t*(22) = 1.22, *p* = .235 and represented a small effect, *r* = 0.25. Consequently, with participants choosing less red and amber, selection of green before the class increased from pre-intervention (*M* = 1.08, *SE* = .61) to post-intervention (*M* = 2.08, *SE* = .65). However, this was also non-significant, *t*(22) = -1.13, *p* = .272 and represented a small-sized effect, *r* = 0.23.

Physical health after the class

Statistical analyses of the Traffic Light Metric colour selected pre- and post-intervention demonstrate that after the exercise class, participant's perception of their physical health improved choosing less red in week 12 (*M* = 0.10, *SE* = .10) compared to week 1 (*M* = .60, *SE* = .34). However, this was a non-significant difference *t*(22) = 1.41, *p* = .175, representing a medium-sized effect, *r* = 0.32. Choices of amber also reduced pre-intervention (*M* = 4.0, *SE* = 1.26) to post-intervention, (*M* = .30, *SE* = .21), and this was significantly different, *t*(22) = 2.8, *p* =.01 and represented a large-sized effect, *r* = 0.56. Consequently, participants' selection of green increased from pre-intervention (*M* = 3.6, *SE* = 1.13) to post-intervention (*M* = 5.0, *SE* = .1.01). However, this was also non-significant, *t*(22) = -.92, *p* =.367 and represented a small-sized effect, *r* = 0.21.

Mental health before the class

Statistical analyses of the pre- and post-intervention data demonstrate that participant's perception of their mental health before the class improved over the 12 weeks choosing less red in week 12 (*M* = 1.25, *SE* = .63) compared to week 1 (*M* = 2.58, *SE* = .74). This was a non-significant difference *t*(22) = 1.37, *p* =.185, representing a small-sized effect, *r* = 0.28. Choices of amber also reduced pre-intervention (*M* = 3.17, *SE* = .68) to post-intervention, (*M* = .50, *SE* = .15), which was significant, *t*(22) = 3.81, *p* =.001 and represented a large-sized effect, *r* = 0.63.

Consequently, selection of green increased from pre-intervention (*M* = 2.50, *SE* = .69) to post-intervention (*M* = 3.58, *SE* = .93). However, this was non-significant, *t*(22) = -.93, *p* =.361 and represented a small-sized effect, *r* = 0.2.

Mental health after the class

Analyses of the after class data, pre- and post-intervention demonstrate the selection of red in week 1 to week 12 did not change (both M = .08, SE = .08), which of course reported no significant difference *t*(22) = 0.00, *p* = 1.00. There was a great decrease in the mean number of amber selected after the class pre-intervention (*M* = 2.2, *SE* = .68) to post-intervention, (*M* = .42, *SE* = .23), which was significant, *t*(22) = 2.57, *p* = .017 and represented a medium-sized effect, *r* = 0.48. Finally, the mean selection of green decreased from pre-intervention (*M* = 5.67, *SE* = .99) to post-intervention (*M* = 4.92, *SE* = .81). However, this was non-significant, *t*(22) = .59, *p* > .561 and represented a small-sized effect, *r* = 0.13.

Patient feedback

On the final week of the programme, participants were asked to complete a simple self-reported evaluation form. Table 13 below presents the responses from the participants, with 99% of patients reporting that they enjoyed the sessions and 93% reporting they feel their quality of life has improved. The majority of participants also reported that they felt more active following the intervention and that their COPD has improved.

Table 13. Scores from the final evaluation questions shown as a percentage (%) and absolute value (n).

Question	Strongly Disagree	Disagree	Agree	Strongly Agree	Not Sure
1. I have enjoyed the exercise classes	1(2)	0(0)	10(17)	89(150)	0(0)
2. The exercise classes have improved my quality of life	0(0)	4(6)	44(74)	49(83)	4(6)
3. I am able to be more active now, than before I started the classes	0(0)	4(6)	39(66)	51(86)	7(11)
4. I feel my COPD has improved since starting the classes	0(0)	5(8)	46(78)	39(66)	10(17)
5. The classes have given me more control over my COPD	0(0)	5(8)	38(64)	46(78)	11(19)

Discussion

The aim of this study was to broaden understanding of the relationship between physical activity and biopsychosocial function of older adults by measuring the levels of adherence to a 12-week exercise programme. And a secondary aim was to evaluate the practical utility of field-based assessment measures to determine biopsychosocial function in a clinical setting. The results have demonstrated the improvement of physical function among those attending the intervention for at least 5 weeks, as corroborated by an enhanced perception of their health. The field-based assessment measures used demonstrated practical utility in a clinical setting to determine biopsychosocial health of COPD patients.

These findings will be discussed in greater detail below in two sections in relation to the thesis objectives; 1.) enhance understanding of biopsychosocial relationships and 2.) the evaluation of field-based assessment of biopsychosocial function.

Enhancing understanding of biopsychosocial relationships

The findings of the present study have demonstrated that physical activity in later life can improve biopsychosocial function of older adults with COPD, in primary care settings. The improvement in physical function is reported through greater STS repetitions and reduced TUG times post intervention. Interestingly, all groups improved physical function however, perhaps unsurprisingly, only the high and moderate adherers did so significantly. These positive benefits of exercise to treat COPD to reduce admission, mortality and increase quality of life are echoed in a large-scale review by Puhan et al. (2011). Furthermore, due to the implications of breathlessness associated to COPD, many sufferers of the disease are sedentary which increases the risk of frailty and associated loss in muscle mass and strength (Lahousse et al., 2015). The results presented here suggest that even a few weeks of exercise adherence can begin to improve physical function, with adherence of at least five weeks required to make significant benefits in the TUG and STS. Previous literature has reported that a 25% improvement in the time taken to complete 5x STS is equivalent to '*dropping a decade'* in terms of functional ability benefiting both the individual and the econmy (McNally, Nunan, Dixon, Butler & Gray, 2017).

Not only has physical function improved, but also psychosocial wellbeing by way of participants perceptions of their physical and mental health. This was demonstrated by less selections of red in week 12 compared to week 1 being made both before and after the exercise class.

This suggests that the improvements to physical function resulting from the class had a lasting effect on the participants perceptions of their physical health, with more positive selections made (i.e. green) in the latter stages of the intervention. To further demonstrate the shift towards positive perception of physical health, less selections of amber were also made at the end of the intervention compared to the start. However, this can only be said for high adherers that were included in the Traffic Light Metric reporting. Only high adherers that completed all 12 weeks of the intervention and provided a full set of scores were included to avoid adherence bias and the risk of type I error by incorrectly rejecting a null hypothesis.

Perceptions of mental health also shifted positively, with a greater number of green selections before the class in week 12, compared to before the class in week 1. It is possible that the improved physical function positively impacted on the patient's mental wellbeing. Previous literature has demonstrated the impact of exercise to improve psychosocial perceptions of health, including mood, self-efficacy and perceived social support (Taylor-Piliae, Haskell, Waters & Froelicher, 2006). Although the findings of health perception in the present study are positive, it should be noted that effect sizes were generally small ($r < 0.3$). There was one statistically significant large effect in the shift away from selecting red before the class, in relation to perception of physical health. Thus suggesting patients could be feeling *'OK'* or *'Good'* more often and *'Bad'* less often throughout the intervention. However, the Traffic Light Metric is a novel assessment tool and its validity to provide practically useful data warrants further research with larger samples to give greater statistical power to reported effects.

A key practical observation was that 85% of patients self-reported a belief that the classes improved their COPD, and 84% stating they now had better control over their COPD. Although not reflected in the statistical analyses, this self-reported information supports the quantitative data collected by the Traffic Light Metric demonstrating perceptions of physical and mental health had improved.

Alongside these improved perceptions of health, high levels of enjoyment were reported, with 99% of patients stating they have enjoyed the classes (Table 13). Enjoyment is important for exercise adherence to group-based programmes and behaviour change (Farrence et al., 2016), Hence, high enjoyment levels are one contributing factor to maintaining high adherence levels to exercise classes, as lack of enjoyment or perceived lack of enjoyment is a common barrier to exercise for older adults (Nied and Franklin, 2002).

Indeed, 73% of patients that started the intervention attended five weeks or more (moderate to higher adherers), an attendance rate higher than that reported for pulmonary rehabilitation within the literature (Hayton et al., 2013). Furthermore, COPD patients who partake in regular physical activity report reduced hospital admissions and mortality rates (Garcia-Aymerich, Lange, Benet, Schnohr & Antó, 2006). Accordingly, ensuring the exercise intervention is enjoyable and adhered to is a vital element for impactful practical applications.

Evaluation of field-based assessment tools to measure biopsychosocial function

The TUG is an effective field-based assessment measure, as reported in the previous chapter. As with the STS, both are quick and easy to administer and reported improvements in the physical function of the patients, with greater improvements in those who attended for longer. The scatter plot analyses illustrate this by way of a negative relationship suggesting that as STS scores increase i.e. more repetitions, TUG times decrease, i.e. standing, walking and turning more quickly. This data is practically useful as it demonstrates the impact the exercise intervention has on physical function and in particular on ADLs such as standing from a chair and walking, an important independence-promoting ability. Previous research has reported the negative impact of COPD on completion of ADLs (Vaes et al., 2011). Hence evidencing an enhanced ADL ability subsequent to this intervention positively adds to the existing knowledge base.

Statistical analyses reported the relationship shared between the TUG and STS pre-intervention was small and not significantly different ($\tau = -.105$, $n = 169$, $p = .06$). The post-intervention results however were significantly different and represent a medium sized relationship ($\tau = -.344$, $n = 169$, $p < .001$). As mentioned previously (Chapter 6), the TUG has been associated with cognitive function, due to the motor stabilisation challenge imposed on cortical processing during walking (Skoyles, 2008; Hausdorff, 2007). Hence the TUG is reported as a reliable indicator for falls risk in older adults (Shumway-Cook at al., 2000; Nordin et al., 2006). However, the association with the STS and falls risk is not as strong within the associated literature. That said, previous research has demonstrated that older adults who rise from the chair more slowly than their counterparts have a higher falls risk (Ejupi et al., 2017). The findings of the present study therefore support previous literature and provide novel and practically meaningful evidence to suggest that the TUG and STS should not be used interchangeably, although both provide valid field-based measures of physical function.

The Traffic Light Metric is a simple field-based tool to measure perceptions of health in a clinical setting. This metric has the advantage of being able to quickly and easily test the effectiveness of interventions targeted at enhancing health and, accordingly, may be relevant to both individuals and the NHS. The cost of care doubles between the ages of 65 and 75, and triples between the ages of 65 and 85 due to declining health (McNally et al., 2017). Older adults with COPD are significantly more likely to be frail than older adults without the disease (Lahousse et al., 2015) further amplifying the cost of care associated with these individuals. Furthermore, older adults with functional impairments are more likely to have negative perceptions of their health status (Rakowski & Cryan, 1990).

Hence, the findings from the Traffic Light Metric reporting improved health perceptions in older adults with COPD demonstrates a highly positive impact of the exercise intervention on physical and psychosocial wellbeing. This supports previous literature which states that exercise capacity and psychosocial wellbeing improves in COPD patients following a rehabilitation programme (Zoeckler, Kenn, Kuehl, Stenzel & Rief, 2014). Therefore, the Traffic Light Metric does seem to provide practically useful data in line with previous research using validated tools. However, only a small number of participants successfully completed the metric after every session, identifying a practical limitation to the metric with it being required to be completed before and after each session. Thus, as previously mentioned, further investigation is warranted to establish the reliability and validity of the Traffic Light Metric as a potentially novel and practically informative field-based assessment measure.

Conclusion

Physical activity can improve physical function and perceptions of health in older adults with COPD. Furthermore, this can be evaluated in clinical settings with simple field-based assessment measures.

These findings corroborate evidence illustrating the effectiveness of field-based assessments of biopsychosocial health, demonstrated in the experimental studies in Chapters 5 and 6. Furthermore, it has now been demonstrated that this holds true within a clinical setting with COPD patients. This has important practical applications for interventions aimed at improving the health of COPD patients, for which the FABS exercise programme can be effectively implemented.

At a time when the economic pressures on the NHS are severe, adoption of cost-effective interventions and assessment measures such as those reported here are vital for the sustainability of the service provision within the NHS. The group-based exercise programme used has been demonstrated to be effective, enjoyable for patients and benefit actual and perceived biopsychosocial health.

Furthermore, these outcomes can be determined using simple field-based assessment measures in a clinical setting which has significant practical applications for clinical professionals working with COPD patients aged over 60 years. Further research is necessary to establish the validity and reliability of the novel use of the Traffic Light Metric. Also, there is a need to replicate the exercise intervention in different locations to discern the national scalability of the exercise programme used in the present study as an NHS-based intervention to improve biopsychosocial health of COPD patients.

CHAPTER 8 – DISCUSSION, CONCLUSIONS AND FUTURE DIRECTIONS

Introduction

The growth of the ageing demographic is a worldwide phenomenon with current estimates suggesting there will be two billion over 65s by 2050 (Department of Economic and Social Affairs: Population Division, United Nations, 2017). In 2017, there were an estimated 12 million people aged 65 and over in the UK, representing approximately 18.2% of the population: equivalent to one in every five people. (Coates, 2018). This figure is projected to rise to 24% by 2037, suggesting that one in every four people in the UK will be aged 65 or over (Coates, 2018). Furthermore, by 2066 it is estimated there will be an additional 8.6 million people aged 65 and over in the UK, for a total of 20.4 million people: equating to 26.5% of the projected population (Coates, 2018).

These population predictions reflect increases in life expectancy, with people living longer than ever before (Coombes, 2018). However, over four million older people are living with multi-morbidities, the incidence of which increases with advancing age (Welmer et al.,2012). Consequently, it has been reported that as much as the final 16 years of life are spent in poor health resulting in an increased dependency on care and medication (Brayne et al., 2001).

I believe that the latter years of life should be enjoyed, not just endured, and given the sharp increases predicted for the ageing population, there is an urgent need to find interventions that can help prevent or at least attenuate age-related declines in health. The potential financial implications of treating an additional eight million older people over the next four decades could have grave consequences for the NHS; hence advancing knowledge and practical application of healthy ageing is a national priority (Humphries, 2015).

Gerontological research is continually making discoveries to enhance knowledge and understanding of the ageing process. Understanding the mechanisms underlying how and why the body changes over time, often into a state of decline, and the impact this has on the ability to function is vital. For example, as highlighted in Chapter 2, it is now understood that telomere shortening results in biological ageing, which can be heavily influenced by lifestyle (Tucker, 2017). Poor diet and physical inactivity promote inflammation and contribute to accelerated telomere shortening, hence the term *inflammaging* (Bartlett et al., 2012). Such insights enable the design of interventions to specifically target, and maintain, function for as long as possible.

As first proposed by Engel (1977) over 40 years ago, one's health and ability to function is influenced by more than solely biological factors. This thesis aimed to broaden understanding of biopsychosocial ageing and its impact on function. Hence, in light of previous research (Verghes et al., 2010; Smith-Ray, et al., 2013) it was hypothesised that physical, cognitive and psychosocial functions shared a relationship, with the potential to interact and improve or decline simultaneously, whether through direct or indirect intervention.

Thesis aims and objectives

Within this thesis I sought to expand current knowledge by exploring the biopsychosocial influences impacting the health of older adults. Accordingly, this thesis was designed to contribute to an enhanced understanding of physical, cognitive and psychosocial functions, and to investigate the influence of a potential *tri-directional* relationship between these dimensions of health. In order to do this, a conceptual review (Chapter 3) and three empirical studies (Chapters 5, 6 & 7) were conducted to explore biopsychosocial influence on function in older adults. Furthermore, to evaluate the practical utility of these findings, simple, accessible field-based assessments were utilised with the aim of maximising practical application into impactful practical intervention.

In Chapter 3 evidence was provided that links both cognitive and physical functions to cerebral cortical processing abilities (Skoyles, 2006), and subsequently it has been suggested that improving executive function can in fact influence physical actions, such as reducing the risk of falling in older adults (Segev-Jacubovski et al., 2011). Furthermore, evidence has emerged to suggest that positive emotions and social connections can influence physical health in young and older adults (Kok, et al., 2013; Farrance et al., 2016). Given that exercising in a group can benefit psychosocial health (Killingback, Tsofliou & Clark, 2017) it would appear that biopsychosocial functions are all inter-related and mutually modulating, and that benefit in one of these functions bestows a corresponding benefit another.

It was therefore hypothesised that high physical function would be facilitated through high cognitive and social function and vice versa, and that these capacities would demonstrate strong correlational values. If this hypothesis is proven right, it would allow practitioners to help older adults improve or maintain levels of function by interventions designed at any of the three biopsychosocial domains.

It would also allow older adults to maintain their functional independence through activities aimed at improving either physical, cognitive or psychosocial health, as improving one would in turn benefit the others.

To investigate the relationship shared between physical function, cognitive function and social wellbeing, a series of four investigations were produced and presented in Chapters 3 and 5, 6 and 7. In this chapter I will review and assimilate the key conclusions emanating from these chapters and discuss their subsequent implications against the stated chapter objectives, before providing an overarching conclusion.

The aim of this chapter therefore, is to review the key learning outcomes originating from these investigations, and to discuss these in the context of the core thesis objectives, which were:

Thesis aim 1.) Understanding biopsychosocial function and the role of physical activity in older adults,

- To understand the relationship between physical function, cognitive function and psychosocial function in older adults.
- To understand the relationship between levels of physical activity across the life span and biopsychosocial function in later life.
- To understand if physical activity in later life can improve biopsychosocial function in older adults, in the community and primary care settings.

Thesis aim 2.) The evaluation of field-based assessment tools in older adults,

- To use different field-based assessment tools to measure biopsychosocial function of older adults.
- To identify which field-based assessment tools are most effective in measuring biopsychosocial function of older adults.
- To use this evaluation of assessment measures and translate them into impactful practical applications to promote longevity and independence in old age.

Studies' aims, methods and results

Four investigations where produced to explore and achieve the thesis objectives outlined above, consisting of a conceptual review and three experimental studies. The contents of each of these studies are described below in relation to the aims, methods, results and limitations.

Chapter 3 - Preventing falls in older adults: Can improving cognitive capacity help?

Chapter 3 presented the following publication which can be seen in Appendix 7:

Robinson, J. E. and Kiely, J. (2017). Preventing falls in older adults: Can improving cognitive capacity help? *Cogent Psychology*, 4(1), doi/abs/10.1080/23311908.2017.1405866

The aim of this article was to explore the interaction between physical and cognitive function in older adults with a focus on falls risk. Existing literature was reviewed and discussed and the links between executive function and physical function, particularly walking gait, were highlighted. The use of computerised cognitive training as a tool for enhancing not only cognitive, but also physical function was discussed with early evidence suggesting potential for a novel application to preventing falls risk.

The article illustrated that a wealth of literature exists suggesting that the high-level cognitive processes required to maintain a stable and upright bi-pedal gait, are also shared with particular executive functions such as problem-solving, decision-making and attention (Skoyles, 2006; Hausdorff, 2007). The novel practical application of cognitive training to promote improvements to walking gait, through enhancing closely related executive functions is also evidenced through existing research. (Verghese et al., 2010; Smith-Ray et al., 2013).

Accordingly, the key findings of the study were:

- Executive functions are related to walking gait.
- Computerised cognitive training can illicit improvements to characteristics of walking gait.
- Potential exists for the novel practical application to reduce falls risk through enhancing cognition.

The evidence presented highlights how computerised cognitive training could be utilised as a novel intervention, capable of reducing falls risk in the ageing population.

However, due to novelty of this evidence, further research is needed to broaden current understanding of the relationship between cognitive and physical function. Accordingly, an empirical study was designed to investigate the extent to which previous and current activity levels influence physical and cognitive function in older adults.

Chapter 5 - Do physical activity levels across the lifespan correlate with cognitive and physical function measured in the field in British community dwelling older adults?

This was the first in the series of empirical studies. The primary aim of this study was to provide greater understanding of the relationship between levels of physical activity across the life span on physical and cognitive function in community-dwelling British older adults. Furthermore, a secondary aim was to use simple field-based assessment measures of biopsychosocial function that could translate into practical applications.

It was hypothesised that older adults that were more active would score higher in assessments of physical and cognitive function. This hypothesis was based on the aforementioned literature demonstrating the two functions are related, and that higher physical activity levels are associated to higher levels of physical function and cognition (Di Pietro, 2001; Taylor et al., 2004).

The participants used in the study were all community-dwelling, and were asked to complete the following assessments:

- OptoJump March in Place protocol (at 60, 90 and 120 steps per minute; MIP60, MIP90, MIP120 respectively),
- Short Physical Performance Battery (SPPB),
- Computerised Brain Performance Tests (BPT) (Lumos Labs, CA, USA),
- Past and Present Physical Activity Questionnaire.

The outcomes of each of the above measures were then analysed for a relationship using Pearson correlation coefficient (*r*) and were interpreted according to the following scale of magnitude: ≤ 0.1, trivial; >0.1-0.3, small; >0.3-0.5, moderate; >0.5-0.7, large; >0.7-0.9, very large; and >0.9-1.0, almost perfect (Hopkins et al., 2009).

The key findings from the study identified that:

- There was a positive significant relationship of being more active either in early life (15 and 30 years of age) or in later life (50 years of age and over the course of the last year).
- Being active in later life positively correlated to scores in the Memory Span BPT, indicating the protective effect of activity on memory decline.
- Simple field-based assessment measures using easy to use technology can be employed to practically assess cognitive and physical function in older adults.

It is well documented that being regularly active will benefit physical and cognitive health (Taylor et al., 2004). However, a significant finding from this study was the discovery that different life stages can result in differing activity levels, as the participants were reportedly either more active in adolescence and early adulthood or in later adulthood.

Being regularly active across the lifespan reportedly leads to enhanced cognitive functioning, with activities of higher intensity facilitating greater benefits (Dregan & Gulliford, 2013; DiPietro, 2001). What has been demonstrated by this study is that being more physically active in early adulthood bestows cognitive benefits that differ to those expressed when an individual is more active in later adulthood.

This finding holds positive implications for the ageing demographic of the UK where 42% of over 55s are reportedly inactive (Sport England 2016). However, interventions to be more physically active will enable older adults to enhance their physical and cognitive function, demonstrating the ability improve function is not lost through advancing age.

These are practically informative results, giving practitioners a basis for interventions for different age groups. However, although several of the relationships between functions were statistically significant throughout this study, given the small sample size of the study, the risk of type I error is increased. Furthermore, one potential limitation of this study is the methodological approach to quantifying the self-reported activity levels using METs. Further research with larger sample sizes is therefore warranted to strengthen the robustness of this approach and therefore the findings of this study. This subsequently means that a cautious approach should be taken when interpreting these study findings.

In addition, further research to enhance understanding of why people might be more or less active at a particular life stage, and what interventions are most effective in enabling physical activity throughout the life span is warranted.

Similarly, exploring the differences in function in those who are active early in life, those who are active later in life and those who are active throughout life would broaden the current knowledge base which is in the interest of public health. Subsequently, the next experimental study was designed to enhance understanding of the relationship of biopsychosocial functions and investigate those of active older adults by comparing their biopsychosocial function to age-matched normative data.

Chapter 6 - The biopsychosocial health of older adults that attend group-based exercise compared to population normative data

The primary aim of this study was to compare biopsychosocial functions in older adults that attend a group-based exercise class with population normative data. Simple field-based assessment measures were used to collect the data and evaluating the effectiveness of such measures was a secondary aim of the study. The biopsychosocial function data from class members, who attend the class once per week, was compared to population normative data based on age and/or gender. It was thought that there would be a relationship between being physically active on a regular basis in a group setting and greater physical, cognitive and psychosocial function through a potentially integrated relationship shared between these dimensions of health. Furthermore, it was thought that this would result in proficient ADL ability and thus prolong independence.

This assumption was based on literature demonstrating physical activity can attenuate the natural decline in physical (van de Vijder, Wielens, Slaets, & van Bodegom, 2017), cognitive (Northey et al., 2017) and social function (Killingback et al., 2017). If biopsychosocial functions are indeed related, through a self-modulating tri-directional relationship, then physical exercise would not only benefit physical function, but cognitive and psychosocial function too, as activities that benefit one function would in turn benefit the others.

To investigate these potential relationships, 18 participants from a group-based community exercise class (mean±SD age = 68±2) completed the following assessments:

- Timed Up and Go (TUG) to determine physical function,
- Timed Up and Go Dual Task (TUG DT) to determine ADL ability,
- Ravens Standard Progressive Matrices (RSPM), to determine cognitive function,
- UCLA 3-item Loneliness Scale to determine perception of loneliness

Kendall's tau (ꞇ), a non-parametric bivariate correlation, was used to establish the relationship between each function, as measured by the field-based assessments. The correlation coefficients were assessed according to the following scale of magnitude: ≤0.1, trivial; >0.1-0.3, small; >0.3-0.5, moderate; >0.5-0.7, large; >0.7-0.9, very large; and >0.9-1.0, almost perfect (Hopkins et al., 2009). Further analysis involved a Wilcoxon Signed Ranks test to compare participant data to normative data, and was reported as z-scores (z) with effect sizes (r) based on the following magnitudes: small; +/- 0.1 – 0.3, medium; +/- 0.3 – 0.5 and large; +/- 0.5 – 1.0 (Cohen, 1988, 1992).

The key findings from the study identified that:

- A large and statistically significant relationship was identified between physical function (TUG) and ADL ability (TUG DT) (ꞇ = .636, n = 19, *p* = .000).
- The relationship between ADL ability (TUG DT) and cognitive function (RSPM) demonstrated in this study was small and not significant (ꞇ = -.336, n = 19, p = .078).
- Physical function and social perceptions of study participants were significantly above normative reference values

The findings of the study demonstrate that attendees of a group-based exercise class exhibit biopsychosocial function above chronological age predicted levels, in accordance with normative data. The most significant impact of the exercise class seems to be on physical and social function, which reported the largest effect sizes.

The mean automaticity score of 84% when completing the TUG DT was similar to previously reported scores (Shumway-Cook et al., 2000). This suggests that when performing ADLs, the participants' cognitive resources are challenged above capacity in terms of switching attentional demand between the concurrent physical and cognitive tasks. Furthermore, these results suggest the relationships shared between biopsychosocial functions is complex and not a linear or bi-directional in nature. This discovery is discussed further in the following sections of this chapter.

The small sample size of this study, as with Chapter 5, poses the risk of type II error, accepting a false null hypothesis due to low statistical power, meaning that the statistical analyses might not be wholly reliable. However, the study did provide useful practical implications, such as the need for biopsychosocial assessment for a holistic understanding of health and function and that this can be successfully achieved in the field.

Furthermore, by using a 'real-world' exercise class, participants attendance levels are very difficult to control for, which poses a limitation to the study. It is known that all participants attend the exercise class as regularly as possible once per week for at least 12 months, however some have attended more often than others. Ideally, this study would have been conducted with a greater understanding of attendance and adherence rates of each participant. This would help strengthen the robustness of the study's findings.

Furthermore, when comparing to normative data, different sources of data are required for the different biopsychosocial functions. Therefore, potentially confounding variables such as age, gender, education, nationality and physical activity levels of the participants used to create the normative data should be taken into consideration.

With this in mind, the final empirical study used a larger sample size to that of the previous two studies. A set programme of 12 weeks was also used to allow for measurement of the effect of adherence levels. Furthermore, in line with Thesis aim 1 and 2, to understand if physical activity in later life can improve biopsychosocial function in older adults in the community and primary care settings, the final empirical study was conducted in a cohort of COPD patients in a clinical setting.

Chapter 7 – The relationship between group exercise adherence and physical function and perceptions of health in older adults with COPD

Chapter 7 presented a 12-week group exercise intervention designed specifically to increase activity levels and improve physical function and mental wellbeing in patients with Chronic Obstructive Pulmonary Disease (COPD). This study furthered investigation into the potential practical utility of simple field-based measures within a clinical environment. Participants all had COPD and were recruited and sign-posted into the programme via their General Practitioner (GP), although participation was voluntary. In total, data from 169 participants (mean±SD age = 62±12) was taken forward for analysis of physical function. Only full data sets were taken forward for analysis of the Traffic Light Metric data (n = 24) to avoid adherence bias of health perceptions.

To evaluate the effectiveness of the programme the following assessments were conducted:

- Timed Up and Go (TUG),
- 30 seconds Sit to Stand (STS),
- Traffic Light metric for perceptions of mental and physical health.

To identify the impact of the programme on biopsychosocial functions, pre-intervention and post-intervention comparisons of means were performed on all dependent variables, by way of a non-parametric MANOVA, with univariate contrasts and a Games-Howell *post-hoc* test. Participants were categorised into three groups; 1.) high adherers, (attending 8-12 weeks), 2.) moderate adherers, (attending 5-7 weeks) or 3.) low adherers, (attending < 4 weeks) in order to discern if adherence had an impact on function.

Furthermore, to evaluate the field-based assessment of physical function, Kendall's tau (ꞇ), was used to establish the relationship between each assessment. The correlation coefficients were assessed according to the following scale of magnitude: ≤0.1, trivial; >0.1-0.3, small; >0.3-0.5, moderate; >0.5-0.7, large; >0.7-0.9, very large; and >0.9-1.0, almost perfect (Hopkins et al., 2009).

The Traffic Light Metric data did not violate assumptions of parametricity and hence an independent *t*-test was performed to compare the pre- and post-intervention means for each metric i.e. perceptions of wellbeing before and after the class for both body and mind. To establish the size of the effect, effect sizes (r) were based on the following magnitudes; small, +/- 0.1 – 0.3; medium, +/- 0.3 – 0.5 and large, +/- 0.5 – 1.0 (Cohen, 1988, 1992).

Key findings from the study identified that:

- Moderate to high adherence to exercise significantly improved physical function in COPD patients,
- Participants expressed greater perceptions of physical and mental health after the exercise class compared to before the class,
- Simple field-based assessment measures can be implemented in clinical settings to assess biopsychosocial function.

These findings have demonstrated that the 12-week exercise programme is an effective intervention suitable for COPD patients. Eighty four percent of the participants felt that their COPD had improved as a result of attending the classes. Physical function improved in all participants but only did so significantly ($p < 0.05$) in moderate to high adherence groups.

One emergency hospital admission for a COPD related incident can cost the NHS approximately £3,000 with a combined annual spend of £1.9 billion (NHS, 2011; Truman, Woodcock & Hancock, 2017).

Hence, interventions of relatively short duration could prove highly cost effective for the NHS. Through improving physical function, the presented 12-week programme could reduce the risk of an admission and help people to self-manage their condition which are vital for both the individual and the NHS.

Furthermore, psychosocial health was also demonstrated to improve through enhanced perceptions of health and wellbeing. Using the Traffic Light Metric, participants who completed the 12-week intervention, reported feeling better mentally and physically after the exercise class, and this perception was sustained throughout the 12-week intervention.

Combined with the reported high levels of enjoyment (99% of participants) suggests the intervention has had a very positive impact on the participants psychosocial health, supporting previous literature (Taylor-Piliae et al., 2006; Zoeckler et al., 2014).

Not only has this project demonstrated the effectiveness of a specific exercise programme with this population group, but also the effectiveness of the simple field-based assessment measures used. The fact that this has taken place in a clinical setting illustrates the potential practical utility of implementing such resource-efficient interventions with at risk populations. This aligns with the thesis objective of using simple-field based measures and translating findings into impactful interventions to promote longevity and functional independence in old age. This is of great significance to professional practice within public health contexts.

There are some potential limitations to the study, most notable the use of the Traffic Light Metric which is a non-validated assessment measure. However, as discussed within Chapter 7, the findings of Traffic Light Metric do align to previously validated tools, however it is noted that further research to confirm this is warranted. Furthermore, the reported effect size of the relationships between biopsychosocial functions were generally small ($r < 0.3$). Overall, as an assessment measure the Traffic Light Metric has high practical utility as it is simple and quick to complete but it can only provide an indication of health perceptions. The lack of strength in any statistical findings suggest more robust further research is needed to provide greater confidence in the reliability and validity of using the metric and its outcomes to state changes to perceived health.

The next sections of the chapter compile the findings from these empirical studies and discusses them in relation to the two broad thesis objectives, which were;

1.) Understanding biopsychosocial function and the role of physical activity in older adults
2.) The evaluation of field-based assessment measures in older adults

Key integrated findings related to Thesis aim 1

A key objective of the thesis was to enhance understanding of biopsychosocial function in older adults. The conceptual review article in Chapter 3 explored the literature to identify what was currently known and unknown in regard to the relationship between physical and cognitive function. It was reported that physical functions such as walking gait are dependent on the integration of input from cortical and sensory systems to coordinate human locomotion due to its unique bipedal nature (Hausdorff, 2007). Hence, high-order cognitive processes (i.e. executive functions) are closely related to walking gait and past research has demonstrated how cognitive decline, such as the onset of dementia, can be observed through changes to walking pattern (Ijmker & Lamoth, 2012).

Experiments requiring physical and cognitive dual-tasks have highlighted this relationship due to the competition within the cerebello-cerebral circuitry to maintain focus on each stimulus, leading to a deterioration of concurrent performance (Skoyles, 2008; Schabrun et al., 2014). Hence, age-related deteriorations to the brain regions primarily, but not exclusively, located in the prefrontal cortices facilitating executive function, are reported to influence the risk of falling (Herman et al., 2010). Nonetheless, computerised cognitive training interventions have reportedly improved cognitive function and consequently improved characteristics of walking gait (Verghese et al., 2010, Smith-Ray et al., 2013). Hence, the evidence presented in Chapter 3 was suggestive of a direct, potentially bi-directional relationship, between physical and cognitive function. This finding required further research and the integration of psychosocial function to enhance understanding of how the three dimensions of biopsychosocial health are related.

Therefore, a series of experimental studies were conducted, the first of which explored how physical activity levels influence the relationship between physical and cognitive function. The findings presented a positive and significant relationship between being more physically active either in early life (15 and 30 years of age) or in later life (50 years of age and over the course of the last year).

Furthermore, being active later in life (aged 50 and in the last year) was shown to have a negative and large relationship to memory span performance (r = -.526, n = 15, p = .044) but no other tests of cognitive function. Furthermore, the participants that reported higher activity levels in early adulthood performed better in tests of grammatical reasoning, attention and processing speed. Therefore, being active at any life stage seems beneficial to cognition in later life.

Chapters 6 therefore presented an empirical study to investigate this further and establish just how much physical activity benefits biopsychosocial health in later life. The study demonstrated the physical function of physically active participants was above expected normative values, however in contrast, cognitive function was on par with expected normative values. Interestingly, this result contradicts the evidence presented in Chapter 3 which suggested an inextricable link between physical and cognitive function (Witter, 2010). Previous literature has reported declines in cognitive function are expressed through changes in physical function, such as walking gait (Ijmker & Lamoth, 2012). Similarly, increases in cognitive function have been attributed to physical exercise (Northey et al., 2017).

Therefore, despite previous reports that physical and cognitive functions share cerebello-cerebral circuity (Skoyles, 2008), the lack of a significant relationship presented in Chapter 6 suggests that on a practical level, increases or decreases in functional ability do not necessarily result in equally proportionate change to these functions. This contradictory finding suggests the difficulty to validly and reliability measure these functions in the field by the assessment measures utilised in Chapter 6.

Further support of this finding was that group mean cognitive function (measured using the RSPM) did not relate to the group mean physical function (measured by TUG) (τ = -.27, $p > 0.05$). The low intensity of the exercise class is one potential explanation for this finding. The exercise class undertaken by the participants mixes flexibility, aerobic, balance and strength exercises, with an observed intensity that is relatively low, with each exercise completed seated or standing. This is in line with the literature that states the frequency of high intensity activities decrease with age (DiPietro, 2001). However, enhancing cognition through physical activity requires aerobic and strength-based exercise of at least moderate to vigorous intensity (Northey et al., 2017). Further research of objective measurement of the exercise class intensity along with cognitive function performance in needed to confirm this proposed explanation.

Furthermore, exercising in a group setting has a positive influence on psychosocial function, as shown in Chapter 6 and 7. Perceptions of loneliness, companionship and social isolation were above the reported normative values despite the expected decline in social connections associated with old age (Pinquart & Sorensen, 2001). This demonstrates how exercising in a group environment has benefited the social function of the older adult participants, with 75-88% reporting that they never feel lonely. Research in support of this finding has shown that community-based group exercise programmes often have high adherence rates due to the influence on sense of belonging and perceived physical and psychosocial benefits (Killingback et al., 2017). It is thought that a sense of belonging, demographic homogeneity, socialising and support, described as *social connectedness* is a key determinant of adherence rates in older adult community-based exercise groups (Farrance, Tsofliou & Clark, 2016).

Social networks beyond the class environment often result with the connections made between class members leading to the development of relationships, peer support and on a practical a level, friendly acts such as car sharing (Farrance et al., 2016). As a result of these social networks and relationships, increases in perceived functional independence can result in elevated self-efficacy and perceived quality of life. Indeed, maintaining independence is often a key motivator for attending the classes (Fox, Stathi, McKenna & Davis, 2007). Accordingly, the role of social connectedness and relationships cannot be underestimated in maintaining functional independence in older age.

Chapter 7 illustrated the perceived improvement of physical and mental health in COPD patients following attending a group-based exercise class, and the reasons described above are a likely contributing factor to this finding. This further highlights the importance of social groups to influence adherence, even in populations with a physical health condition such as COPD. This is a common theme associated to group exercise and supported within the literature. For example, in breast cancer patients aged 50 and over, physical benefits of exercise such as improving health and building strength were the most common expected outcomes, however the psychological benefits of exercise were shown to be more valuable to the participants, such as improving state of mind and self-esteem (Rogers, Courneya, Shah, Dunnington & Hopkins-Price, 2006).

Regular physical activity will benefit physical health and function, and often this is the expected outcome but by exercising in a group, the additional social connectedness often becomes the driving factor that motivates the individual to attend regularly in order to obtain the expected physical benefits.

Understanding relationships between biopsychosocial function in older adults

As reported in Chapter 2, age-related declines to physical, cognitive and psychosocial function have been well documented (Taylor et al., 2004). Some authors have reported how changes in one of these functions can impact upon another, for example, cognitive decline demonstrated through changes to walking gait (Ijmker & Lamoth, 2012); the negative impact on physical health from a lack of social affiliations (Cacioppo et al., 2004: Holt-Lunstad et al., 2010); and the benefits of physical activity presented through improved cognition (Northey et al., 2017).

However, the relationship of all three functions and how they interact has been far less extensively reported. The potential for a tri-directional relationship was a logical deduction given the evidence presented in the reported literature suggesting cognitive training can manifest as physical improvement such as walking gait (Verghese et al., 2010), and adequate social relationships can be as beneficial to reducing mortality risk as physical exercise (Holt-Lunstad et al., 2010). It was therefore hypothesised that improvements or declines to physical function would also be reflected in cognitive function and psychosocial function and vice versa in a triangulated relationship. Nonetheless, as discussed in the previous chapter, the relationship is far more complex than a linear triangulation of improvement or decline.

The influence of psychosocial function on physical and cognitive function appears more a consequential one, than a direct one i.e. influenced through the environment. The participants used in study 2 (Chapter 6) self-reported no perceptions of loneliness, but as community-dwelling individuals benefit from a community-based group exercise class. The benefit of this is the motivation it provides to adhere to the exercise class, and this then promotes enhancements to physical function. Although motivation related data was not collected as part of the thesis, anecdotal evidence and previous literature provide basis for this conclusion (Steptoe et al., 2015). Whether attending a group cognitive training class could elicit the same benefits to psychosocial function is unknown but would add depth to the understanding of this relationship.

How are physical, cognitive and psychosocial functions related?

The initial hypothesis of a tri-directional relationship among biopsychosocial functions is illustrated in Figure 4. Here, each function has a direct influence on the others, represented by a solid line with double-ended arrowheads, suggesting improvement or decline in one dimension is mirrored in the other two.

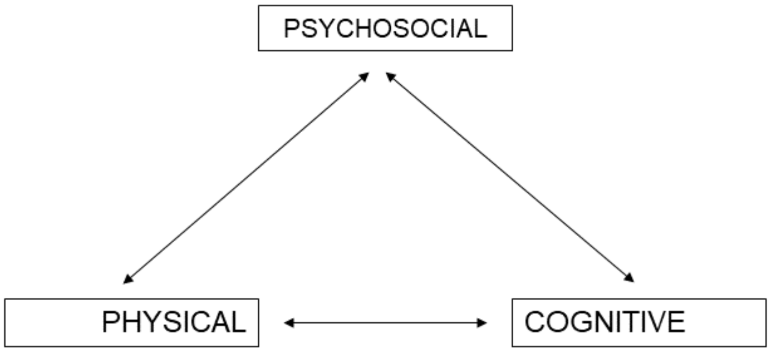


Figure 4. Simplistic illustration of tri-directional relationship hypothesis between biopsychosocial functions

However, the findings presented throughout this thesis suggest that this is not the case, and the relationships shared between biopsychosocial functions are more complex. Therefore, if the relationships were to be illustrated, it could present as Figure 5.

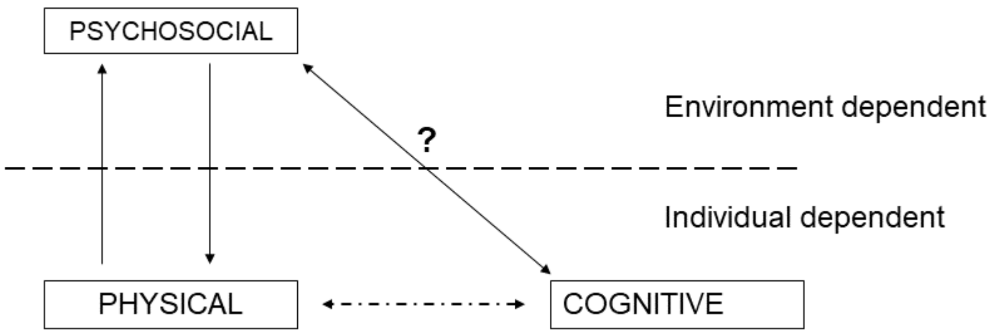


Figure 5. Complex illustration of the possible relationship between biopsychosocial functions

Figure 5 represents an illustrative example of the potential complex nature of the relationship between biopsychosocial functions. This figure reflects a more practical approach to understanding biopsychosocial health compared to biomedical models, for example as first proposed by Engel in 1977 (Smith, 2002). Figure 5 adapts previously reported biopsychosocial models such as *'the dynamic biopsychosocial model of health'* (Lehman, David & Gruber, 2017) using the practically applicable findings in this thesis. Figure 5 does not intend to state how biopsychosocial functions *are related*, but rather indicate how they *could be related*, providing the basis for further research.

For example, the solid line arrows between physical and psychosocial function indicate the integrated benefits these provide, but only under the right environmental conditions (i.e. exercising in a group setting), hence the dashed horizontal line demonstrating how the setting in which the intervention is undertaken can impact on psychosocial health. This comes from empirical studies 2 and 3, which suggested group exercise classes could benefit physical and psychosocial function. However, the arrows from physical function to the psychosocial function and vice versa are separated because a direct influence on each other has not been demonstrated, but rather indirect relationship under the right environmental conditions. Therefore, a practitioner could interpret this to understand that an intervention focused on physical function could benefit physical function directly. However, if the intervention is conducted in a group environment, then psychosocial benefits could also be elicited.

Equally, the double-ended arrow between physical and cognitive function indicates the direct influence these functions have on each other. Previous research findings have demonstrated this relationship inextricably (Ijmker & Lamoth, 2012; Verghese et al., 2010, Smith-Ray et al., 2013). However, what now seems to be apparent is that this the extent of this relationship could vary on an individual basis. Previous research has demonstrated older adults in a state of cognitive decline to exhibit debilitating changes to physical function such as walking gait (Ijmker & Lamoth, 2012). Furthermore, increases in cognitive function have been expressed through enhanced physical function such as improved walking gait speed (Verghese et al., 2010, Smith-Ray et al., 2013).

Empirical study 2 (Chapter 6) has demonstrated that older adults who are physically active and functioning above normative values physically and socially, did not exhibit equally high levels of cognition. Hence, the interaction between physical function and cognitive function is represented by a dashed line, as although there is a direct influence between these functions, it is also influenced by other factors unique to the individual. According to Lehman and colleagues (2017), these individual dynamics can change over time, termed *centrality*, and become more or less influential on one’s health. Further research is needed to strengthen current understanding of the underlying mechanisms of how physical and cognitive function interact with each other which would maximise the impact of practical interventions.

Finally, one element of the relationship that is not evident, either through findings presented here or previous literature is how psychosocial functions influence cognition and vice versa.

For example, whether attending a group-based cognitive training class would elicit the same benefits to psychosocial function and relationships that a group-based physical exercise class can do, is unknown but warrants further research to broaden understanding of this relationship. Hence, on Figure 5, a question mark signals the unknown nature of this relationship.

Individual dimensions of basic biopsychosocial health share a complicated relationship. The findings presented here have enhanced current understanding of how these dimensions of health could be related which can benefit the design of practical applications. Practitioners wanting to improve biopsychosocial health can design interventions based on a greater understanding of how individualised health dimensions integrated with the environment and maximise the impact of such interventions. It would seem apparent that to maximise biopsychosocial health, interventions are individualised for physical and cognitive functional abilities, and undertaken in a group environment.

Key integrated findings related to Thesis aim 2

The second key objective of the thesis was to use field-based assessment measures to determine biopsychosocial health of older adults. This was to increase the practical utility of the research findings and translate these into impactful practical applications to enhance the longevity of health and independence in older adults.

In terms of assessing biopsychosocial functions in the field, it is clear that some assessment measures are more applicable than others. The TUG and STS assessments were easily implemented in the field and the TUG DT provides additional information on physical function and ADL ability. The UCLA 3-item Loneliness Scale and Traffic Light Metric are simple, effective and easy to administer, but further research is needed for validation in the case of latter. Furthermore, none of these measures require specialist equipment or training and hold potential to be self-administered to demonstrate changes to health (Lee, 2000).

Simple technology-based assessments can also be implemented in the field such as with the OptoJump MIP protocol and Lumosity's BPT. Although specialist equipment is required to undertake these assessments it is minimal and easily accessible i.e. a computer and specific software. Furthermore, in the case of the BPT, a reduced number of tests would improve the application of the BPT in a field setting, by increasing time-efficiency.

To that end, it would seem that combining simple and accessible technology with easy to administer field-based assessments holds potential for novel and impactful practical applications.

Field-based assessment of biopsychosocial function

In Chapter 4, the decision-making process and rationale for each assessment measure was presented. In the next section the assessment measures used in each empirical study are discussed and evaluated in line with Thesis aim 2.

Physical Measures

Timed Up and Go

The Timed Up and Go (TUG) provided a validated measure of physical function that was quick to administer and does not require specialist equipment (Podsialdo & Richardson, 1991). As it is widely used in clinical practice there is a wealth of age and gender based normative data to compare participant scores to (Bohannan, 2006). In practical settings, having normative reference values is important in order to identify a participants' level of physical function and measure the effectiveness of an intervention.

Adding a cognitive dual-task to the TUG did make a difference to the participants' reported times, however this difference was not significant (τ = .04, p (one-tailed) <.05). The TUG DT however did highlight practically informative findings, demonstrating the complex relationship between physical and cognitive function.

Short Physical Performance Battery

The SPPB is a simple to administer assessment measure of physical function, highly applicable in the field. The findings from the first experimental study however demonstrated that among a physical active community-dwelling group, the SPPB is not sensitive enough to detect any differences in function. This is evidenced by the majority of participants scoring a perfect score of three on every assessment within the battery.
Hence, there would appear to be a ceiling effect with assessment measure, not previously known to the researcher, and contradicting previous research (Freire et al., 2012).

Therefore, it is suggested that the SPPB would be a useful measure in screening for physical frailty, as shown by Aires da Câmara and colleagues (2012), as opposed to determining physical function level in community-dwelling older adults.

OptoJump March in Place

To the authors knowledge, at the time of writing no published data exists using the MIP protocol to measure physical function of older adults. Due to its requirement of matching step frequency to a metronomic beat at three intensities (MIP 60, MIP 90, MIP 120), the attentional control and cognitive processes involved in doing so, suggests that the MIP could also be thought of a dual-task. Further research is warranted to explore this potential as the test was quick to administer, relatively simple and highly applicable in the field.

30s Sit to Stand

The 30 seconds sit to stand is a widely used assessment and has been reported as a valid and reliable indicator of lower body strength in older adults (Jones, et al., 1998). It is quick and simple to administer when working in a group and hence gives it high practical utility as a field-based measure. As participants are asked to count their own number of repetitions, the STS could quite easily be a considered as a self-administered assessment measure.

Cognitive Measures

Ravens Standard Progressive Matrices

The RSPM was chosen given its reliability and validity as a cognitive assessment measure (Raven, Raven & Court, 2000) and its ease of use within the field, in both computerised and paper versions.

However, it did not seem to capture specific executive function ability of the participants as demonstrated in Chapter 6 by the lack of relationship with the TUG and TUG DT (τ = -.27 & τ = -.09, *p*s one-tailed > .05).

The TUG has been identified in previous studies as a measure of executive function with significant relationships to other cognitive assessments such as Digit Symbol Test and Trail Making Test (Kumai et al., 2017), but this finding was not replicated with the RSPM.

It there seems fair to suggest that the RSPM is best placed as a global measure of cognition rather than a measure of executive function Where it did prove advantageous was with the comparison to normative data, however on reflection this would also be possible for other specific measures of executive function such as the Stroop Colour Word Test (Van der Elst, Van Boxtel, Van Breukelen & Jolles, 2006) or the Trail Making Test A & B (Tombaugh, 2004).

Lumosity Brain Performance Battery

The battery of nine computerised assessments measured cognitive functions including processing speed, decision making, attention, working memory and problem solving. The raw score was used for analysis which included the time taken to complete the assessment and/or the number of correct answers. The results of each assessment were then sent to Lumos Labs (CA, USA) to be processed before being returned to the researcher for analysis, in agreement with the Human Cognition Project (HCP) terms of involvement. This meant that feedback of participant performance for each assessment was delayed, despite the possibility of this being instantaneous. This limits the practical application of the BPT, however, in circumstances outside the HCP this would not occur which strengthens the use of these computerised assessments as a field-based measure of cognition

As discussed previously, shortening the test battery by reducing assessments would be advantageous in increase time-efficiency. Especially when working with groups, practitioners have limited time to undertake assessments, hence time is an important consideration.

Physical Activity

Past and Present Physical Activity Questionnaire

The Past and Present Physical Activity Questionnaire was used due to its reliability of measuring activity levels over a life span (Orsini et al., 2007). It was effectively used in Chapter 5 where a significant finding of being active either early in life or later in life was discovered. Activity levels at age 15 and age 30 where shown to be related (r = .739, p = .001), as were activity levels at age 50 and in the last year (r = .551, p = .022).

The questionnaire was relatively simple to complete, however despite being a self-report questionnaire, some participants required assistance from the researcher due to ambiguous instructions on the questionnaire. It did serve well as a field-based assessment measure, however it was rather time consuming to complete.

Furthermore, the questionnaire only provides a descriptive outcome of activity levels, hence in order quantify this, conversion of answers using METs is required. This makes quantifying scores was rather time consuming and complicated reducing its applicability if used with large groups.

Psychosocial Measures

UCLA 3-item Loneliness Scale

Past studies have shown the UCLA 3-item Loneliness Scale to be highly reliable with a strong validity to a sample of older adults (Russell, 1996; Russell, 2010; Victor et al., 2000). By only asking three questions, it is a short and simple questionnaire suited to field-based assessment. The data output is simple to quantify and feedback can be provided quickly, which can also be compared to a national sample which is advantageous for research purposes. Hence, this questionnaire was a successful field-based assessment of social engagement in older adults.

Traffic Light Metric

Although not validated in the literature, the Traffic Light Metric has been used in a clinical setting with a high degree of success. It is quick and simple to administer and analyse and provides instant results which can be fed back to the participant. It also provides a clear illustration of the effect of the intervention on a participant's perceived mental and physical health when used before and after the intervention. However, further research to validate its use as an assessment measure is warranted.

Considerations for the practitioner

A core objective for this thesis was to use simple, field-based assessment measures with a high practical applicability. Therefore, in addition to the aforementioned field-based evaluations used, considerations for the use of these measures in practise are documented.

With regard to the BPT used in the first empirical study it is important to consider the specific test battery. When using nine assessments, the length of time required to complete it varied from approximately 45-60 minutes per participant. Hence if time is short, which is often the case for a practitioner in the field, the full battery of assessments might be excessive and impractical. Furthermore, given that some of the assessments measure the same executive function, such as ‘Arithmetic Reasoning’ and ‘Digit Symbol Coding’ that both measure processing speed and decision making, it seems logical to select only one of these assessments. This would help reduce the length of time required to complete the assessments. A further consideration to computerised assessment is the practicality issue that all participants require a computer, and possibly the internet in order to complete the assessment. Hence, computerised assessment of group-based activities is difficult unless the required equipment is available.

A consideration for use of the UCLA 3-item Loneliness questionnaire is the negatively worded questions which are reported to potentially lead to a ‘response set’ i.e. giving the same answer without much deliberation (Robertson et al., 2012). This is opposed to mixing positive and negative worded questions which require more thought to answer. However, due to the reported high reliability of the questionnaire (Russel, 1996), the incidence of a response set is low.

In regard to the TUG DT, conscious task prioritisation by the participant may be considered as a limitation. This could be reduced by counting the verbalised numbers given by each participant, which would provide greater insight into potential conscious prioritisation of either the physical or cognitive task. Furthermore, it would appear that the assessment has a slight bias on mental arithmetic ability. For example, the cognitive task would be less demanding for those with better mental arithmetic, hence demanding less attention– and thus less demand on competing neural resources would be required to complete the backwards counting task in these participants. Therefore, using one dual-task that involved arithmetic ability and one that involved verbal fluency might be considered to avoid this potential bias.

Can biopsychosocial function be measured in the field?

In summary, field-based assessment measures can be successfully used to determine biopsychosocial functions of older adults. However, it is important that practitioners are aware of the complex relationship shared by physical, cognitive and psychosocial functions when assessing in the field.

Furthermore, when interpreting assessment results, it is important to be conscious of the influence the environment and unique individual characteristics can have on the potential outcomes.

As has been previously demonstrated throughout the thesis and in previous literature, the TUG and STS are easily administered assessments, producing valid and reliable results (Al Haddad et al., 2016; Bohannon, 2006; Nordin et al., 2006; Jones et al., 1998). Adding the cognitive dual-task to the TUG assessment did impact on the time required to complete the assessment in the empirical studies, supporting previously reported data (Muir et al., 2012; Springer et al., 2006). In the absence of expensive equipment to measure cognitive function, the TUG DT would be proficient to determine an individual with a potential cognitive impairment. Further investigation in clinical setting could then be advised and administered, but this finding gives practitioners an impactful assessment of physical and cognitive function, and related ADL ability.

On a more novel note, the MIP protocol and BPT have been trialled and successfully used in the field using a cohort of community-dwelling older adults (Chapter 5). In the case of the MIP protocol, it is understood that this is the first reported data using this protocol with older adults. Therefore, further research with different population sub-groups is warranted, such as those with cognitive impairment, to establish how this impacts upon performance on the MIP protocol. The findings of such research hold great potential for an impactful practical application in community or clinical settings, using a simple field-based measure with inexpensive equipment in a small space, such as GP consolation room or similar.

The BPT have demonstrated that computer-based assessments can be implemented in the field with a cohort of community-dwelling older adults. Given the trend of increased usage of technology among older adults (Evandrou & Falkingham, 2015), this finding also holds potential for novel applications to be developed. However, assessments with shorter duration than the BPT used in Chapter 6 is recommended. There are benefits to computerised assessment including instantaneous feedback, and the effective presentation and secure storage of results.

Simple questionnaires such as the UCLA 3-item Loneliness Scale have also proven to be effective in the field. This is a quick and unobtrusive way to obtain information of perceptions of loneliness and social relationships which can be a sensitive subject.

Furthermore, the simple and self-reported nature of the questionnaire would suggest that a computerised version would be possible. It therefore seems plausible to suggest that self-reported field-based assessments of biopsychosocial health can be applied through simple technologies, providing impactful and novel practical interventions.

It is acknowledged that biochemicals such as BDNF or IGF-1 secreted in response to physical activity, as highlighted in Chapter 3, cannot be measured using field-based assessments. Nor can regional brain activity during cognitive assessment be identified in the field. For this, laboratory based controlled environments and specialised equipment would be necessary, and research of this kind is duly required to broaden understanding of the inner workings and underlying mechanisms of the human body in relation to biopsychosocial health. However, the evidence presented in this thesis demonstrates how field-based assessment measures are useful for practitioners to gain valuable insight into the biopsychosocial function of their clients. This allows theoretical knowledge to be applied maximising the impact of interventions. Accordingly, the field-based assessment measures identified here present the potential to achieve the final core objective of translating the thesis findings into impactful interventions to promote longevity and functional independence into older age.

In summary, the interaction of biopsychosocial influences on function in older adults has been identified as a complex relationship. The practical implications of this have been illustrated in Figure 5. There are clear direct and indirect influences on different aspects of function, which cumulatively impact on an older adult's health and independence. It cannot be said that any one of these functions is more or less influential than another, with the environment and unique individual characteristics identified as potential influencing factors.

Seeking opportunities that promote physical, social and cognitive stimulation are therefore advised and potentially hold greater benefit to quality of life, than activities that promote these functions in isolation. Interventions that can help older adults achieve this are warranted and would significantly benefit the older person but also help reduce the burdensome economic implications of an ageing population for the health service.

Practical implications

At the start of the thesis, statistics reporting how the older adult population is increasing were presented, stating that ~25% of the population in the UK are estimated to be aged over 65 by 2037 (Coates, 2017). This would represent approximately 17 million people, an increase of over 5 million people in two decades (Coates, 2017). Furthermore, the costs associated to the treatment of poor health of an ageing nation are unsustainable for the NHS. Already at ~£46.5 billion, this figure would be set to rise in line with the population demographics due to the reported final 16 years of life that are reportedly spent in poor health (Brayne et al., 2001). Hence, based on the findings of this thesis, the following section will present a novel approach to help older adults identify and maintain functional independence, potentially reducing the economic implications facing the NHS and enhance the quality of life of older adults.

The conceptual review article in Chapter 3 demonstrated how computerised cognitive training could be utilised as a novel intervention, capable of reducing falls risk in the ageing population. The empirical study in Chapter 5 found that that different life stages can result in differing activity levels, and accordingly the studies presented in Chapters 6 and 7 reported that those who are more active through attending a community-based group exercise class demonstrate significant benefits to physical and social function, particularly for those aged 80 years and over.

Hence, an application that could combine these findings would benefit from the use of both computerised and simple-field based measures. Due to the simplicity of such measures, the ability to be self-administered is possible, as no specialist equipment or knowledge is necessarily required. The use of self-assessment to successfully predict functional decline in community-dwelling older adults has been reported previously (Lee, 2000). Furthermore, if computerised, the self-administered assessments could be accessed almost anywhere, for example on any internet connected device. It would also have the advantage of producing immediate results for the user allowing for tailored interventions to be suggested.

A novel approach to identifying functional independence – is technology the key?

The number of older adults that use internet connected mobile devices is rapidly increasing. In the UK, internet use among 55-64-year olds increased from 49% in 2005 to 84% in 2014, representing the greatest increase among any age group (Evandrou & Falkingham, 2015).

This is largely due to the increased use of mobile smartphones and tablets, allowing internet access 'on the go', with the trend set to continue (Evandrou & Falkingham, 2015).

Furthermore, as device usage grows, increasingly efficient data networks such as 4G—soon to become the even faster 5G network—, will only increase the possibilities for internet connected interventions (West, 2016). This poses endless possibilities for data processing such as streaming video sessions with exercise professionals, GP consolations and even the potential for virtual or augmented reality with group-based sessions. Regardless of geographical location, so long as the network is available, the great advantage of these interventions is that they are permanently available to the individual This provides empowerment and greater self-control over one's health. With the ageing demographic of the UK and the number of over 60-year olds using mobile devices both increasing, there is great potential to utilise this medium for a wide scope of practice such as to maintain or even improve biopsychosocial health and functional independence.

Combining the approach of using technology with the findings of this thesis suggest the potential to use simple, self-reported assessments in one's own home through an internet connected device, to determine functional independence. As computers can provide instant feedback, results from the assessments could be programmed to provide appropriate interventions for the individual to take control of their own health to maintain or improve biopsychosocial health and levels of functional independence. The thesis findings would suggest that individualising the intervention could maximise the impact on biopsychosocial health and function.

From a professional perspective, it is my opinion that as a practical application, this intervention would be most impactful if the reported results could feed into the NHS electronic database. In respect of older adults, loss of functional independence often coincides with the onset of frailty, due to the multisystem dysfunctional nature of frailty (Dent et al., 2016). Hence frailty is often the clinical term used to relate to functional independence, with those who are mildly frail having lost some functional independence and those who are severely frail presenting as dysfunctional and completely dependent.

Traditionally, frailty identification has been opportunistic, relying on an GP admission to be able to assess for frailty, leading to approximately 25% of older people living with frailty unidentified (Moody, Lyndon & Stevens, 2017). However, under the recent 2017/18 GP Contract, each GP is required to routinely identify frailty among patients.

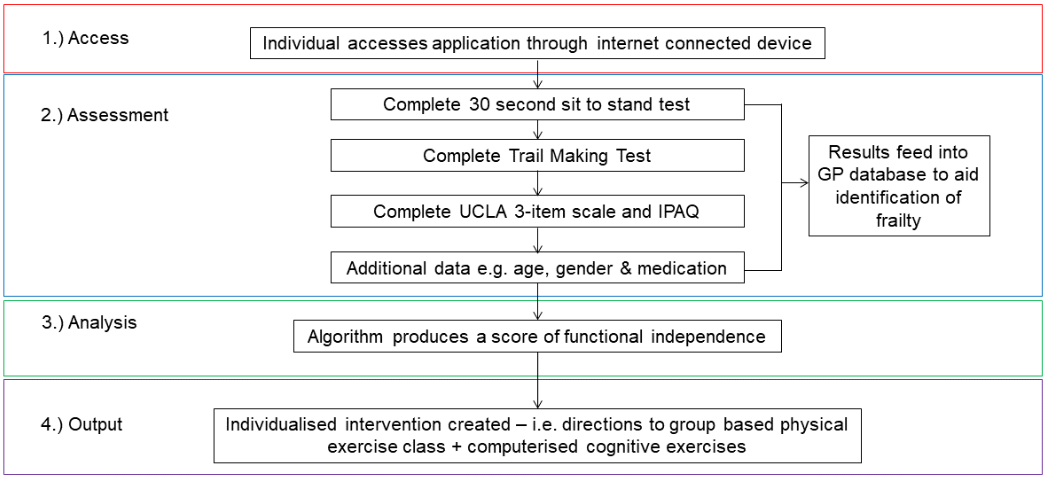
The regulation was brought in to move from opportunistic identification to a more systematic population-based approach to provide targeted interventions for those in need. The regulation was introduced because the NHS recognises the challenges associated with frailty identification and as such the contract states *"…it can be difficult to distinguish those living with frailty to those without frailty"* (General Medical Services contract 2017/18, pp. 6). Therefore, interventions that could overcome the barrier of frailty identification would prove highly impactful for the NHS and the wellbeing of the older adult population.

To that end, although the introduction of this regulation is welcomed, there is still a great deal of labour involved for the GP and practice staff. Tools such as the *electronic Frailty Index* (eFI) have been introduced which calculate primary care data with patient records to identify patients in need of further assessment (Moody et al., 2017). Furthermore, not all practices have access to the eFI and hence are encouraged to carry out assessments such as gait speed to identify frailty in their patients. However, this represents a treatment solution not a preventative solution. It is focused on identification of frailty and then supplying treatment. Interventions that are less labour intensive for primary care staff and aimed at preventing or at least attenuating the onset becoming moderately or severely frail would present greater value for money for the health service. As reported in Chapter 2, frail individuals cost local authorities £8.8 billion in health and social care costs (McNally et al., 2017). Hence interventions to attenuate health decline and the onset of frailty would reduce these financial implications.

As such, based on the findings of the thesis the forthcoming proposed practical application represents a concept for an intervention that demonstrates how simple technological innovation combined with self-administered field-based assessment measures and individualised programmes could help older adults maintain functional independence and attenuate the onset of frailty.

A proposed workflow for the intervention is illustrated in Figure 6. It uses simple and accessible technology to identify and maintain functional independence in older adults. It is based on four key stages;

1. Access,
2. Assessment,
3. Analysis,
4. Output.



IPAQ = International Physical Activity Questionnaire

Figure 6. Illustration of the novel approach to promote biopsychosocial health through technology

Stage 1. Access

Access to the intervention is crucial in order for it to be effective and impactful. As aforementioned, an advantage of internet connected devices is the ability to provide access to the intervention at the convenience of the individual user. This helps overcome some of the challenges faced by clinical staff whereby the responsibility of identifying functional decline is solely dependent on them. Here, older adults can access the intervention themselves anytime, and the data is stored and used for individualised programmes.

Large-scale population surveys report that over 70% of 55-75-year olds now own a smartphone ("Smartphone sales boom with older adults", 2017), and nearly one third of those aged 75 and over own a tablet capable of connecting to the internet ("Rise of the social seniors", 2017). This would equate to approximately 6.2 million older people (Coates, 2018) having access to the intervention either through a smartphone or tablet.

This number is estimated to increase as internet connected devices become more prevalent among the older adult population. Biopsychosocial assessment to identify functional independence on this scale would require significant time and financial resources through traditional methods involving a clinician or health professional. Thus demonstrating the powerful impact utilising technology can have on practical interventions to benefit public health. Furthermore, this intervention could prove less labour intensive and more cost effective for the health services, as the individual would self-administer the assessment and the GP only required to consult those most in need.

The additional benefit of an internet-based intervention is that it can connect to other applications over the internet, such as feeding into the eFI and patient records for this purpose.

Stage 2. Assessment

Once the intervention has been accessed, the older adult would be able to self-administer assessments of biopsychosocial health to indicate the level of functional independence. This would be achieved through;

1. A measure of physical function,
2. A measure of cognitive function,
3. A measure of social and activity levels,
4. Additional data such as, demographic information and medication use.

Physical function assessment

A major threat to independence is the onset of frailty, due to the associated multisystem decline and vulnerability such decline poses to the individual (Turner & Clegg, 2014; Dent et al., 2016). Simple-field based assessments that could be self-administered, such as the 30 second sit to stand would allow the user to identify physical function and lower-limb strength. This would be achieved by counting repetitions of chair rises and using a stopwatch to time 30 seconds and then entering the number of repetitions into the application on the smart device. There is no requirement to measure out and set up the course as with the TUG, hence reducing the risk of error and improving the accuracy of the assessment. Hence, it is proposed that the first assessment would be the 30 seconds sit to stand.

Cognitive function assessment

Secondly, an assessment of cognitive function is required. The onset of frailty and loss of functional independence is associated to an increased rate of cognitive decline (Clegg et al., 2013). Hence, identifying an older adult’s cognitive function, in key executive functions, would provide great insight into their level of functional independence. By using a smartphone or tablet, the cognitive assessment would be computerised allowing for it be self-administered, the scores could be calculated immediately and instant feedback provided to the older adult. As shown from this thesis, the BPT used in Chapter 5 are effective measures of cognitive function, however, the full battery of nine assessments is too long for field-based assessment.

Therefore, taking these reflections into consideration, combined with existing published literature, it is suggested that the Trail Making Test (part B) (TMT B), as used within the BPT battery, will significantly indicate cognitive function and hence would be the second assessment (Cahn-Weiner, Boyle & Malloy, 2002; Johnson, Lui & Yaffe, 2007; Davis, Marra, Najafzadeh & Liu-Ambrose, 2010).

It is important to note that, as shown in Chapter 6 and in previous literature, dual-task activities can effectively identify cognitive impairment. However, due to a lack of existing literature and limitations to the reliability of self-administered dual-task assessments, it is not possible to suggest its inclusion in this proposed intervention. Further research into the efficacy of self-administered dual-task assessments would therefore be warranted.

Social and activity level assessment

Social and activity levels are important to identify, due to the influence these have on functional independence. Higher levels of social connectedness through association with peer groups and activities will often be an indication of better overall health and function (Holt-Lunstad, Smith & Layton, 2010). The UCLA 3-item Loneliness Scale has been shown to be quick and effective measure of social relationships and perceptions of loneliness among community-dwelling older adults in this thesis (Chapter 6) and published literature (Robertson et al., 2012). Although these results do not represent a computerised version, the simple nature of the questionnaire would suggest that it is replicable in a computerised form and used as the third assessment. However, further research would be required to confirm this supposition. Understanding current activity level is important for the identification of appropriate interventions to enhance or maintain the level of functional independence.

Similarly, higher levels of sedentary behaviour are linked to a greater risk of functional decline, inflammaging and the onset of frailty (Chastin, Ferriolli, Stephens, Fearon & Greig, 2011; Bartlett et., 2012). Given the limitations of the Past and Current Activity Questionnaire identified previously, and that the proposed intervention does not require historical activity levels, an alternative questionnaire such as The International Physical Activity Questionnaire (IPAQ) short form could be used, which has been reported as a reliable measure of self-report physical activity levels (Healy et al., 2011). Therefore, the UCLA 3-item Loneliness questionnaire and the IPAQ short form would capture important information relating to the user's level of physical activity and perceptions of psychosocial health.

Additional data input

Additional data such as gender and age are crucial to allow assessment scores to be compared to normative values. Similarly, taking four to six prescription medications increases the incidence of frailty by 55% compared to taking three or less medications (Veronese et al., 2017). Hence, collecting self-report medication use data would provide additional information of levels of functional independence not identified in the other assessment measures. This data is also important for the patient records, as should the intervention result in increased levels of biopsychosocial health, a medication review would be in order, i.e. to reduce or change prescription requirements. Accordingly, the users GP needs to be aware of the assessment results.

Stage 3. Analysis

Once the self-reported assessment scores have been recorded the analysis stage can commence. Analysis of the physical and cognitive assessment scores would require relating them to normative population data to determine if the scores entered were above, on par with or below age and gender related normative data. This methodology follows that used in the second empirical study in Chapter 6 of this thesis. Of course, as previously discussed, the use of comparison to normative data should be approached with caution due to potentially influential confounding variables such as age, gender and socioeconomic status. Further research would be required to ensure accuracy of such analysis and to establish ecological validity.

Social and activity levels would also be analysed with scores determined based on the outcome of the questionnaires and their respective scoring system. Each input of data would then essentially create a scenario of biopsychosocial health as shown in Table 14.

It is important to note however that this table is a representative example, purely hypothetical and subject to further research and clarification. Its inclusion in purely illustrative of how a technologically advanced application might be utilised based on deduced logic and the findings of this thesis.

Table 14. Representative example of intervention data collection and computed score for an output

Assessment measure	User data input	Normative data/ assessment score	Computed score	Computed score carried forward
Age	78	n/a/	n/a	n/a
Gender	Male	n/a	n/a	n/a
Number of prescriptions	5	<4 = normal >4 = polypharmacy	Normal = 1 Polypharmacy = 2	2
30s sit to stand	8	11-17	Below average = 3 Average = 2 Above average = 1	3
Trail Making Test B	190 sec	≥283 200-282 ≤199	Below average = 3 Average = 2 Above average = 1	1
UCLA 3-item Q.	6	3 = least lonely 9 = most lonely	3 – 4 = 1 5 – 7 = 2 8 – 9 = 3	2
IPAQ short form	120 mins/wk	Low = <150mins/wk Moderate = 150mins/wk High = >150mins/wk	Low = 3 Moderate = 2 High = 1	3
Total				10

The computed score carried forward, presented in the final column in Table 14, would be computed by an algorithm to produce the required individualised intervention programme. In this hypothetical example the inputted data represents a scenario whereby a 78-year-old male with polypharmacy, has low physical function, high cognitive function, moderate social engagement and low activity levels.

Therefore, the computed score carried forward (*n* = 10) would provide an intervention based on this scenario, tailored to the reported level of biopsychosocial function. This would take into account the complex relationship identified between biopsychosocial functions, including the environment and individual characteristics.

Although hypothetical, it is important to consider the ethical implications of such technological interventions. As aforementioned, technology use among older adults is growing, however there are still a significant number of older adults without access to smart devices or the internet. Therefore, for the suggested intervention to work on a large scale in practice would require more advanced technology infrastructure than currently available. This would reduce potential to discriminate those in rural areas who, currently might not have access to the internet.

Furthermore, issues such as privacy, informed consent, equity of access, patient-provider communication, and usability are some ethical issues that have been discussed in the literature (Demiris, Doorenbos & Towle, 2009). Ensuring older people are included in the development of health technology is an important ethical consideration, as well as not using technology to replace face-to-face healthcare, but rather enhance healthcare creating a more efficient framework (Mort, Roberts, Pols, Domenech & Moser, 2015). Technology driven healthcare is a priority for the NHS, however for this intervention to be implemented it would have to comply with the NHS digital, data and technology standards which would ensure an ethical approach.

Stage 4. Output

The output provided by the intervention would be a practical solution, tailored to the individual's needs, highlighted through the assessment scores. Using the hypothetical scenario provided above, a local group exercise class might be suggested, with details of where the user would need to go to attend one. This would provide physical exercise to improve physical function, stimulation for social engagement, and increase overall activity levels. Simple, homed-based exercises could also be suggested with video tutorials of how to perform them, with the aim of improving physical function.

Previous literature has stated how self-efficacy in older adults can be enhanced through improvements in physical function, driving greater perceptions of functional independence (Farrance et al., 2016).

Depending on the outcome of the assessments, other outputs would be provided in accordance to the needs of the individual, such as cognitive training to improve elements of executive function shown to aid functional independence (Edwards, Xu, Clark, Guey, Ross & Unverzagt, 2017). Details of local social or special interest groups could be provided to promote social engagement.

Individualised tailoring of interventions is a method recognised in published literature (Brawley, Rejeski & King, 2003). By utilising technology in an ethical manner and exploiting the growing trend of smartphone and tablet usage among older adults, the potential for a novel and highly impactful intervention exists to promote longevity and functional independence in old age. Not only would this benefit the older adult, improving biopsychosocial health but in doing so, reduce the workload for the NHS. The proposed innovation offers a prevention-based approach to enhancing biopsychosocial health which would attenuate associated economic implications of identifying, assessing and treating frail older people by reducing the prevalence of frailty.

As eluded to in the introduction of this thesis, the NHS needs to adopt prevention-based methods to provide solutions for modern day public health issues. The use of technology as described above might be one solution to ease the encroaching issues of an increasing ageing demographic and the potential economic burden this poses.

Final conclusions

There have been several findings that have emerged from the completion of this thesis. Each one has added to the knowledge base and understanding of biopsychosocial health of older adults and assessing for this in the field. In conclusion the key thesis findings, in relation to key thesis objectives are:

Thesis aim 1.) Understanding biopsychosocial function and the role of physical activity in older adults,

- The relationship between physical, cognitive and psychosocial function in older adults is complex and influenced by intrinsic and extrinsic confounding variables,
- Physical activity levels across the life span show a peak in either early or late adulthood which can impact on physical and cognitive function in later life,
- Undertaking physical activity in later life can improve biopsychosocial function in older adults, in both the community and primary care settings.

Thesis aim 2.) The evaluation of field-based assessment tools in older adults,

- Field-based assessment of biopsychosocial function in older adults is possible using a variety of measures,
- The selection of assessment measures is an important consideration when measuring biopsychosocial function of older adults,
- Impactful practical applications to promote longevity and independence in old age are possible through the combination of field-based assessment and technological advances.

A key finding of this thesis is that it is possible to measure biopsychosocial functions with simple field-based assessments. Expensive laboratory-based assessments, such as an fMRI, would provide insight into the brain regions being used while completing a physical and cognitive dual-task for example. This would further enhance current knowledge and understanding of the underlying mechanisms of the complex relationship shared between functions. However, the field-based assessments used in this thesis represent valid and reliable methods to assess biopsychosocial health in community and clinical settings, with the absence of specialist equipment. Furthermore, due to the simplicity of such measures and lack of specialist equipment required, it is possible to self-administer these assessments. Combined with technology the potential for a novel and highly impactful practical application exists, which could aid early identification of potential age-related declines in health, and attenuate further decline through individualised interventions.

Older adults should be encouraged to attend and adhere to group-based exercise programmes which have the potential to benefit physical, cognitive and social dimensions of health. Furthermore, be ensuring such exercise interventions are enjoyable, perceptions of health and wellbeing will also improve. In the future, the impact of these interventions on health could be measured by advances in technology, individualising the programme to the requirements of the older person. It appears that as each person is unique, so is how we age. Hence, interventions to promote healthy ageing and attenuate age-related declines in health should be unique to the individual but delivered in a group-based environment.

No-one wants to lose their independence, yet this happens to so many people as they age. The findings of this thesis have helped broaden current understanding of how biopsychosocial health impacts on functional independence and hence, how independence can be maintained.

This has provided a basis for a novel intervention, utilising simple available technology that gives older people the ability to take control of their biopsychosocial health promoting longevity of functional independence and quality of life. As a health professional this is all I can aim to achieve through practical application of impactful interventions because, as aptly summarised by Abraham Lincoln, *"…and in the end, it's not the years in your life that count. It's the life in your years."*

Personal journey and future directions

My thesis journey began in 2012 and between then and now, I have reached a number of personal milestones such as turning 30 years of age, getting engaged and buying my first home. Completing this doctoral thesis whilst building a future in my personal life and making significant changes in my career path has been both challenging and rewarding in equal measure. Over the past seven years I believe I have matured as a person and so too has my professional capabilities and career direction. Completing this thesis over that period of time has no doubt contributed to this, which I would like to think is reflected in the thesis itself.

As a final section of this thesis, I present my personal and professional reflections as I give an honest evaluation of my doctoral experience. I will document what I have learned and how this will inform my future practice as a health practitioner and researcher. I also outline how this thesis has helped me develop both personally and professionally and enhanced my ability to fulfil my career ambitions as I look forward to the future and the direction in which I wish my career to go.

Personal and professional reflections

I am sure that anyone with doctorate status will agree that the award cannot be achieved without self-discipline, commitment and focus. It would be untrue of me to state that these soft skills have not waned at times, when the metaphorical mountain of the ‘PhD’ title seems too high to climb. However, now back on *terra firma*, there is a great sense of pride in having stuck with it for the duration. It strikes comparison with the London marathon I completed in 2007, at 18 years of age. It was by far the most challenging activity of my life, but literally step by step I made it to the finish line albeit in the sluggish time of 5 hours and 37 minutes. Nonetheless, I now have a medal to show for it which can never be taken away, but the pain and anguish of that day is long in the past. Similarly, the last seven years of study, late nights, early mornings, weekends and hours spent reading and writing are left behind but the PhD title is one I will cherish forever. I knew that to get there, perseverance and determination would be at the epicentre of my achievement.

Through the process of completing this Professional Doctorate, I have developed my ability to review literature, think critically and creatively, as well as enhancing my research skills such as data collection, analysis and dissemination. My written communication has matured as I pursued and achieved publication and I have enhanced my understanding of what it takes to produce impactful research.

I have learned that being a great researcher is as much about knowledge and understanding of the research process as it is about study design and analysis. A well-designed study can fall short if the study findings are not interpreted effectively. This requires an in-depth knowledge of statistics and choosing the most appropriate method of analysis, something which I believe I have improved from completing this thesis. Similarly, a statistical analysis is only as good as the data it has to analyse, hence a poorly designed study will likely produce insignificant results – both significantly and practically. This boils down to the selection of assessment measures, the participants recruited and the rationale for the decision. An informed systematic decision-making process is key to a successful outcome.

Accordingly, becoming a published author has most definitely been a highlight of completing this thesis. After previous attempts at publication had been rejected, it was extremely pleasing to have been accepted by Cogent Psychology. In line with my desired career path, I would hope this is the first of many publications that can not only increase knowledge and understanding, but also practical application for those working with older adults. Reflecting on this, it is with thanks to my supervisors who have contributed to my development through their supervision and expertise, which no doubt assisted in the acceptance for publication.

Other noteworthy reflections include the novelty of using the March In Place protocol. At the time of writing, no published data exists using the OptoJump March In Place protocol with older adults. I have shown that the protocol has practical application in the field, and therefore would encourage further investigation of this protocol with older adults as a form of gait analysis. Also, I am pleased to have contributed to the Lumos Labs Human Cognition Project (HCP) through the use of Lumosity's BPT. At the time of writing, the HCP has recorded over 3 billion cognitive task completions, involved over 40 institutions and disseminated over 50 research studies to help advance cognitive research (Lumosity's Human Cognition Project, n.d.). This is helping to advance the field of neuroscience and also the practical application of cognitive training to help attenuate age-related decline.

In addition to this, through my professional role, I am aware of how crucial it is to find practical and sustainable interventions to aid the UK's growing older adult demographic. Not only for the health and quality of life of the individual, but also to reduce the economic burdens poor health, multimorbidity and polypharmacy places on increasingly strained NHS resources.

I have significantly increased my knowledge of this through reviewing literature around geriatrics and public health, and I would like to think that the research I have undertaken has helped take one (albeit small) step towards finding practical interventions. This is something that I would like to further in my future work. With that in mind, the next section will outline how I intend to apply what I have learned over the last seven years, both personally and professionally, to shape my future career path.

Future directions

The findings of this thesis will inform my future practice as I have demonstrated the practical application of simple, field-based measures to assess biopsychosocial health of older adults. I have presented the evidence suggesting that the relationship shared between dimensions of health is complex, and that when designing holistic public health interventions, the environment and individual characteristics of ageing are important considerations. The decision to integrate technology with practical application, as proposed in the preceding sections of this chapter, is something I believe is necessary as the world around us becomes increasingly technologically advanced. Older adults are becoming more au fait with technology which provides health practitioners with a medium not previously utilised. Hence, this novel practical application is one I am keen to pursue further.

Combining real-world research with practical application is what I enjoy and the direction I would like my career to take. I have great respect and enthusiasm for research, which has only been strengthened through completing this thesis. Research provides knowledge, and knowledge can lead to change for the better. Hence, I am also passionate about implementing such changes through practical application of knowledge acquired through research. In my opinion, the two go hand in hand, as without research there is nothing to apply and without application there is nothing to research.

Further research and innovation

I believe there is great potential to harness technology and its ability to offer large scale interventions. The world has never been as connected through technology as it is today, and current predictions suggest this will only increase (West, 2016). It therefore seems only logical to utilise this powerful medium for the benefit of public health. However, as I have discussed in previous chapters, further research of the biopsychosocial relationship is needed, before effective practical applications can be implemented.

For example, the following research questions have emanated from this thesis;

- Does attending a group-based cognitive training class improve psychosocial health in the same way that group-based exercise classes do?
- Is the MIP protocol a dual-task – does it replicate findings of the TUG dual-task?
- Can self-administered dual tasks report reliable results?

Answering these research questions would provide further understanding of the relationship shared among dimensions of biopsychosocial health. Furthermore, novel impactful practical applications could be developed to enhance the function of older adults, promoting independence and reducing the amount of time spent in ill health.

In additional to this further research, I aim to further develop the proposed practical application in the previous chapter. This development requires a its own series of research undertakings to be successfully applied in real world settings. For example, identifying which executive functions are most closely related to walking gait and how to measure them in a simple and effective manner needs to be established. As I have highlighted in my discussion, a full battery of cognitive assessment is too time consuming in the field, and likely beyond the capacity for self-administered assessment. Hence, I suggest the TMT B assessment but implementing this would require confirmation through further research. Similarly, a computerised version of the UCLA 3-item Loneliness Scale would require validation.

Furthermore, the algorithm to analyse results requires development and testing before the application could be made publicly available. This will most likely involve a series of trial and error tests before being evaluated through a large-scale validity and reliability study comparing its performance against already established measures of falls risk. This would follow in the footsteps of other technological medical devices such as the Quantitative Timed Up Go development (Greene, O'Donovan, Romero-Ortuno, Cogan, Scanaill & Kenny, 2010; Greene & Kenny, 2012).

Finally, a feasibility study is likely required to establish the success of using such an application in community-dwelling settings. This would be similar to that of the REmote Assessment of older adults in a Care Home Setting (REACHES) project (McCarthy et al., 2017). This was designed to test the use of the application as an approach to help older adults maintain and/or improve functional independence levels, reducing the number of falls related injuries and associated costs to the NHS.

Finally, to turn this research into a mobile app would require expertise in app development. I am familiar with this process having led the development of three apps through my current role as Director of Research and Innovation with Move it or Lose it. Consequently, through the contacts I have made in my current profession, I aim to bring together a research team to undertake the steps outlined above.

I aim to take these steps because I am passionate about research and the impact it can have in real-world environments. The fact that we all get older makes researching the older adult demographic highly rewarding as it affects everyone, whether it's your friends and family or someone else's. I aim to use the power of research and technology so that we can all benefit in older age from practical applications that influence biopsychosocial function and enable us to enjoy and not endure our older years, living independently for as long as possible.

If I can achieve these aims and contribute to the great work being done to enhance quality of life as we age, when I am classed as an older adult, I will be able to look back at my achievements with a great sense of pride. This is what I intend for my future direction, and this doctoral thesis is just the start of my journey.

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APPENDIX 1 – CURRENT AND PAST ACTIVITY QUESTIONNAIRE (ORSINI ET AL., 2007)

This questionnaire is designed to establish you activity level at present and in the past. Please tick the box that most applies to you, as shown:

School/Work

When you were 15 years old, were you:

- ☐ Mostly sitting down
- ☐ Sitting down half the time
- ☐ Mostly standing up
- ☐ Mostly walking, lifts, carry *little*
- ☐ Heavy manual labour
- ☐ Mostly walking, lifts, carry *heavy*

When you were 30 years of age, were you:

- ☐ Mostly sitting down
- ☐ Sitting down half the time
- ☐ Mostly standing up
- ☐ Mostly walking, lifts, carry *little*
- ☐ Heavy manual labour
- ☐ Mostly walking, lifts, carry *heavy*

When you were 50 years of age, were you:

- ☐ Mostly sitting down
- ☐ Sitting down half the time
- ☐ Mostly standing up
- ☐ Mostly walking, lifts, carry *little*
- ☐ Heavy manual labour
- ☐ Mostly walking, lifts, carry *heavy*

In the past year, were you:

- ☐ Mostly sitting down
- ☐ Sitting down half the time
- ☐ Mostly standing up
- ☐ Mostly walking, lifts, carry *little*
- ☐ Heavy manual labour
- ☐ Mostly walking, lifts, carry *heavy*

Walking/bicycling

When you were 15 years old how often did you walk or ride a bicycle:

- ☐ Hardly ever
- ☐ Less than 20 min/day
- ☐ 20 – 40 min/day
- ☐ 40 – 60 min/day
- ☐ 60 – 90 min/day
- ☐ More than 90 min/day

When you were 30 years of age, how often did you walk or ride a bicycle:

- ☐ Hardly ever
- ☐ Less than 20 min/day
- ☐ 20 – 40 min/day
- ☐ 40 – 60 min/day
- ☐ 60 – 90 min/day
- ☐ More than 90 min/day

When you were 50 years of age, how often did you walk or ride a bicycle:

- ☐ Hardly ever
- ☐ Less than 20 min/day
- ☐ 20 – 40 min/day
- ☐ 40 – 60 min/day
- ☐ 60 – 90 min/day
- ☐ More than 90 min/day

In the past year, how often have you walked or rode a bicycle:

- ☐ Hardly ever
- ☐ Less than 20 min/day
- ☐ 20 – 40 min/day
- ☐ 40 – 60 min/day
- ☐ 60 – 90 min/day
- ☐ More than 90 min/day

Home/household work

When you were 15 years old how much household work did you do (e.g. cleaning/gardening):

- ☐ Less than 1 hour/day
- ☐ 1 – 2 hour/day
- ☐ 3-4 hour/day
- ☐ 5 – 6 hour/day
- ☐ 7 – 8 hour/day
- ☐ More than 8 hour/day

When you were 30 years of age, how much household work did you do (e.g. cleaning/gardening):

- ☐ Less than 1 hour/day
- ☐ 1 – 2 hour/day
- ☐ 3-4 hour/day
- ☐ 5 – 6 hour/day
- ☐ 7 – 8 hour/day
- ☐ More than 8 hour/day

When you were 50 years of age, how much household work did you do (e.g. cleaning/gardening):

- ☐ Less than 1 hour/day
- ☐ 1 – 2 hour/day
- ☐ 3-4 hour/day
- ☐ 5 – 6 hour/day
- ☐ 7 – 8 hour/day
- ☐ More than 8 hour/day

In the past year, how much household work have you done (e.g. cleaning/gardening):

- ☐ Less than 1 hour/day
- ☐ 1 – 2 hour/day
- ☐ 3-4 hour/day
- ☐ 5 – 6 hour/day
- ☐ 7 – 8 hour/day
- ☐ More than 8 hour/day

Leisure Time – Watching TV/reading

When you were 15 years old how much leisure time did you have, to read books and/or watch television:

- ☐ Less than 1 hour/day
- ☐ 5 – 6 hour/day
- ☐ 1 – 2 hour/day
- ☐ More than 6 hour/day
- ☐ 3-4 hour/day

When you were 30 years of age, how much leisure time did you have, to read books and/or watch television:

- ☐ Less than 1 hour/day
- ☐ 5 – 6 hour/day
- ☐ 1 – 2 hour/day
- ☐ More than 6 hour/day
- ☐ 3-4 hour/day

When you were 50 years of age, how much leisure time did you have, to read books and/or watch television:

- ☐ Less than 1 hour/day
- ☐ 5 – 6 hour/day
- ☐ 1 – 2 hour/day
- ☐ More than 6 hour/day
- ☐ 3-4 hour/day

In the past year, how much leisure time did you have, to read books and/or watch television:

- ☐ Less than 1 hour/day
- ☐ 5 – 6 hour/day
- ☐ 1 – 2 hour/day
- ☐ More than 6 hour/day
- ☐ 3-4 hour/day

Exercise

When you were 15 years old how much time did you spend exercising:

- ☐ Less than 1 hour/week
- ☐ 4-5 hour/week
- ☐ 1 hour/week
- ☐ More than 5 hour/week
- ☐ 2-3 hour/week

When you were 30 years of age, how much time did you spend exercising:

- ☐ Less than 1 hour/week
- ☐ 4-5 hour/week
- ☐ 1 hour/week
- ☐ More than 5 hour/week
- ☐ 2-3 hour/week

When you were 50 years of age, how much time did you spend exercising:

- ☐ Less than 1 hour/week
- ☐ 4-5 hour/week
- ☐ 1 hour/week
- ☐ More than 5 hour/week
- ☐ 2-3 hour/week

In the past year, how much time have you spent exercising:

- ☐ Less than 1 hour/week
- ☐ 4-5 hour/week
- ☐ 1 hour/week
- ☐ More than 5 hour/week
- ☐ 2-3 hour/week

APPENDIX 2 – UCLA 3-ITEM LONELINESS SCALE

We would like to ask you a few questions to enable us to measure how helpful our services are. You can choose to answer all or none of the questions, and choosing not to answer will not affect your access to any of our services in any way.
When answering the questions, you could take account of the following:

- There are no right or wrong answers
- We would like you to be completely honest
- In answering the questions, it is best to think of your life as it generally is now (we all have some good or bad days)

Please tick (☑) to show your answer.

1. How often do you feel that you lack companionship?

Hardly ever	**Some of the time**	**Often**
1	2	3

2. How often do you feel left out?

Hardly ever	**Some of the time**	**Often**
1	2	3

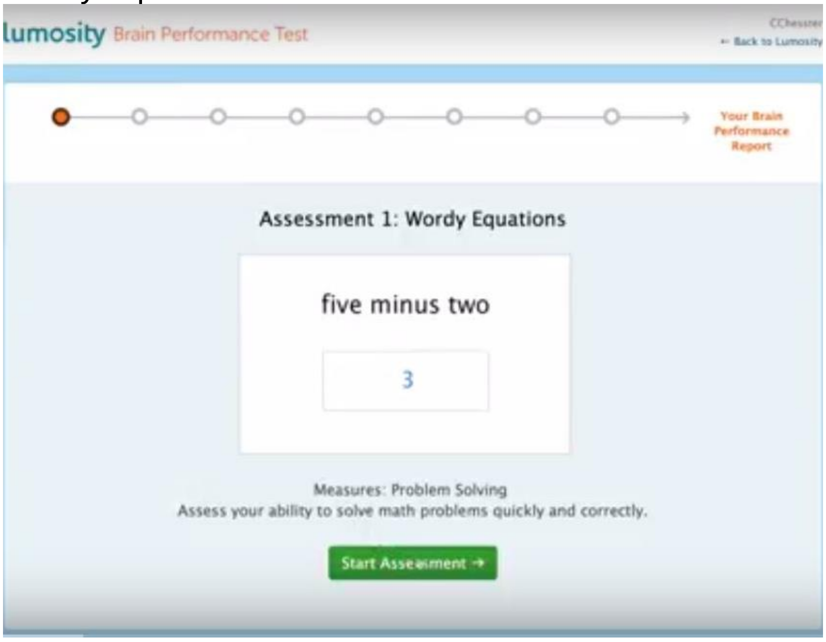
3. How often do you feel isolated from others?

Hardly ever	**Some of the time**	**Often**
1	2	3

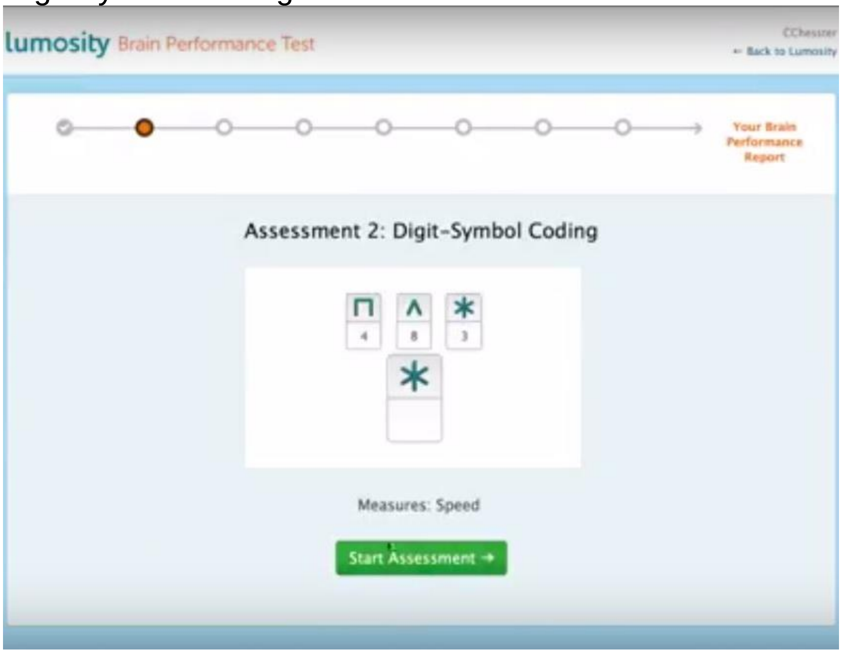
Thank you for your time.

APPENDIX 3 – LUMOSITY BRAIN PERFORMANCE TESTS

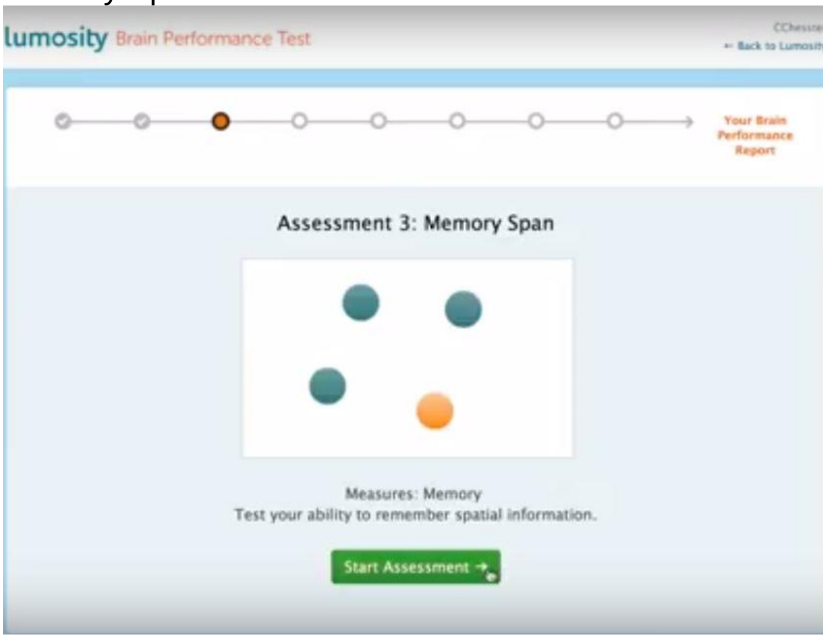
Wordy Equations



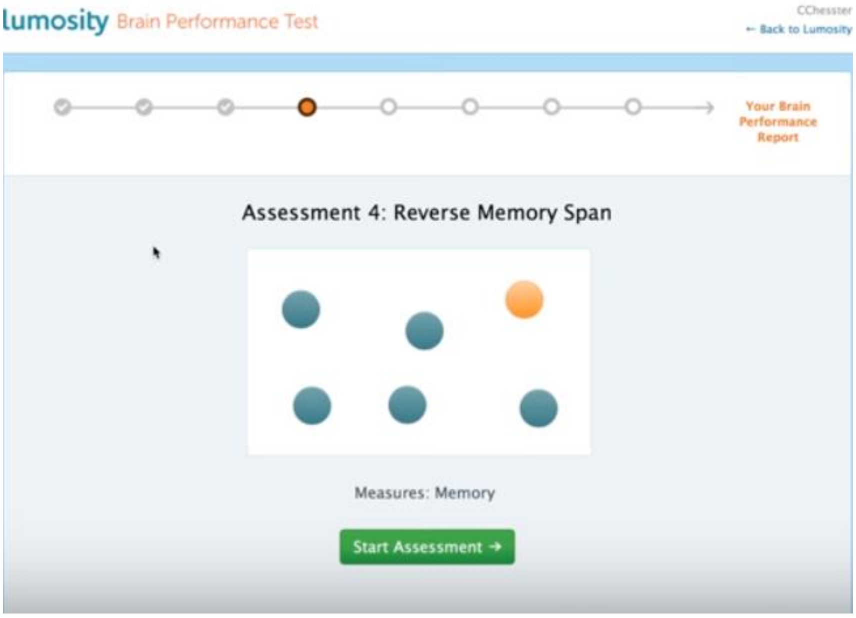
Digit Symbol Coding



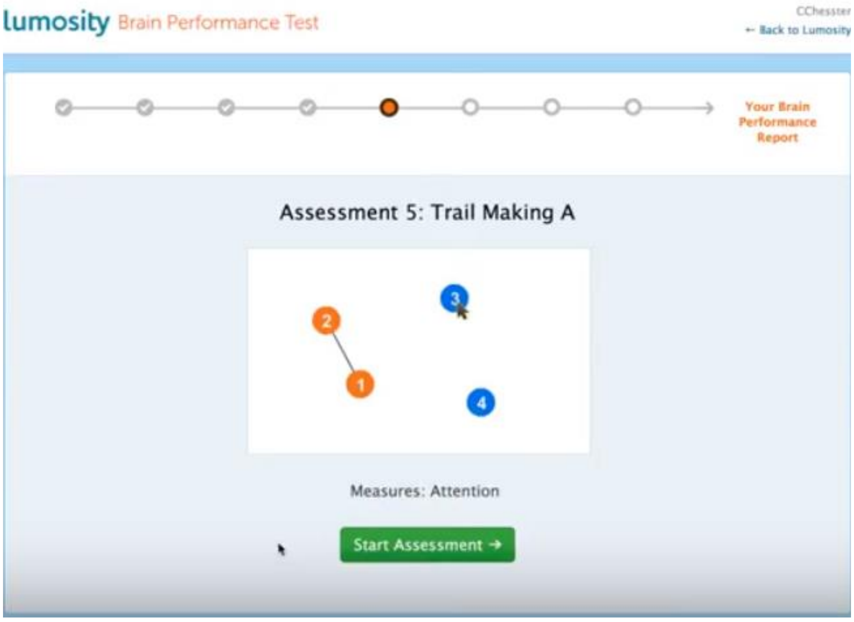
Memory Span



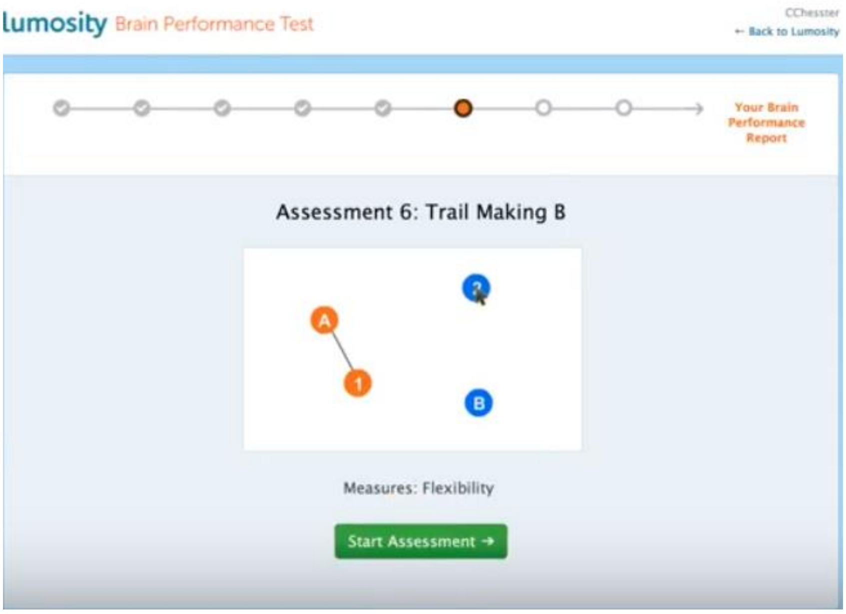
Reverse Memory Span



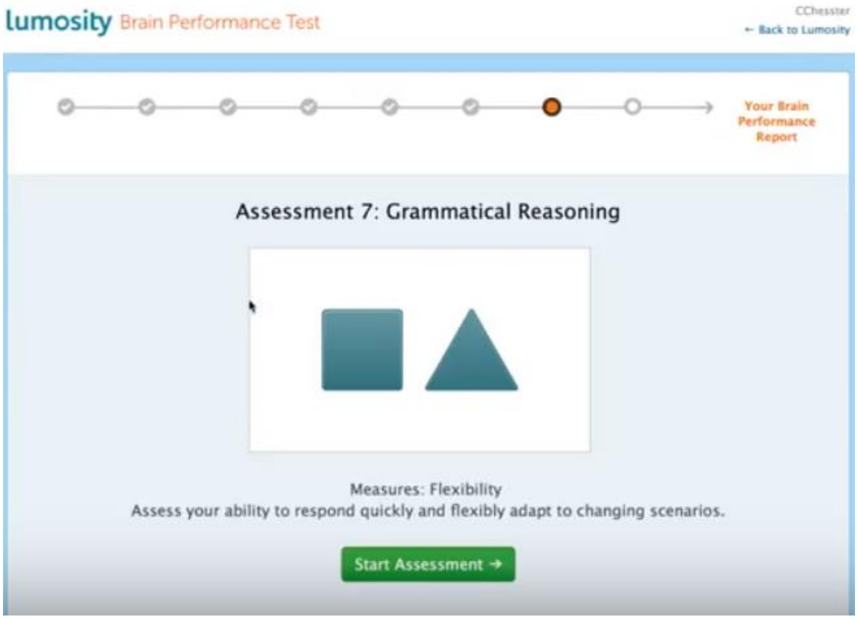
Trail Making Test A



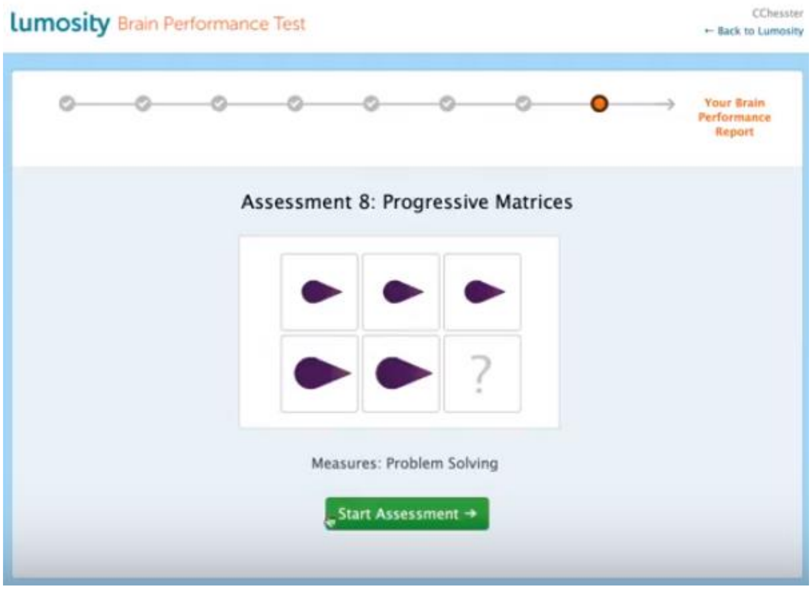
Trail Making Test B



Grammatical Reasoning

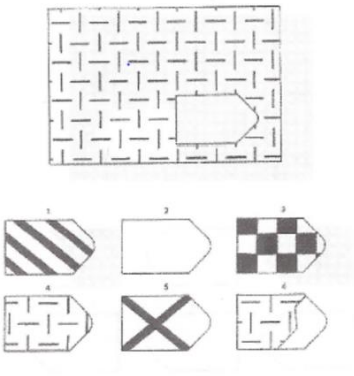


Progressive Matrices



APPENDIX 4 – RAVENS STANDARD PROGRESSIVE MATRICES, SETS A, B, C, D & E

A1



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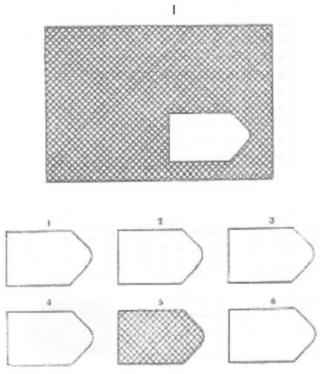

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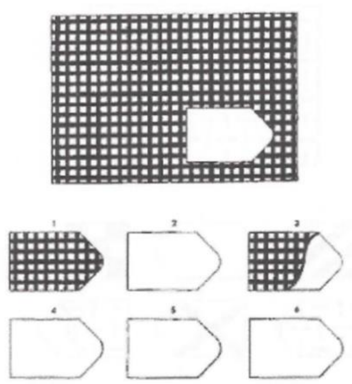

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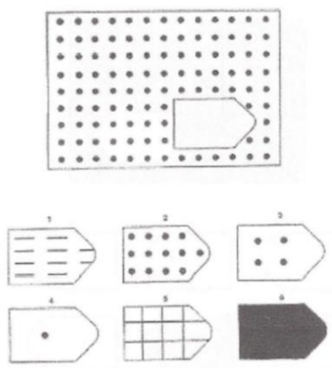

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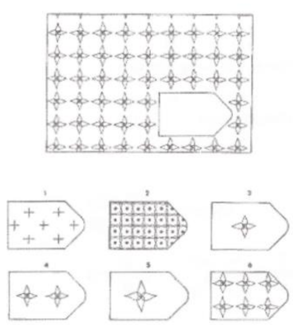

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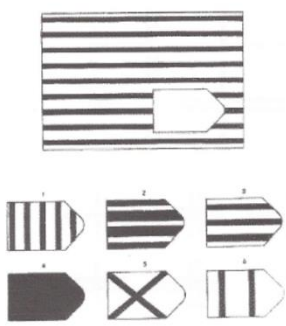

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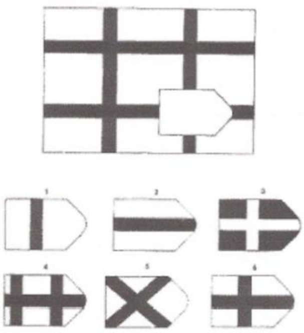

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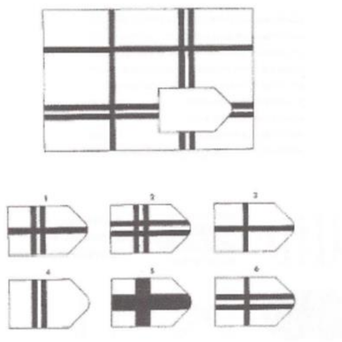

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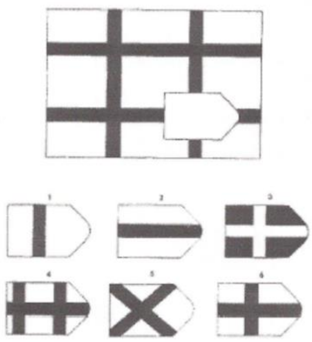

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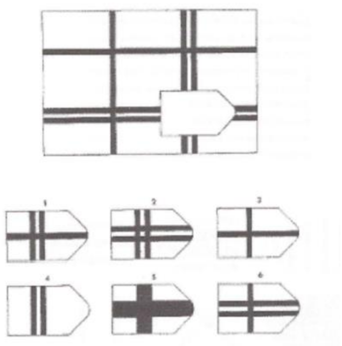

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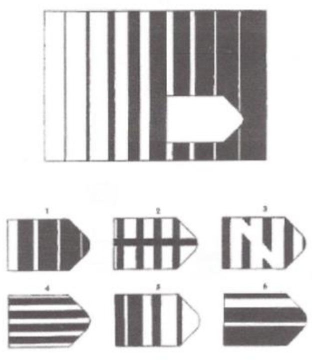

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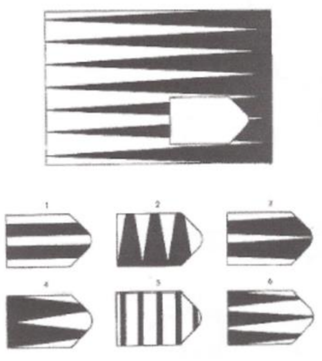

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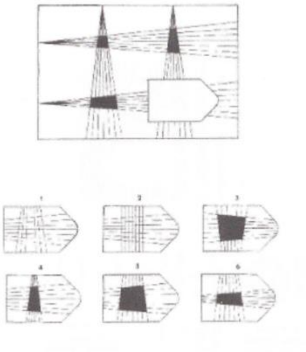

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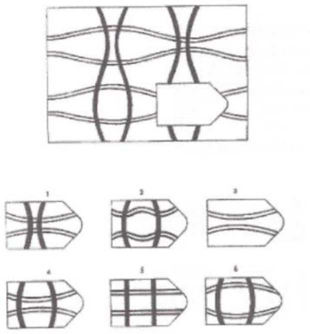

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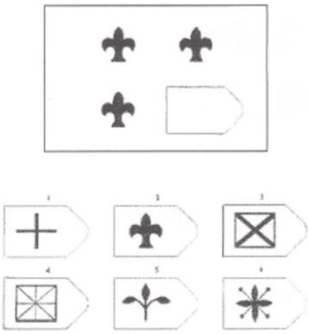

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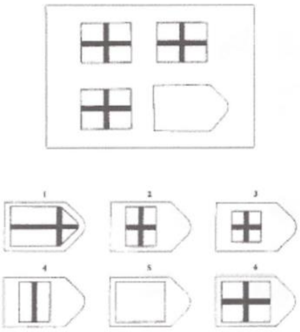

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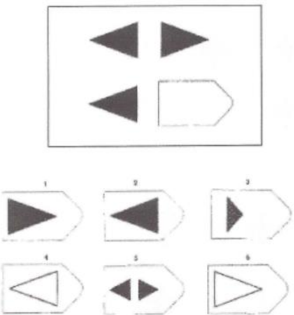

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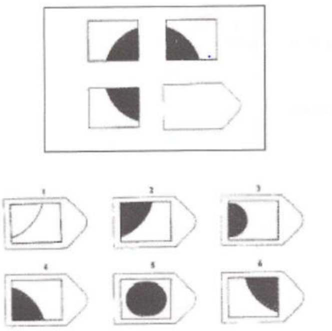

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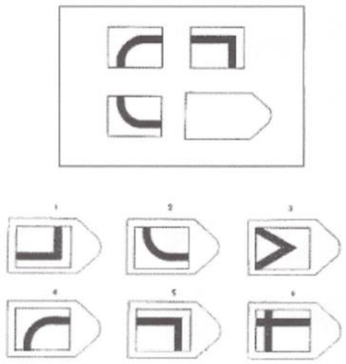

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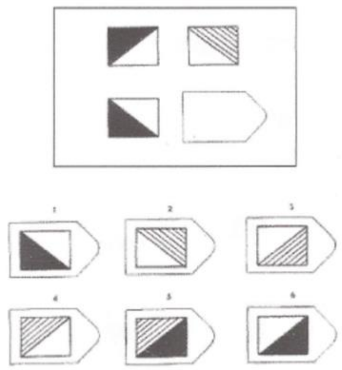

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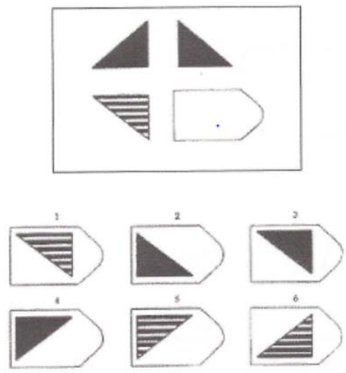

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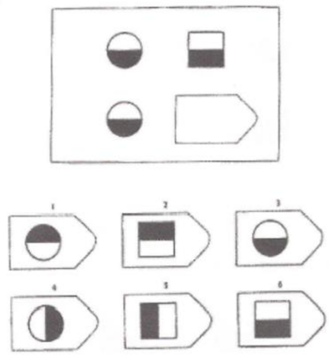

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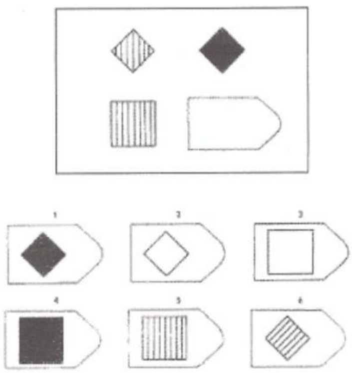

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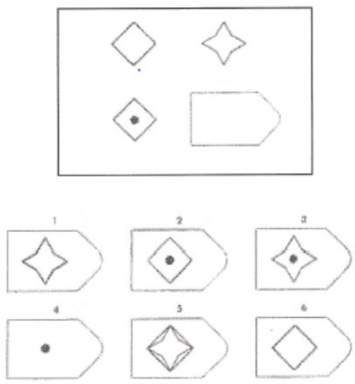

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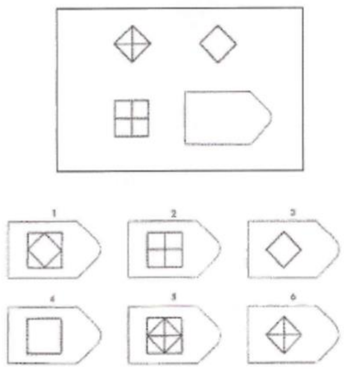

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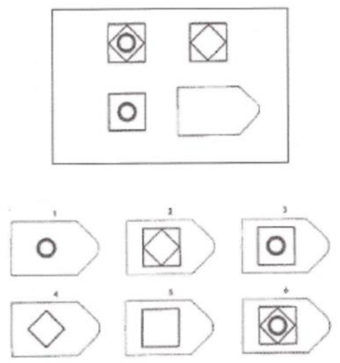

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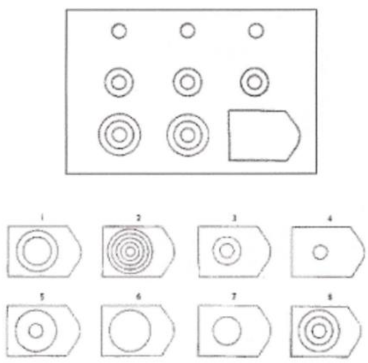

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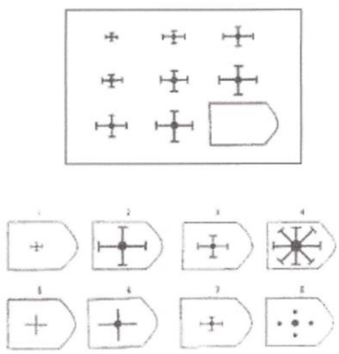

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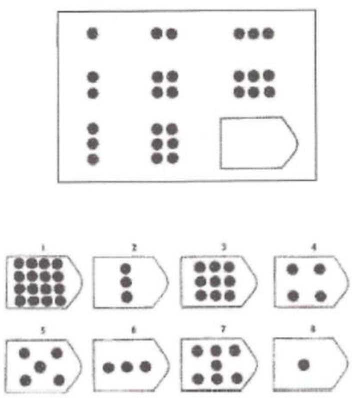

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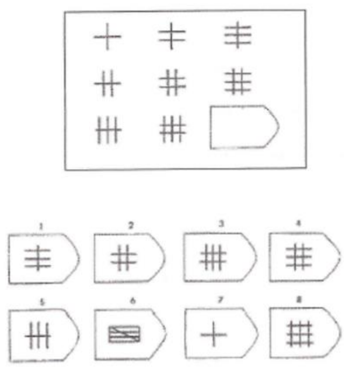

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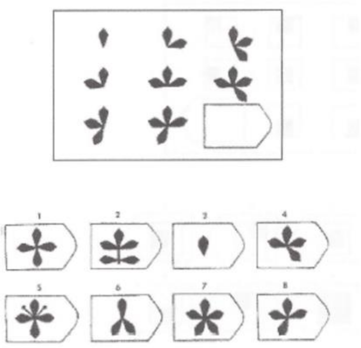

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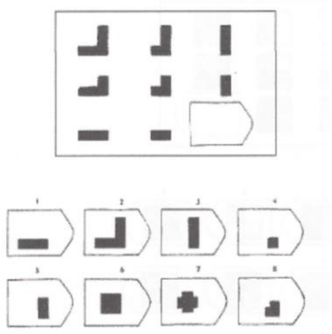

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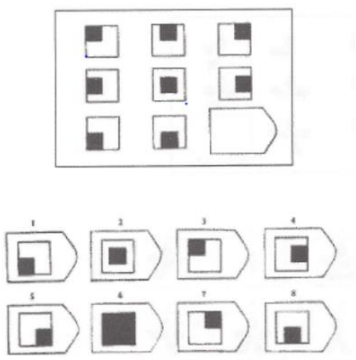

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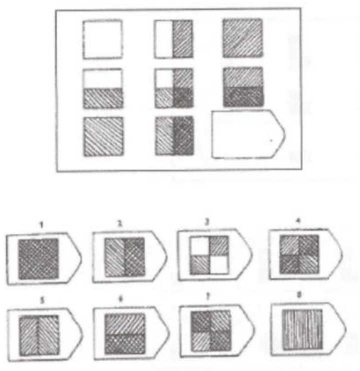

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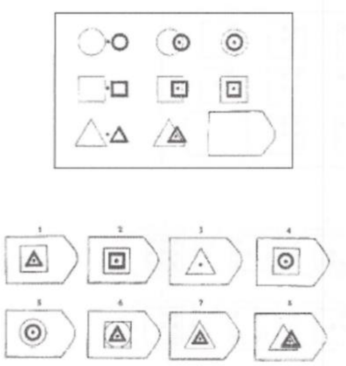

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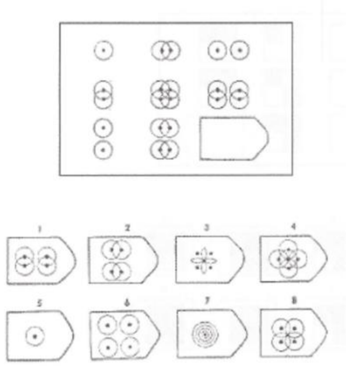

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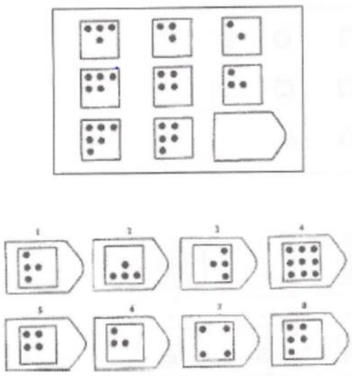

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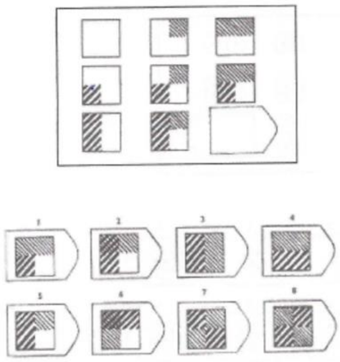

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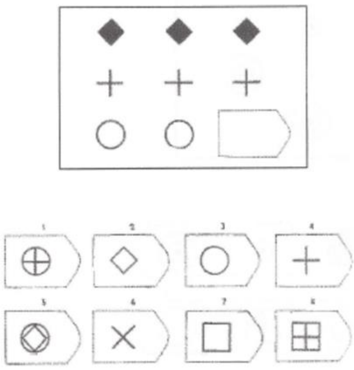

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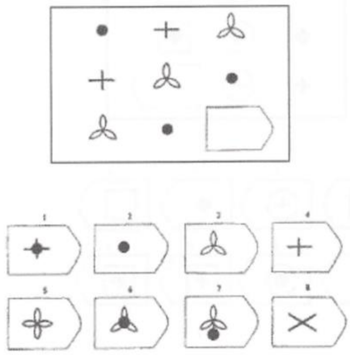

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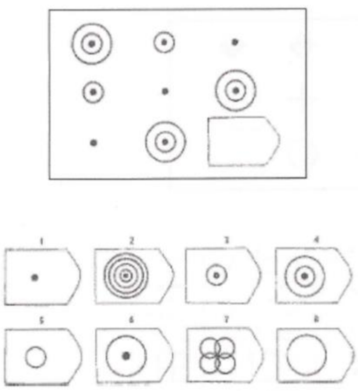

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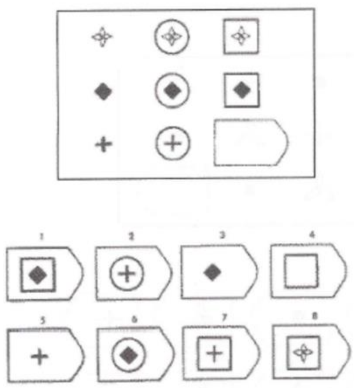

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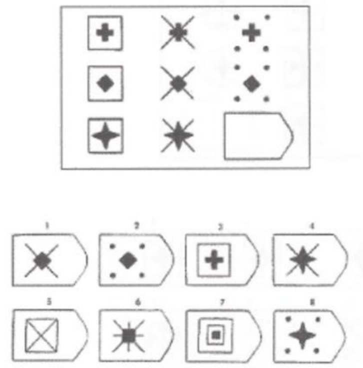

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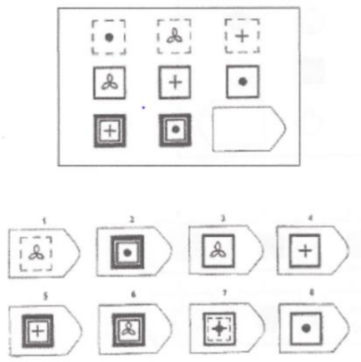

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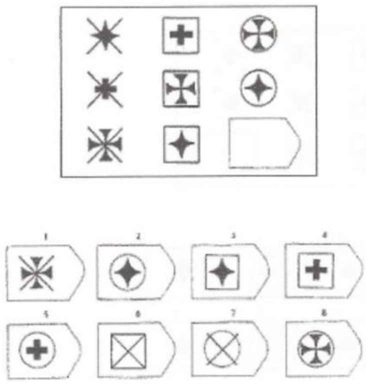

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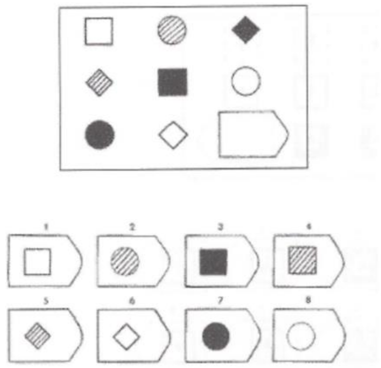

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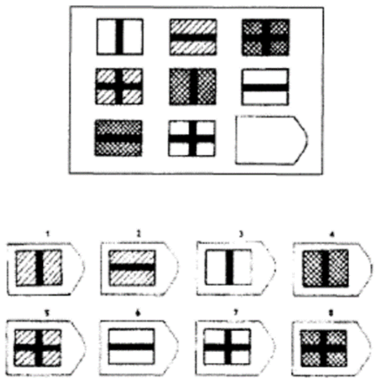

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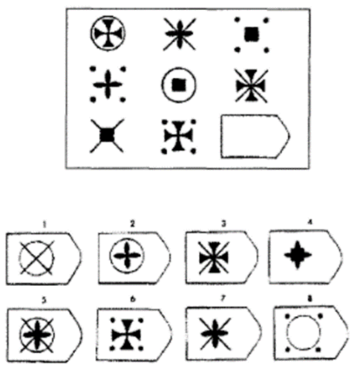

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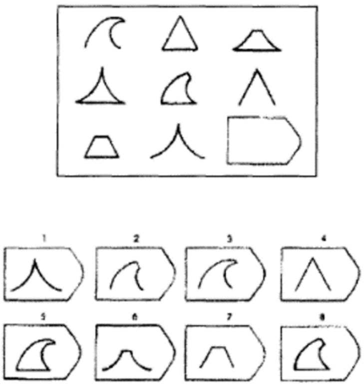

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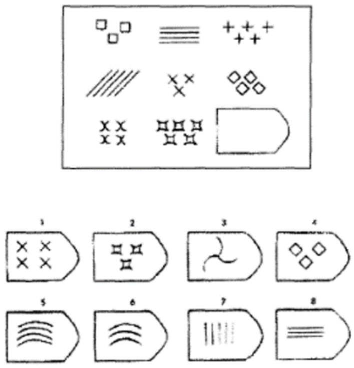

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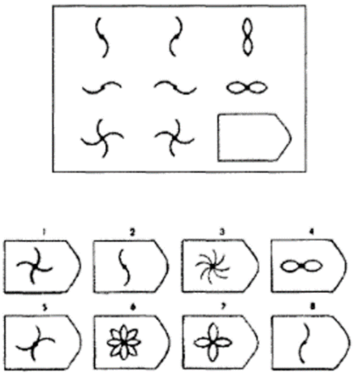

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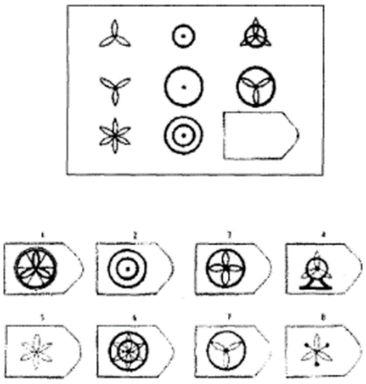

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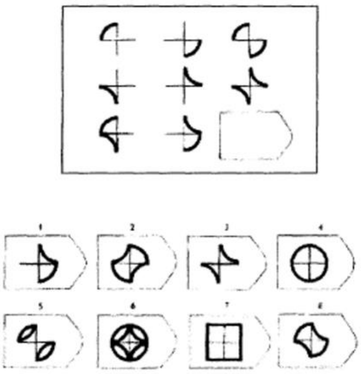

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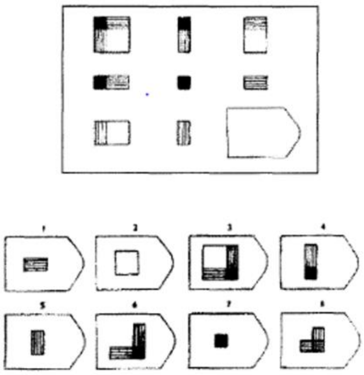

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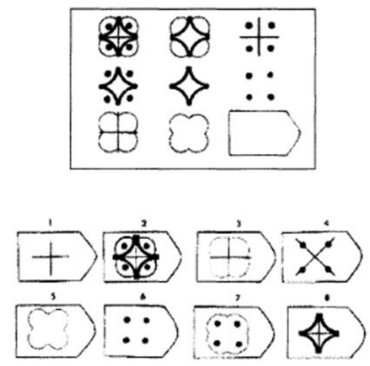

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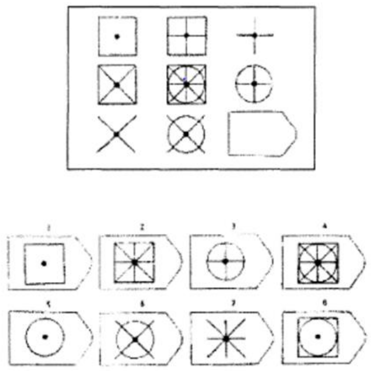

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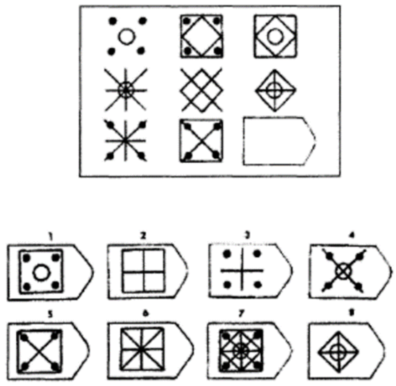

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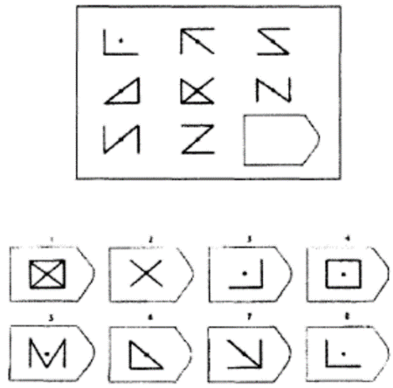

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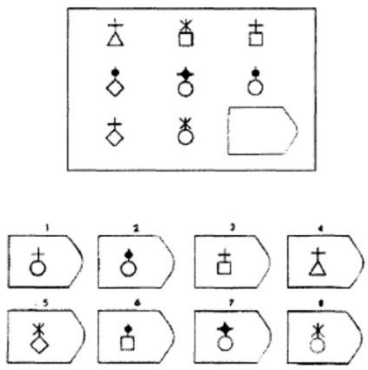

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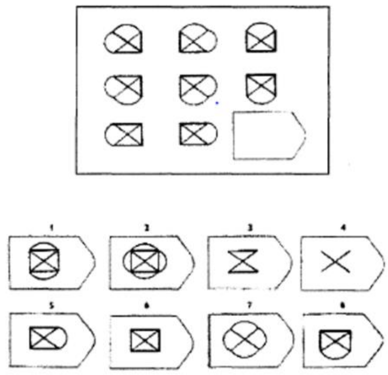

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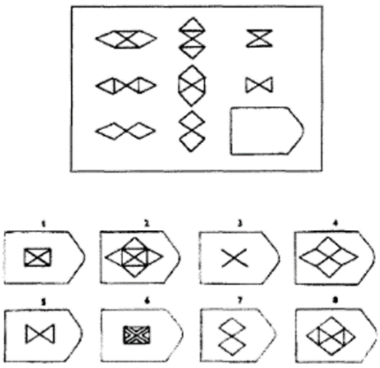

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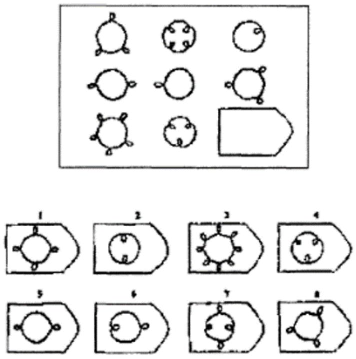


APPENDIX 5 - MOVE IT OR LOSE IT! COPD CLASS 12-WEEK EVALUATION

Please tick to indicate your answer.

	Strongly Disagree	**Disagree**	**Agree**	**Strongly Agree**	**Not sure**
I have enjoyed the exercise classes					
The exercise classes have improved my quality of life					
I am able to be more active now, than before I started the classes					
I feel my COPD has improved since starting the classes					
The classes have given me more control over my COPD					

Which discussion topic did you find most helpful? (tick all that apply)

Topic	☐	**Topic**	☐
Hydration		Mood and mental health	
Nutrition		Flu jab	
Sedentary behaviour		Medication	
Being active/ overcoming barriers		General discussion – week 1	
Alcohol		General discussion – week 12	

Additional comments – Please make any comments about the 12-week programme.

Name……………………………………Date……………………

Email…………………………………………………………

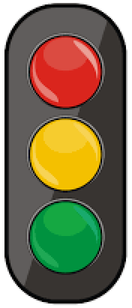
May we use your comments? Yes / No

APPENDIX 6 - TRAFFIC LIGHT METRIC

Date:…………………………………………… Class:……………………………………………………………………….

Ask the class members individually how they feel today based on the traffic lights below.

They can answer; **red**, **yellow/amber**, **green**. Write the corresponding number in the table below. Take an answer before AND after the class for their body and mind.

 1 2 3	**How do you feel in your <u>BODY?</u>** 		**How do you feel in your <u>MIND?</u>** 	
Participant ID Number	Before	After	Before	After

APPENDIX 7 – PUBLICATION

Robinson, J. E. and Kiely, J. (2017). Preventing falls in older adults: Can improving cognitive capacity help? Cogent Psychology, 4(1), doi/abs/10.1080/23311908.2017.1405866

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COGNITIVE SCIENCE & NEUROSCIENCE | NEW PERSPECTIVE

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Cogent Psychology **(2017), 4: 1405866** cogent psychology

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Preventing falls in older adults: Can improving cognitive capacity help?

Joseph E. Robinson[1*] and John Kiely[1]

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Additional information is available at the end of the article

Abstract: **Evidence linking physical health with beneficial cognitive outcomes is well established. However, the potential bi-directional nature of this relationship is far less explored. Falls-related injuries are frequently caused by age-related deterioration of walking gait, and cost the NHS in Britain ~£1 billion per annum. Interventions capable of reducing falls risk are significantly beneficial from both health and economical perspectives. In recent years, evidence has emerged suggesting that the cognitive capacity required for executive function and motor stabilisation share a fundamentally limited pool of neural resources. In tandem, research suggesting that computer-based cognitive training can—via neuro-plastic mechanisms—stimulate executive function enhancements. Subsequently, this suggests the possibility that cognitive training can positively impact motor control functions, such as walking gait. Thereby raising the potential that movement coordination may be enhanced through cognitive training interventions. This novel perspective is just beginning to be explored within the literature, and some intriguing evidence already exists. Accordingly, the objective of this discussion is to review the rationale and evidence underpinning the suggested linkage between cognitive resources and walking gait and to suggest how such interventions could provide novel, impactful and financially efficient practical applications for reducing the fall risk in older adults.**

Subjects: Motor Control and Development; Physical Activity and Health; Motor Skills; Cognitive Science; Cognitive Development

Keywords: cognitive training; cognitive capacity; walking gait; falls

Joseph E.

ABOUT THE AUTHOR

Joseph E. Robinson is a doctoral student at University of Central Lancashire, following completion of BSc (Hons) and MSc degrees on Sport and Exercise Science. He works for a family business promoting healthy and active lifestyles for the over 60s. He works on a day-to-day basis to develop the company and has created eLearning courses for CPD of exercise instructors. His interest in cognitive and physical function of older adults stemmed from his professional work. Hence, he is keen to ensure his research has a practical application to enhance the quality of life of this demographic. He aims to complete his PhD in 2017 and continue to research this area of science.

PUBLIC INTEREST STATEMENT

Physical activity and exercise has been widely accepted as beneficial for both physical and cognitive function. Interestingly, recent research has shown that this link could potentially work reciprocally. Certain cognitive functions, called executive functions have been linked to physical actions such as one's walking gait. This suggests that interventions to improve cognition could also improve associated physical functions. Clearly, this holds significant potential to benefit quality of life for those whose cognitive and physical abilities are in decline, such as older adults. Furthermore, falls-related injuries cost the UK NHS in excess £1 billion per annum hence any intervention able to reduce the risk of falling holds significant economic benefit. This article will investigate this premise further and present evidence to discuss the potential of such interventions.

1. Introduction

It is well known that in order to achieve and maintain physical health, one must partake in regular physical activity. With regard to promoting health and preventing disease in older adults (65 years and over) The American College of Sports Medicine (ACSM) and American Heart Association (AHA) recommends 30 min of moderate-intensity aerobic activity five times a week, or 20 min of vigorous-intensity aerobic activity three times a week, in addition to muscle-strengthening exercises at least twice a week (Nelson et al., 2007). In addition to this a meta-analysis of studies published between 1966 and 2001 revealed a significant positive effect of physical exercise on cognitive function in older adults (Colcombe & Kramer, 2003). Psychosocial benefits of physical exercise have also been reported in the literature (Taylor et al., 2004).

However, whether a bi-directional relationship exists is less clear as the potential consequences of cognitive training on physical function, such as walking, are far less prevalent within the literature. However, there is emerging evidence of a link between executive brain functions and walking gait, which holds potential for a novel approach to enhancing physical function through cognitive training. Accordingly, the aims of this article are to:

(1) Present current knowledge on physical and cognitive exercise and the functional interaction between them.
(2) Review emerging evidence surrounding cognition, cognitive training and walking gait, specifically in olderadults.
(3) Suggest a logical conceptual framework explaining why cognitive training might improve walking gait.

2. Current knowledge: Physical exercise for physical and cognitive function

Adults over 50 years of age represent the most sedentary segment of the adult population, with 88% of over 65s living with at least one chronic health condition (King, Rejeski, & Buchner, 1998). Both low- (40–60% VO_{2max}) and high-intensity aerobic exercise (75% VO_{2max}) have been demonstrated to increase endurance capacity, by 12 and 20–30%, respectively (Lakatta, 1993). Further, studies have demonstrated that aerobic endurance training can lead to reduced body fat, fat mass and waist-to-hip ratios in 60–70-year-old men and women (Kohrt, Obert, & Holloszy, 1992). Moreover, resistance training in older adults has been shown to increase muscle strength and bone density, therefore, potentially reducing falls risk and the subsequent risk of fracture following a fall (Taylor et al., 2004).

As well as improving physical function, physical exercise has also been shown to positively affect cognitive function. This has been demonstrated in both children (Sibley & Etnier, 2003) and adults (Moonen, van Boxtel, de Groot, & Jolles, 2008), as well as across the human lifespan (6–90 years) (Etnier et al., 1997). In a recent study, cognitive function in older adults aged 50 years and over was reported to improve, after aerobic and resistance-based exercise programmes of at least moderate intensity (Northey, Cherbuin, Pumpa, Smee, & Rattray, 2017). Thus, illustrating the importance of physical exercise for the development and maintenance of cognitive function in childhood and adult life. Importantly for older adults, regular participation in physical exercise has been shown to attenuate cognitive decline (Fox, 1999), and has repeatedly been reported to reduce risk of cognitive impairment such as dementia (Barha, Galea, Nagamatsu, Erickson, & Liu-Ambrose, 2017). One potential reason is through aerobic exercise promoting the secretion of brain-derived neurotropic factor (BDNF), a protein that encourages the growth of new neurons termed *neurogenesis* and formation of new synapses termed *synaptogenesis*. Lower concentrations of BDNF are associated with Alzheimer's disease, Parkinson's disease, depression, anorexia and many other diseases (Adlard, Perreau, Pop, & Cotman, 2005). However, not all studies investigating the influence of BDNF on cognition have been positive. It is thought this may be due to the form of BDNF being tested, as the precursor molecule, pro-BDNF is neurotoxic, which is later converted into the neuroprotector, mature BDNF (Barha et al., 2017). Nonetheless, whether BDNF is the primary driver for morphological and structural changes to cognitive function in response to exercise or not, the benefits of physical exercise in the prevention of cognitive morbidities is clear (Taylor et al., 2004).

Strength, or resistance training (RT) seems to promote different responses to aerobic training, resulting in greater increases in levels of insulin-like growth factor 1 (IGF-1) (Kramer, Colcombe, McAuley, Scalf, & Erickson, 2005). Together, IGF-1 and BDNF interact to fulfil a neuro-protective function, preserving neuronal micro-architectures from progressive structural deterioration, thereby facilitating the preservation of higher order cognitive processes (Cassilhas et al., 2007; Kramer et al., 2005). Following aerobic training, such changes are less pronounced, thereby proposing different mechanisms through which aerobic and RT mediate cognitive enhancements (Barha et al., 2017). This, therefore, suggests the importance of both aerobic and resistance training to elucidate the cognitive enhancing effects of physical exercise, as previously reported (Northey et al., 2017). This is one potential explanation for the positive effects of physical exercise on cognitive function, as it stimulates biochemical and neurological processes, and thus influences change to cognitive capacity.

It is also evident that physical exercises promote psychosocial benefits such as reduced levels of depression (Kritz-Silverstein, Barrett-Connor, & Corbeau, 2001), enhanced mood (Arent, Landers, & Etnier, 2000) and reduced feelings of loneliness (McAuley et al., 2000). It is thought that the increased neurotropic factor expression and the increased opportunities for social interaction presented, for example, by attending an exercise class, are potential reasons for these psychosocial benefits (For further review see Duman, 2005; Taylor et al., 2004).

2.1. Current knowledge: Cognitive exercise for cognitive function

Just as the body adapts in response to regular physical stimuli, the brain adapts to regular cognitive stimuli through robust neuroplasticity (Anguera et al., 2013; Fernandez & Goldberg, 2009). Such stimulation can be applied through adequately challenging, structured and focussed cognitive training (Fernandez & Goldberg, 2009; Gates & Valenzuela, 2010). As such, cognitive training demands that the participant attempts to solve novel cognitive challenges, specifically targeted to dimensions of cognitive function such as attention, working memory and processing speed. Thus, it requires the participant to stimulate specific functional brain networks on multiple occasions, promoting neurogenesis and synaptogenesis (Perrey, 2013).

Previous research has illustrated that cognitive training for older adults can drive the maintenance and enhancement of cognitive function (Anguera et al., 2013; Gates & Valenzuela, 2010). A systematic review by Keuider and colleagues (2012) examined 38 studies of computerised cognitive training methods with older adults between 1984 and 2011. The studies were split into three categories: classic cognitive training; to train specific aspects of cognition individually, neuropsychological software; designed to enhance multiple cognitive domains with a variety of tasks, and video games; involving manipulating "on-screen" images to achieve a goal (Kueider et al., 2012). All three types of training provided improvements to cognitive abilities with the authors concluding that computer-based interventions are less labour intensive than paper-and-pencil methods, and being technology savvy is not a requirement in order to benefit (Kueider et al., 2012).

These findings are of importance as cognitive decline is a common feature of ageing, particularly with regard to processing speed, working memory and inductive reasoning (Singer, Verhaeghen, Ghisletta, Lindenberger, & Baltes, 2003). Cognitive training of such functions has been shown to improve self-efficacy, and preserve independence in older adults (Wolinsky et al., 2009). Openness to experience—thinking creatively and enjoying intellectual pursuits—also declines with age, but can be increased following a period of cognitive training (Jackson, Hill, Payne, Roberts, & Stine-Morrow, 2012). Similar to physical exercise, it appears that participating in cognitive training has an indirect benefit of improving psychosocial health in older adults, as well as improving functional cognitive abilities.

3. Emerging evidence: Cognitive training for cognitive and physical function

Motor stabilisation is central to proficient movement execution (Skoyles, 2008). Uniquely within the animal kingdom, human's predominant locomotive gait is bipedal in nature which poses unique stabilisation challenges requiring continuous skeletomuscular adjustments and multi-level neural control to maintain posture and on-going gait stability (Hausdorff, 2007; Skoyles, 2008). These adjustments require cognitive processing and demand uptake of neural resources, (Melzer, Benjuya, & Kaplanski, 2001) using sensory systems to anticipate destabilising perturbations and initiate remediating limb movements in advance of destabilisation occurring (Hausdorff, 2007; Skoyles, 2006). Therefore, it is clear that walking not only requires muscular activation, but also demands higher order neural processing capacity, dependant on the integration of input from cortical and sensory systems to coordinate locomotion (Hausdorff, 2007). As such cerebral cortical processing abilities and balance are closely linked (Skoyles, 2006) in which emerging evidence is beginning to explain and broaden the understanding of how it can be utilised to enhance cognitive and physical function.

3.1. Executive function

Executive function refers to high-order cognitive processes that control, integrate and organise cognitive abilities to enable goal-orientated tasks such as decision-making and problem solving (Fernandez & Goldberg, 2009; Segev-Jacubovski et al., 2011). Recent evidence has suggested a close relationship exists between executive function and walking gait (Ijmker & Lamoth, 2012).

Walking is often thought of as an automatic task in young adults, requiring no cognitive effort (Smith-Ray et al., 2013), whereas in the early and late phases of life it is visibly less automated requiring greater conscious effort. The complex processing essential to anticipatory movement control to maintain a stable gait demands dedication of an inevitably limited reservoir of higher level cortical resources, not fully developed in the young, and in a state of decline in the old (Lacquaniti, Ivanenko, & Zago, 2012). Under normal walking conditions, gait pattern is relatively rhythmical due to the natural bilateral coordination of α-motoneurons, controlled by spinal neuronal networks activating on both sides of the body in synchronisation (Ivanenko, Poppele, & Lacquaniti, 2006; Lacquaniti et al., 2012). When task constraints become unpredictable, and the consequence of error is high—for example, when traversing icy or broken surfaces—additional attentional capacity is required to effectively process sensorimotor information. The autonomous motor programme is, therefore, competing with high-level cortical capacity, or executive functions, to safely navigate the demanding environmental conditions. As individual safety is instinctively paramount, gait stability is prioritised to maintain an upright posture (Schabrun, van den Hoorn, Moorcroft, Greenland, & Hodges, 2014), and so the timing of muscle activation is altered to counteract perturbations and thus gait pattern becomes less rhythmical (Ivanenko et al., 2006; Skoyles, 2008).

Additionally, in persons with cognitive impairments such as, for example, Alzheimer's disease, deterioration of physical abilities such as walking decline in tandem with cognitive capacity (Wittwer, Webster and Menz, 2010). Many community-dwelling activities such as walking through a crowd of people depend on the successful execution of executive functions. Problem solving and decision-making ensure a safe route through the crowd, working memory ensures information can be manipulated in real-time, inhibition allows distractions to be withstood and mental flexibility allows the brain to quickly switch between functions (Fernandez & Goldberg, 2009; Smith-Ray et al., 2013). All this needs to take place along with the execution of motor function to allow the person to walk, regulate gait fluctuations (Decker, Cignetti, & Stergiou, 2013) and reduce the risk of falling through maintaining stability (Mirelman et al., 2012).

3.2. Linking executive function and physical function

In the ageing brain, neural connections begin to deteriorate from 40 years of age (Fernandez & Goldberg, 2009). Authors have demonstrated an age-related decline in executive functions such as working memory (Buckner, 2004) and processing speed (Park, 2000). Multi-tasking performance also declines with age (Anguera et al., 2013), which requires executive functions such as mental flexibility and attention—a specific type of executive function (Segev-Jacubovski et al., 2011). Although age-related cognitive decline is an inevitability, its consequences can be offset through regular stimulation. Research has demonstrated that being cognitively active delays the onset of cognitive morbidities such as mild cognitive impairment, dementia and Alzheimer's disease (Wilson et al., 2010). It is thought the stimulation of different brain regions builds a resilience to decline likely to be due to its promotion of neurogenesis and synaptogenesis (Fernandez & Goldberg, 2009). Moreover, such declines in executive function have been demonstrated to present more than just reductions in cognitive function. For example, older adult fallers perform more poorly in computerised tests of executive function than their non-faller counterparts (Hausdorff et al., 2006). Similarly, older adult fallers with poor working memory overestimate their reach capacity by 16% compared to only 2% in older adult fallers with good working memory (Liu-Ambrose, Ahamed, Graf, Feldman, & Robinovitch, 2008). Further, in persons with dementia a reduction in walking gait velocity has been reported (Ijmker & Lamoth, 2012). Such findings support the aforementioned high-level cortical capacity demands of bipedal gait mastery and motor stabilisation. This capacity naturally declines with age, and is worsened with disease, but if stimulated regularly it can be maintained (Fernandez & Goldberg, 2009), benefiting both cognitive and physical function.

3.3. Dual-tasking

An implication of cognitive deterioration within the older adult population is increased falls risk. One key contributing factor to falls risk appears to be the decline of attention. This impacts on the ability to maintain focus on a stimulus to complete one or more tasks simultaneously (Segev-Jacubovski et al., 2011). This is known as dual-tasking which often occurs in community-dwelling daily living (Muir et al., 2012; Segev-Jacubovski et al., 2011). Should an individual be required to walk and complete a second attention-demanding task, the competition for resources within the cerebello-cerebral circuitry would lead to a deterioration of concurrent performance, posing a risk to safety by increasing the risk of falling (Schabrun et al., 2014; Skoyles, 2008). Furthermore, age-related deteriorations to the brain regions—primarily, but not exclusively, located in the prefrontal cortical areas—facilitating executive function, are reported to influence the risk of falling (Herman, Mirelman, Giladi, Schweiger, & Hausdorff, 2010).

In a novel study, walking while reading and typing text on a mobile phone slowed walking gait, incurred postural changes and caused deviation from walking in a straight line (Schabrun et al., 2014). The cognitive task (reading or typing text) was prioritised over walking, as it is a more complex task, hence the walking gait was affected. The two tasks were unable to be executed simultaneously as they draw upon the same high-order cortical resources, forcing task prioritisation of the more cognitively complex task leading to a deterioration in performance (Segev-Jacubovski et al., 2011). The authors suggest that these changes to walking gait impact on the safety of the individual (Schabrun et al., 2014).

This affect has been further demonstrated in the literature by researchers who have asked participants to walk while performing cognitively stimulating tasks, such as counting backwards from 100 in ones or sevens (Muir et al., 2012). Inevitably this dual-task resulted in reduced gait velocity and increased stride time gait variability, indicating the gait pattern became unstable increasing the likelihood of a fall (Muir et al., 2012). In older adults with mild cognitive impairment or Alzheimer’s disease, there is a much greater reduction to gait velocity than those with normal cognitive function (35% and 39% vs. 15%, respectively), and increases in stride time gait variability exceed the fall-risk threshold (Muir et al., 2012). Such findings highlight the increased risk of falling when cognition is in a state of decline, and completing more than one cognitively stimulating task simultaneously is required.

However, it is important to acknowledge that a deterioration of gait in the aged may be due to physical reasons such as arthritis, joint pain and diminished range of motion, leading to gait and balance disorders which influence gait variability and stride length (Salzman, 2010). The authors do not intend to suggest that changes to executive function will bring about transformations to structures such as joints and musculature. The intention here is to present the emerging evidence of a link between cognitive capacity—in particular executive function—and walking gait and how cognitive training may provide a novel solution to enhancing ones walking competence through potential hierarchical pathways (Figure 1).

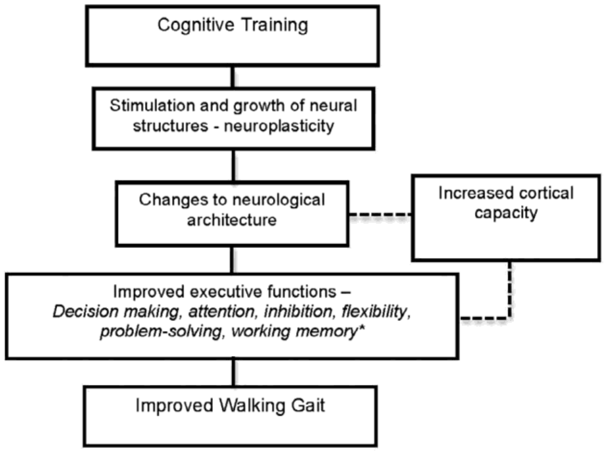

Figure 1. Hierarchical pathway to improve walking gait following a cognitive training programme.

Source: *Fernandez and Goldberg (2009), Segev-Jacubovski et al. (2011).

4. Can executive function be improved?

Despite age-related cognitive decline often proving detrimental to health, studies have demonstrated that older adults can improve cognitive capacity, through specific training. A recent study by Saposnik and colleagues (2011) has shown how virtual reality gaming, which taxed decision-making and processing speed, enhanced motor function in stroke patients. It is thought that the games drive neurological change in the participants' brains, due to neuroplasticity, which leads to improvements in motor function (Saposnik et al., 2011). Essentially, the game works as a form of cognitive training stimulating neurogenesis and synaptogenesis as the brain "remodels" its neural network. In further support of this, playing a custom-designed video game improved the multi-tasking abilities of older adults (65–80 years old) to greater levels than those found in "untrained" 20-year-olds (Anguera et al., 2013). One hour per day, three times a week for one month playing the multi-tasking game enhanced cognitive abilities, which the authors claim is due to the robust plasticity of the ageing brain (Anguera et al., 2013).

Intriguingly, recent research suggests that dimensions of walking performance (specifically gait velocity and balance), can be improved in older adults, consequent to computerised cognitive training programmes (Smith-Ray et al., 2013; Verghese, Mahoney, Ambrose, Wang, & Holtzer, 2010). Ten weeks of computerised visual, spatial memory and decision-making games slowed the decline of walking speed and balance in a cohort of older adults on average 83 years of age (Smith-Ray et al., 2013). The authors attributed the results to the nature of the training, which focused on elements of executive function. Similarly, Verghese and colleagues (2010) reported a statistically significant improvement in walking speed (0.68 ± 0.20 vs. $0.77 \pm 0.18\ ms^{-1}$) in 10 sedentary older adults following an eight-week computerised cognitive training intervention. These findings hold even greater significance when considered alongside the increased likelihood of mortality at walking speeds less than $0.82\ ms^{-1}$ (Stanaway et al., 2011). Furthermore, the Advanced Cognitive Training for Independent and Vital Elderly (ACTIVE) study—the largest cognitive intervention study to date ($N = 2802$)—has demonstrated that training induced improvements to cognitive abilities such as memory, reasoning and processing speed are maintained for 24 months (Ball et al., 2002). Such findings demonstrate the robustness of the ageing brain and highlight the important role cognitive training can play in maintaining cognitive and physical function in the ageing population and it should be applied in a structured and specific manner.

5. Conclusions

Studies have outlined the importance of physical exercise for physical, cognitive and psychosocial function (Colcombe and Kramer, 2003; Duman, 2005; Nelson et al., 2007). Similarly, cognitive training has also been shown to be beneficial to cognitive and psychosocial health (Anguera et al., 2013; Gates & Valenzuela, 2010). These outcomes are advantageous in terms of attenuating age-related declines to biopsychosocial well-being. However, approximately 50% of community-dwelling older adults aged 85 and over will fall each year. Crucially, those with a cognitive impairment are twice as likely to suffer a fall (Iinattiniemi, Jokelainen, & Luukinen, 2009). This not only impacts individuals, but also has huge economical implications with fall-related treatment costing the UK NHS ~£1 billion per annum (Davis et al., 2010).

The uniqueness of human bipedal gait demands high-level cognitive processing to enable motor stabilisation and an erect posture suggesting that cognition and gait mastery share cerebello-cerebral circuitry (Skoyles, 2008). Recent evidence has emerged within the literature suggesting such a link between executive function and walking gait (Ijmker & Lamoth, 2012) and its impact on fall risk. It has, therefore, been suggested that improving executive function would reduce falls risk (Segev-Jacubovski et al., 2011).

One method of doing this is via computerised cognitive training and measuring the impact on characteristics of walking gait, such as stride length, stride time and stride time variability in single and dual-task environments. Studies such as Verghese and colleagues (2010) and Smith-Ray and colleagues (2013), have shown the power of cognitive training to reduce the effects of cognitive decline and how this impacts on walking gait velocity and balance. The neuroplasticity and robustness of the ageing brain to rejuvenate has also been demonstrated (Anguera et al., 2013; Bherer et al., 2005, 2008; Saposnik et al., 2011). Importantly, however, further research is needed to broaden understanding of the relationship between this type of cognitive function and walking gait. Furthermore, the utility of computerised training to augment cognitive capacity may, following the rationale and evidence presented here, prove a novel intervention capable of indirectly reducing falls risk in the ageing population.

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