JYU DISSERTATIONS 14

Taina Poranen-Clark

Relationship between Cognitive Performance and Mobility over the Life Course

UNIVERSITY OF JYVÄSKYLÄ
FACULTY OF SPORT AND
HEALTH SCIENCES

JYU DISSERTATIONS 14

Taina Poranen-Clark

Relationship between Cognitive Performance and Mobility over the Life Course

Esitetään Jyväskylän yliopiston liikuntatieteellisen tiedekunnan suostumuksella
julkisesti tarkastettavaksi yliopiston vanhassa juhlasalissa S212
lokakuun 19. päivänä 2018 kello 12.

Academic dissertation to be publicly discussed, by permission of
the Faculty of Sport and Health Sciences of the University of Jyväskylä,
in building Seminarium, auditorium S212, on October 19, 2018 at 12 o'clock noon.

JYVÄSKYLÄN YLIOPISTO
UNIVERSITY OF JYVÄSKYLÄ

JYVÄSKYLÄ 2018

Editors
Ina Tarkka
Faculty of Sport and Health Sciences, University of Jyväskylä
Päivi Vuorio, Sini Tuikka
Open Science Centre, University of Jyväskylä

Permanent link to this publication: http://urn.fi/URN:ISBN:978-951-39-7536-4

ISBN 978-951-39-7536-4 (PDF)
URN:ISBN:978-951-39-7536-4
ISSN 2489-9003

ABSTRACT

Poranen-Clark, Taina
Relationship between cognitive performance and mobility over the life course.
Jyväskylä: University of Jyväskylä, 2018, 78 p.
(JYU Dissertations
ISSN 2489-9003; 14)
ISBN 978-951-39-7536-4 (PDF)
Finnish Summary
Diss.

We studied cross-sectional, longitudinal and temporal associations between executive function and life-space mobility in old age. We assessed the association between intellectual ability in early adulthood and physical functioning in old age, and the association between early life motor development and cognitive performance in early old age.

The participants of the first dataset were 157 persons aged 76-91 y who were followed up for two years as part of the Life-Space Mobility in Old Age study, and who took part in measurements on executive function (EF) implemented with the Trail Making Test and Life-Space Assessment. The second dataset comprised persons from the Helsinki Birth Cohort Study. Data on cognitive performance in early adulthood, assessed with The Finnish Defence Forces Basic Intellectual Ability Test at age 17-27 y, was available for 360 men. Data on age at first walking, used as a marker of early life motor development, and extracted from child welfare clinic records at age 6-24 months was available for 398 persons. Later life physical functioning was assessed twice at ten y intervals using self-reported Short Form 36 questionnaire, and later life cognitive performance with CogState computerized cognitive test in old age.

People with better EF had higher life-space mobility. This was explained by better lower extremity functioning and absence of transportation difficulties (general linear model). Better EF at baseline predicted higher life-space mobility at the two-year follow-up whereas baseline life-space mobility did not predict EF at follow-up (cross-lagged model). Better intellectual ability in young adulthood predicted better physical functioning at mean age 71.4 (SD 2.2) y through better physical functioning at mean age 60.9 (SD 2.3) y (longitudinal path model). People who had learned to walk at an earlier age performed better in cognitive tests at mean age 64.2 (SD 3.0) y (linear regression model).

Earlier attainment of motor skills and better early life intellectual ability may lead to better cognitive and physical functioning in older ages. Supporting EF may enhance maintenance of higher life-space mobility, an important correlate of good quality of life in old age.

Keywords: Cognitive aging, Executive function, Mobility, Physical functioning, Life-space mobility, Cognitive reserve, Life course

Author's address Taina Poranen-Clark, MSc, M.A.Ed
Gerontology Research Center
Faculty of Sport and Health Sciences
P.O. Box 35 (Viv)
40014 University of Jyväskylä, Finland
taina.poranen-clark@jyu.fi

Supervisors Professor Taina Rantanen, PhD
Gerontology Research Center
University of Jyväskylä
Jyväskylä, Finland

Docent Mikaela von Bonsdorff, PhD
Gerontology Research Center
University of Jyväskylä
Jyväskylä, Finland

Professor Johan Eriksson, MD
University of Helsinki
Folkhälsan Research Center
National Institute for Health and Welfare
Helsinki, Finland

Reviewers Assistant Professor Jenni Kulmala, PhD
Karolinska Institutet
Stockholm, Sverige

Associate Professor Annemarie Koster, PhD
Maastricht University
Maastricht, The Netherlands

Opponent Professor Eija Lönnroos, MD
University of Eastern Finland
Kuopio, Finland

ACKNOWLEDGEMENTS

This study was carried out at the Gerontology Research Center (GEREC) and the Faculty of Sport and Health Sciences, University of Jyväskylä, Finland. I had an opportunity to work in the Life-space Mobility in Old Age (LISPE) project since the beginning of the project first as a technical assistant interviewing the participants at baseline, then later as a project researcher in Hearing, Cognition and Wellbeing section and as a PhD student in Mobility and Active Aging section. I am thankful for this opportunity to work in all phases of LISPE project and learn how to conduct scientific research within multidisciplinary research team with support of talented researchers. I am also thankful for the opportunity to participate in the Helsinki Birth Cohort study group.

My sincere thanks go to my supervisors, Professor Taina Rantanen, Docent Mikaela von Bonsdorff and Professor Johan Eriksson. I thank you all, first of all, for having faith in me as a potential doctoral student. I had a great trust on you, that you would be able to guide me through this project. Taina, I appreciate your scientific knowledge and experience in the field of gerontological research. Mikaela, I greatly appreciate your skillful, and before anything, a patient guidance throughout this project. Johan, I am grateful that I had an opportunity to be a part of the HBCS group. I thank you for your effort and time you put on supervising me. I sincerely thank Professor Tuomo Hänninen, a member of the steering group of my PhD project, for giving your valuable time for meetings in Jyväskylä. Your knowledge in the field of cognition was very valuable for me. I also want to thank Research Director of GEREC Katja Kokko and Dean of the Faculty of Sport and Health Sciences Ari Heinonen for providing facilities to conduct this study at GEREC and in the University of Jyväskylä.

I want to thank the official reviewers of this thesis, Assistant Professor Jenni Kulmala and Associate Professor Annemarie Koster. I appreciate your careful reviewing of my thesis. Your comments helped me to improve the book. I also thank Professor Eija Lönnroos for agreeing to be my opponent in the public defense of this thesis.

I want to thank my co-authors from GEREC. Anne Viljanen, Merja Rantakokko, Erja Portegijs, Johanna Eronen and Katja Pynnönen, you all have been very helpful and always willing to find time to answer any of my questions. It has always been easy to knock on your doors. I also thank all the co-authors Jari Lahti, Minna Salonen, Niko Wasenius, Katri Räikkönen, Clive Osmond, and Eero Kajantie from from HBCS group. You made me feel very welcome to your study group and I sincerely thank for sharing your time and knowledge with me during the writing process of the original publications. I thank my co-authors Timo Törmäkangas and Markku Kauppinen for all the statistical help. This work would have not been done without your expertise. I have enjoyed working with all of you. I also want to thank Michael Freeman for revising the English language of this thesis and Docent Ina Tarkka for scientific editing of the thesis. I am grateful for the financial support I have received for carrying out this thesis. I have received personal grants from The Juho Vainio

Foundation, Helsinki, Finland, and the Yrjö Jahnsson Foundation, Helsinki, Finland. This work has also been supported by Samfundet Folkhälsan, Helsinki, Finland and the Finnish Concordia Fund, Helsinki, Finland.

My very special thanks I want to dedicate to my colleagues in GEREC for providing a supportive and friendly atmosphere at work. Milla Saajanaho and Eeva-Maija Palonen have been closely sharing my life by being ready to give me any help or support I have ever needed during this process. I also want to thank all the other PhD students in GEREC for help and friendship. I especially enjoyed our common experiences in attending conferences.

I want to thank all my family members for all the great support they have been giving me during these years. I want to express my warm gratitude to my parents, my late mother Liisa and father Esko, who have always supported me whatever kind of decisions I have made in my life. Also they have always encouraged me to study and educate myself. I also want to thank my dearest friends, Virpi and Kaisu, outside university who have cast me trust that I am capable to finish this project. You have been good listeners when I have needed encouragement. My dearest thanks go to my beloved husband, Stephen, and our three lovely children, Viivi, Roope and Liisa. You all have given me a great support during this process and you never stopped in believing in me. Thank you for your love and understanding throughout these years.

Jyväskylä 1.8.2018

Taina

FIGURES

TABLES

LIST OF ORIGINAL PUBLICATIONS

The thesis is based on the following, original publications, which will be referred to in the text by their Roman numerals.

I Poranen-Clark, T., von Bonsdorff MB., Rantakokko M., Portegijs E., Eronen J., Kauppinen M., Eriksson JG., Rantanen T., Viljanen A. Executive function and life-space mobility in old age. Aging Clinical and Experimental Research 2018; 30: 145–151.

II Poranen-Clark T., von Bonsdorff MB., Rantakokko M., Portegijs E., Eronen, J., Pynnönen K., Eriksson JG., Viljanen A., Rantanen T. The temporal association between executive function and life-space mobility in old age. The Journals of Gerontology, Series A: Medical Sciences 2018; 73 (6): 835-839.

III Poranen-Clark, T., von Bonsdorff MB., Törmäkangas T., Lahti J., Wasenius N., Räikkönen K., Osmond C., Salonen MK., Rantanen T., Kajantie E., Eriksson JG. Intellectual ability in young adulthood as an antecedent of physical functioning in older age. Age and Ageing 2016; 45 (5): 727-731.

IV Poranen-Clark, T., von Bonsdorff MB., Törmäkangas T., Lahti J., Räikkönen K., Osmond C., Rantanen T., Kajantie E., Eriksson JG. Infant motor development and cognitive performance in early old age: the Helsinki Birth Cohort Study. AGE 2015; 37 (3): 44.

ABBREVIATIONS

ADL	Activities of Daily Living
AL	Associate Learning
ANOVA	One-way Analysis of Variance
AR	Arithmetic Reasoning
BMI	Body Mass Index
CI	Confidence Interval
CRT	Choice Reaction Time
DA	Divided Attention
Delta-TMT	Trail Making Test part-B minus Trail Making Test part-A
DOHaD	Developmental Origins of Health and Disease
EF	Executive Function
GEE	General Estimation Equations
GLM	Generalized Linear Regression Models
HBCS	Helsinki Birth Cohort Study
IA	Intellectual Ability Test
IADL	Instrumental Activities of Daily Living
IQ	Intellectual Quotient
LISPE	Life-Space Mobility in Old Age
LSA	University of Alabama at Birmingham Study of Aging Life-Space Assessment
MCI	Mild Cognitive Impairment
MCR	Motoric Cognitive Risk Syndrome
MMSE	Mini-Mental State Examination
ms	milliseconds
n	number
p	p-value, indicator of statistical significance
PF1	Physical Functioning in 2001-04
PF2	Physical Functioning in 2013
SD	Standard Deviation
SE	Standard Error
SES	Socioeconomic Status
SF-36	Short Form of RAND 36-Item Health Survey
SPPB	Short Physical Performance Battery
SRT	Simple Reaction Time
TMT	Trail Making Test
TMT-A	Part A of the Trail Making Test
TMT-B	Part B of the Trail Making Test
VR	Verbal Reasoning
VSR	Visuospatial Reasoning
WHO	World Health Organization
WLSMV	Weighted Least Square Estimator
WM	Working Memory
y	years

CONTENTS

1 INTRODUCTION

Learning to walk is one of the most remarkable developmental milestones in a child's life. Motor development in infancy is a continuous process through which a child achieves new movement patterns and learns new motor skills (WHO 2006, Gallahue, Ozmun & Goodway 2012). As one moves from infancy to adulthood and acquires greater physical and cognitive resources, the environment in which mobility takes place expands (Webber, Porter & Menec 2010). Learning to walk in infancy is a critical milestone in both motor development and central nervous system maturation (Diamond 2000, Ferrucci et al. 2016).

Mobility, i.e. the ability to go where, when and how one wants to go, is a key component of independence and active participation in old age (Satariano et al. 2012). Broadly, the concept of mobility is defined as the ability to move oneself within one's own environment (Webber, Porter & Menec 2010) and includes all purposeful bodily movements, such as changing and maintaining body positions, carrying or moving objects, and walking and moving through one's environment, including the use of transportation (McDonough et al. 2018). Life-space mobility, a measure of community mobility, reflects the actual movement taking place in a person's daily life environment (Peel et al. 2005) including frequency of mobility as well as the ability and independence for mobility (Baker, Bodner & Allman 2003, Barnes et al. 2007).

The Developmental Origins of Health and Disease (DOHaD) hypothesizes that poor early life environment induces changes in development which have long-term effects on later life health and disease risk (Barker 1998). A life course approach to aging studies links physical and social exposures during gestation, childhood, adolescence, and adult life to changes in health and risk for diseases in later life (Kuh et al. 2014). A life course approach to mobility proposes that development and growth earlier during the lifespan affects physical functioning in later life (Kuh et al. 2002, von Bonsdorff et al. 2011). Early life physiologic characteristics, aging, and intervening health conditions all have cumulative and interactive effects over a long period that shape the trajectories of mobility loss associated with aging (Ferrucci et al. 2016).

Mobility requires both cognitive processing and physiological functioning (Wood et al. 2005). Moving outside and travelling further away from home entail higher environmental complexity, which in turn imposes higher physiological and cognitive requirements on older people (Schooler 1984). As people age, decline in cognitive and physical functioning is inevitable, although heterogeneous (Wilson et al. 2002). Loss of mobility in older adults results from multiple impairments in the central nervous system, muscles, joints, and energetic and sensory physiological systems. It occurs when burden of impairments starts to challenge normal daily life, and the ability to compensate for their effects becomes increasingly limited (Ferrucci et al. 2016).

Both cognitive and physical functioning are predictors of health, independence and mortality in later life (Rosano et al. 2008). The co-occurrence of declines in cognitive and physical functioning has been established among older people (Demnitz et al. 2016). Longitudinal studies have shown bidirectional associations between cognitive and physical functioning, as well as concurrent declines in cognitive performance and mobility measures (Clouston et al. 2013). Data on the temporal relationship between cognitive decline and mobility limitations among older adults are inconsistent (Atkinson et al. 2009, Mielke et al. 2013, Stijntjes et al. 2016).

Motor and cognitive disorders may share the same pathologic background (Tabbarah, Crimmins & Seeman 2002). The same prefrontal areas of the brain support executive functions i.e. the cognitive abilities that control and guide goal-directed performance (Banich 2009), and are ultimately involved in all goal-directed motor performances (Rosano et al. 2005). Furthermore, these prefrontal areas of the brain have been shown to be the most vulnerable areas of the brain in the aging process (Kramer et al. 1999, Ren et al. 2013). In the life course approach to cognitive ageing, cognitive reserve, which indicates that certain aspects of brain structure, such as brain size, neural density and synaptic connectivity, and brain function, such as efficiency of the neural network, can buffer against the effects of cognitive ageing (Richards & Deary 2005). Better early life cognitive ability is a key ingredient of cognitive reserve and can protect against the cognitive decline (Wilson et al. 2002) that accompanies declines in functional status in later life (Auyeung et al. 2008).

The present study investigated the association between cognitive performance and mobility in old age. We were also interested in the temporal association between these two factors. Additionally, we studied this association accross the life course from infancy and early adulthood into old age. Applying a life course approach can help to reveal new and valuable knowledge about early developmental factors affecting mobility in old age. Identifying the direction of the association between cognitive performance and mobility along with the potential early life factors that affect functioning in old age, enables more effective targeting of preventive interventions during the life course. Maintaining mobility enables independence as well as participation in meaningful activities and is a prerequisite of active ageing.

2 REVIEW OF THE LITERATURE

2.1 Mobility

Mobility, defined as the ability to move freely and safely in one's own environment in any way one wants, is fundamental for maintaining independence in old age (Webber, Porter & Menec 2010, Satariano et al. 2012). The concept of mobility comprises all dimensions of movement ability and all forms of physical activity. The International Classification of Functioning, Disability, and Health (World Health Organization 2001) presents three different levels of mobility, viz. bodily functions and structures, activities performed and participation. Adequate levels of physiological and psychological functioning are prerequisites for independent mobility (Wood et al. 2005), while assistive devices and vehicles also allow mobility for those with physiological or cognitive decline. Maintaining mobility is important for older people, as it enables them to continue active participation in society for as long as possible (Webber, Porter & Menec 2010, Rantanen 2013).

2.1.1 Early motor development

Motor development is a dynamic process through which a child learns new movement patterns and skills (Malina 2004). The process of continuous motor development involves the interaction of neuromuscular maturation, physical growth, behavioral development, and movement experiences (Malina 2004). Environmental experiences are also important in a child's motor developmental process (Malina 2004). Learning new motor skills opens up an infant's world during the first year of life, when the infant transitions from being unable to move independently to being able to move around and explore the environment (Thelen 1995). Learning to walk independently during the first years of life is thus a major motor development skill (Malina 2004).

Motor development in infancy and early childhood is associated with rapid growth of the brain and central nervous system (Diamond 2000, Malina 2004).

The ability to walk marks a critical milestone in both motor development and central nervous system maturation (Diamond 2000, Ferrucci et al. 2016). The maturation of the central nervous system in infancy and childhood enables children to gradually acquire new movement patterns (Malina 2004). The ability to walk allows a child to move more rapidly in the environment, and thus contributes to exploratory behavior (Thelen 2000). Along with brain development exploration and selection are fundamental processes that play key roles in the acquisition of motor skills in infancy (Thelen 1995). The complexity of learning new motor skills requires, among other things, problem-solving skills (Thelen 2000). As one moves from infancy to adulthood and gains greater physical and cognitive resources, the environment in which mobility takes place expands (Webber, Porter & Menec 2010). The sequential attainment of new motor milestones that help a child to explore the world more completely is like opening a series of new windows of opportunity (Thelen 2000).

2.1.2 Mobility decline in old age

Mobility performance peaks with the maturation of motor development in adolescence during the second decade of life and starts to decline around the ages of 60-70 years. This decline shows considerable variation between individuals (Ferrucci et al. 2016). The progression of mobility decline can be explained by the model of the disablement process originally proposed by Nagi (1976) and subsequently further developed by Verbrugge and Jette (1994). In the model, the pathway of the disablement process proceeds from pathology, i.e., physiological abnormalities resulting in impairments. These impairments, in turn, lead to functional limitations, and finally to disability.

Muscle strength, balance, cardio-respiratory health, the senses, and the central nervous system are all involved in voluntary controlled mobility such as walking. Walking is one of the most popular forms of physical activity among older people (Mäkilä, Hirvensalo & Parkatti 2010). Walking ability is often a prerequisite for the ability to use other forms of transportation (Rantanen 2013). Among people aged over 75 years, more than one-third of men and almost half of women reported difficulties in walking 500 meters (Sainio et al. 2012).

The first signs of mobility loss can be seen in the more complex mobility tasks, which might require higher order physical or cognitive processing (Shumway-Cook et al. 2007). The farther away one moves from one's home, the more complex are the factors that impact on mobility (Webber, Porter & Menec 2010). Greater concentration is needed for decision making when orienting in more diverse surroundings; the more complex the environment, the greater cognitive investment required (Schooler 1984).

2.1.3 Measuring mobility in older adults

Self-reported measures of mobility among older adults can be assessed using questionnaires or interviews. In cases where participants themselves are unable to provide answers to questions on their mobility, this information may be provided by relevant proxies. The various dimensions of mobility that may be included in self-reports are ability, difficulty, frequency, duration, intensity or need for help (McDonough et al. 2018). Self-reported measures of mobility provide information on a person's actual mobility in their own environment, and hence are sensitive to functional changes (Latham et al. 2008). The advantage of self-reported measures is that they can cover a wide variety of mobility activities in both the activity and participation domains of mobility, including transportation. These easy-to-use measures also often have high ecological validity (McDonough et al. 2018).

Performance-based measures, which are implemented under controlled circumstances, provide more standardized measures of mobility (Latham et al. 2008). Gait, balance and lower extremity strength are important domains for safe mobility in older adults, and are therefore often assessed as "building blocks" of functioning (Guralnik & Ferrucci 2003). A wide variety of physical functioning measures has been developed to assess either single or multiple aspects of functioning. Lower extremity functioning is commonly assessed with gait speed (Reuben et al. 2013) and chair rise tests (Guralnik & Ferrucci 2003). Balance measurements are also a means of evaluating neurological systems (Guralnik & Ferrucci 2003). Some of the measures often used in aging studies, such as the Short Physical Performance Battery (Guralnik et al. 1994), Timed Up and Go test (Podsiadlo & Richardson 1991) and Stair Climb test (Oh-Park, Wang & Verghese 2011) were developed to assess performance in a wide range of tasks that affect functioning. Many performance-based tests are timed and therefore described what an individual is able to do in a given time rather than what they can actually do in their daily lives (Guralnik & Ferrucci 2003). The disadvantages of administrating performance-based measures are that in-person testing is rather time-consuming and the range of mobility activities that can be investigated is limited (McDonough et al. 2018).

Instrumented measures of mobility provide direct measures of real time movement in daily life in the natural environment (McDonough et al. 2018). Pedometers and accelerometers are instruments commonly used to measure mobility among community-dwelling older adults. These easy-to-use instruments record acceleration and provide information about bouts of activity in terms of duration, frequency and intensity, periods of inactivity, and various other parameters describing gait (McDonough et al. 2018). The disadvantage of using accelerometers in research is the high cost of both the equipment and data management (Tudor-Locke & Myers 2001). Pedometers are cheaper than accelerometers but have been criticized for lack of accuracy and reliability. Although instrumented measures provide ecological validity and standardized data, they may have limitations when studying older people (Tudor-Locke & Myers 2001).

For, example, they may lack accuracy in detecting movement in older adults whose movements are very slow or who are using assistive devices (Pruitt et al. 2008, Davis et al. 2011). However, increasing interest is being shown in the use of instrumented measures in aging research (Jarchi et al. 2018).

2.1.4 Life-space mobility

The concept of life-space mobility was originally defined by May, Nayak, and Isaac (1985) as the area in which an individual travels over a certain time period. The purpose of the first life-space measures was to assess a person's movements either at home and in the near-home environment (May, Nayak & Isaacs 1985) or in institutional settings (Tinetti & Ginter 1990). A Life-Space Questionnaire was developed by Stalvey et al. (1999) to cover a broader range of environmental regions to measure the spatial extent of mobility, starting from within the home and extending to areas at an increasing distance from the home and thus characterize mobility for community-dwelling older adults who may travel more frequently beyond the immediate home environment (Stalvey et al. 1999). The University of Alabama at Birmingham Study of Aging Life-Space Assessment (LSA) used in the present study measures community mobility based on the distance through which a person moved during the four weeks preceding the assessment (Baker, Bodner & Allman 2003, Peel et al. 2005). The LSA incorporates not only the distance moved but also the frequency of movement i.e., how often a person goes to specific areas, and whether assistance is needed for those purposes (Peel et al. 2005, Allman, Sawyer & Roseman 2006).

Life-space mobility refers to a person's activity as well as capability to meaningfully move within the home environment and beyond it (Parker, Baker & Allman 2002). The life-space mobility assessment measures both the quantity and independence of mobility. It therefore reflects a person's social integration and participation in the surrounding community (Barnes et al. 2007). Life-space mobility declines with older age (Sawyer & Allman 2010, Rantakokko et al. 2015). Cognitive, psychosocial, physical, environmental and financial factors all affect mobility restriction (Rudman et al. 2006). Restricted life-space mobility is associated with older age, female sex, overweight, depressive symptoms, lower cognitive level (Sartori et al. 2012), poorer physical performance (Portegijs et al. 2014b), perceived walking difficulties (Rantakokko et al. 2017) and disability in activities of daily living (Snih et al. 2012, Curcio et al. 2013). People with a restricted life-space mobility are also less physically active (Tsai et al. 2015). Further, over the two-year follow-up both baseline perceived walking difficulties (Rantakokko et al. 2017) and less time spent in moderate physical activity (Tsai et al. 2015) predicted changes in life-space mobility. Restricted life-space mobility predicts cognitive decline (Crowe et al. 2008, Silberschmidt et al. 2017), Alzheimer's disease (James et al. 2011), frailty (Xue et al. 2007), ADL disability (Portegijs et al. 2016), institutionalization (Sheppard et al. 2013), and mortality (Xue et al. 2007). In previous studies, higher life-space mobility has been found to be associated with better quality of life among older community-dwelling people (Baker, Bodner & Allman 2003, Rantakokko, Mänty & Rantanen 2013).

2.2 Cognitive performance

Cognitive performance refers to the ability to utilize knowledge acquired by mental processes in the brain. Cognitive performance relies on a wide range of cognitive domains such as memory, attention, problem solving, and processing speed (Brewster et al. 2018). Control processes, which are involved in intentional processing and adaptive cognitive performance, increase in power, speed and complexity from infancy to early adulthood, thereafter starting to decline from the twenties to old age (Craik & Bialystok 2006). Cognitive performance depends on the standard of the task and the abilities of the person who is performing the task (Jenkins 1979). Adequate cognitive performance is necessary for independent functioning in old age. Executive function (EF) is a cognitive ability that is involved in any goal-directed actions (Kramer et al. 1999). Holding information in one's mind, resisting distraction, and inhibiting one's actions are examples of cognitive functions supervised by EF and needed for everyday tasks that are also important for skilled motor performance (Diamond 2000).

2.2.1 Decline in cognitive performance in old age

Cognitive abilities develop rapidly from infancy to young adulthood along with brain maturation and thereafter are either relatively stable or start to decline with older age (Craik & Bialystok 2006). On average, cognitive performance declines with older age; however, the rate of decline varies greatly between individuals (Wilson et al. 2002, Singh-Manoux et al. 2012). Fluid cognition, i.e. cognitive processes such as working memory and processing speed, tend to show age-related decline over the adult life course. So-called crystallized cognitive abilities like vocabulary and semantic knowledge remain stable until late in life. Long-term memory is one of the cognitive processes that show life-long stability across the life course (Park et al. 2002).

Some changes in neural structure and functioning have been detected in normal ageing. For example, a reduction in grey matter due to lower synaptic densities takes place in older adults. Aging also affects white matter density and the number of white matter lesions in the brain (Guttmann et al. 1998). White matter abnormalities are related to poor performance in tasks that require higher processing speed and executive function (Hedden & Gabrieli 2004). Cognitive decline related to normal aging does not necessarily effect everyday life, if so, that might be an early sign of cognitive diseases (Di Carlo et al. 2016).

Slowing with age is an inevitable age-related behavioral phenomenon (Salthouse 2009). The processing speed theory of cognitive aging posits that reduction in the speed with which cognitive operations are executed leads to cognitive impairments. This is reflected in a slowing of the speed at which activities are performed (Salthouse 1996). According to the theory, this slowing in cognitive performances can be explained by two distinct mechanisms: the limited time mechanism and the simultaneity mechanism. The limited time mechanism is based on the idea that the time to perform later cognitive processes in the brain is restricted because a proportion of the time available is already occupied by the execution of earlier operations. The simultaneity mechanism, in turn, is based on the idea that the products of early processing are no longer present in the mind when needed for the later processing (Salthouse 1996).

The prefrontal cortex function theory of cognitive aging indicates that cognitive abilities supported by the prefrontal areas of brain shows signs of age-related decline earlier than cognitive abilities supported by other areas of the brain (Moscovitch & Winocur 1995, West 1996). The pre-frontal cortex regions of the brain undergo the largest age-related volumetric changes in adulthood. It has been estimated that on an average a 5% linear decline in volume per decade occurs after the age of 20 years (Raz et al. 2004). Thus, the cognitive processes supported by the prefrontal cortex are the first to decline with increasing age. The prefrontal cortex of the brain plays an important role in cognitive control in planning, making decisions, problem-solving, and executing voluntary behavior (Craik & Bialystok 2006). These areas of the brain are the last to mature in early adulthood and the first to decline in old age (Craik & Bialystok 2006).

Late-life cognition is determined by many factors operating across the life course. Brain development, childhood socioeconomic status, educational attainment, physical development, lifestyle and disease-related factors are all important factors affecting later life cognition (Richards & Deary 2005). Life-time cognitive engagement, environmental complexity, including occupational and leisure activity may protect from age-related cognitive decline (Schooler 1984). Higher socioeconomic status (Kramer et al. 2004), higher education, occupational complexity (Salthouse 2006) and cognitively stimulating leisure time activities (Salthouse, Berish & Miles 2002) are linked with maintaining higher cognitive functioning in older age. Many studies have shown the benefits of physical activity (Yaffe et al. 2001, Lytle et al. 2004, Van Gelder et al. 2004 Weuve et al. 2004) social engagement (Bassuk, Glass & Berkman 1999, Holtzman et al. 2004), and nutrition (Morris et al. 2006) on cognitive function. The Nun Study (Snowdon et al. 1996) was the first longitudinal study to address many early life factors that potentially affect cognitive aging. Diaries of nuns entering a convent were analyzed, and those whose diary texts showed higher linguistic complexity, and who had engaged in more cognitively stimulating roles in the convent, were less likely to experience dementia as confirmed by autopsy, in later years (Snowdon et al. 1996). Cognitively more stimulating early life experiences may protect against cognitive decline in later life.

Cross-sectional studies do not establish causal relationships. Moreover, they may also be influenced by cohort effects: because generations vary, true age-related changes in cognitive functioning may not be detected. Among older adults, longitudinal studies are more useful for detecting changes and temporal relationships between the different factors affecting cognitive functioning. Participant attrition can bias research results, as better functioning individuals tend to be those who complete the study measurements. Large samples with complex research designs controlling for multiple factors are needed to identify changes in cognition in old age (Williams & Kemper 2010). Clinical intervention trials designed to promote cognitive performance are increasing. Cognitive training interventions have shown improvements in cognitive tasks (Kramer et al. 2004, Schaie, Willis & Caskie 2004) and also benefits in functional capability (Willis et al. 2006). Physical activity interventions have reported beneficial effects on executive functioning (Colcombe & Kramer 2003).

Risk for severe dementia increases with age. The most common form of dementia is Alzheimer's disease. Other causes of dementia are vascular dementia, frontotemporal dementia and Lewy body dementia. Parkinson's disease and Creuzfeld-Jacob disease also affect cognition and can cause dementia. All these are caused by pathological changes in the brain. Mild cognitive impairment (MCI) represents a transitional state between normal cognitive aging and dementia, in most cases Alzheimer's disease (Petersen 1995, Petersen et al. 1999). Two types of MCI have been identified. Amnestic MCI is characterized by memory deficits that are greater than would be expected with regard to age and education, while functional activity remains intact. Nonamnestic MCI, in turn, affects attention, use of language, and visuospatial skills, and results in problems with processing speed and executive function (Petersen et al. 2014). Older adults with nonamnestic MCI have also been found to have impairments in lower extremity performance (Petersen 2011).

2.2.2 Assessing cognitive performance in older adults

Memory deficits form one of the most common types of complaint among older adults (Jonker, Geerlings & Schmand 2000). Cognitive performance in older adults is most commonly assessed for possible subsequent clinical screening to detect cognitive impairments. A wide variety of standard measures are available for the clinical diagnosis of cognitive impairment. The most widely used of these screening tests are the standard neuropsychological test batteries such as the Mini Mental State Examination (MMSE) (Folstein, Folstein & McHugh 1975) and The Consortium to Establish a Registry for Alzheimer's Disease (CERAD) (Morris et al. 1989), both of which evaluate global cognition, including separate measurements for different domains of cognitive functioning.

A wide range of cognitive tests have been developed and validated for assessing cognitive performance in aging research. Selection of the optimal tests for a study depends on the cognitive domain and population of interest. Tests of vocabulary, general and word knowledge or understanding proverbs have been used to assess crystallized cognitive performance, which remains relatively stable across the life course (Anstey & Low 2014). Since mobility relies more strongly on the fluid aspect of cognition than crystalized knowledge, the measurements commonly used in mobility studies to assess cognitive performance in older adults are measurements of fluid cognition (Clouston et al. 2013, Demnitz et al. 2016). Measures of fluid cognition involve novel problem solving, processing speed, perceptual organization, visuospatial manipulation, and attention. Tests of fluid cognitive performance usually require the use of short-term memory (Anstey & Low 2004).

Older individuals' cognitive performance is not determined by pathology alone, i.e., brain-related diseases, but also by the brain's ability to compensate for age-related changes in the brain through cognitive reserve. Older adults show wide inter-individual differences on their scores in cognitive performance tests. Some of these differences are due to cohort or generations. Older adults also vary widely in educational background, health status, literacy, functional abilities, and life experiences, all of which affect their cognitive performance and contribute to the considerable inter-individual variability found in it. Therefore, especially in clinical screening, the individual's so called premorbid level of cognitive functions should be determined before drawing any conclusions about the test results (Anstey & Low 2004).

Additionally, factors such as fatigue, acute illnesses, medication use, problems in concentration or distractions may have a huge impact on performance in tests and should be taken into consideration, especially when assessing older adults. Face-to face interviewing, instrumented and computer-based administration methods have been used in studies to measure cognitive performance in older adults. Computer-based tests may present some challenges as older people tend to be less experienced in using computers. On the other hand, computer-based assessment produces good quality data (Collie & Maruff 2003).

2.2.3 Executive function

Executive function (EF) refers to the cognitive processes that are engaged in deliberate, goal-directed thought and action (Zelazo, Craik & Booth 2004, Best & Miller 2010) and especially needed in non-routine situations (Banich 2009). Self-regulation, planning, problem solving, task switching and flexible thinking are examples of skills needed for EF (Rose, Feldman & Jankowski 2012). Cognitive processes such as selective attention, inhibition, working memory and shifting are also involved in executive function (Kramer et al. 1999, Colcombe & Kramer 2003, Hillman, Erickson & Kramer 2008).

The development of EF shows improvements during childhood into adolescence and declines after reaching its peak some time in young adulthood (Zelazo & Müller 2002). Cognitive domains needed for EF include processing speed, visual attention and working memory and are supported by the prefrontal and frontal areas of the brain (Gilbert & Burgess 2008). The goal maintenance account, the theoretical framework developed for understanding age-related changes in executive control, posits that age-related cognitive changes in EF are based on impairments in the ability to internally represent, update or maintain task-related goals (Braver & West 2008).

EF may serve as a mediator in age-related cognitive decline (Salthouse, Atkinson & Berish 2003). Because it comprises a wide range of cognitive processes, no single test exists for measuring EF (Banich 2009, Etnier & Chang 2009). Cognitive tests assessing the function of working memory, selective attention, updating, task-shifting, inhibition and processing speed have all been used to measure EF (Etnier & Chang 2009). The Wisconsin Card Sorting (Delis, Kaplan & Kramer 2001), Stroop task (Stroop 1935), and Trail Making Test (Reitan &

Wolfson 1993) are examples of classic and most frequently reported measures of EF (Etnier & Chang 2009).

2.3 Relationship between cognitive performance and mobility in old age

Scientific interest in the relationship between cognition and physical function among older adults began to be shown a few decades ago. For example, the beneficial effects of physical activity on cognitive performance had been recognized in aging studies already in the 1990s (Chodzko-Zajko et al. 1992, Christensen & Mackinnon 1993, Chodzko-Zajko & Moore 1994). This was further confirmed by a three-year physical exersice intervention study conducted among elderly women (aged 57-85 years) in which exercise program improved both prossessing speed and motor performance (balance, shoulder flexibility and grip strength) (Rikli & Edwards 1991). Later, at the end of 1990s researchers began to show interest in the effects of cognitive decline on functional capability (Greiner, Snowdon & Schmitt 1996, Carlson et al. 1999). Currently, a large body of research supports the view that an association exists between cognitive decline and impairment in peformance of activities of daily living (Wang et al. 2002, Cahn-Weiner et al. 2007). The impact on elderly people's everyday functioning of physical activity (Van Der Bij, Akke K, Laurant & Wensing 2002), cognitive training (Jobe et al. 2001, Ball et al. 2002) and combined physical and cognitive training (Kelly et al. 2014) interventions has also been a focus of research.

Since the more systematic research on these topics conducted during the 21th century, strong evidence of a positive relationship between various specific cognitive domains and different mobility indicators has been adduced. It is clear that successful performance of motor tasks requires cognitive processing as well as motor skills (Rosano et al. 2005, Tabbarah, Crimmins & Seeman 2002). The results of studies have also suggested that cogntive domains, such as executive function (Iersel et al. 2008, McGough et al. 2011, Gale et al. 2014), attention (Inzitari, Baldereschi et al. 2007, Liu-Ambrose et al. 2010, Killane et al. 2014), verbal fluency and psychomotor speed (Soumaré et al. 2009, Welmer et al. 2014) are related to walking speed. Decline in gait performance is common among aging persons and there is evidence to slow gait predicts cognitive decline (Inzitari et al. 2007) and Alzheimer's disease (Verghese et al. 2002).

Thus far, cross-sectional studies have yielded strong evidence of a positive relationship between cognition and mobility (Demnitz et al. 2016). However, the nature and degree of the interrelationship between these domains remain unclear, and thus have been of great interest to researchers. Several longitudinal studies that have sought to determine direction of changes have reported bidirectional associations between cognitive performance and mobility (Clouston et al. 2013). Some other studies have shown that poor cognitive performance predicts mobility decline (Soumaré et al. 2009, Atkinson et al. 2010, Best, Davis & Liu-Ambrose 2015, Beauchet et al. 2016) while yet others have shown that poor physical functioning predicts cognitive decline (Alfaro-Acha et al. 2007, Taniguchi et al. 2012, Kueper et al. 2017). Further, decline in cognitive performance and mobility have been shown to co-occur (Callisaya et al. 2015, Bishop et al. 2016, Demnitz et al. 2017).

However, only a few studies have assessed the temporal relationship between mobility decline and cognitive decline in the same study population, and their results have been conflicting (Stijntjes et al. 2016). A population-based study among 70- to 89-year-old individuals found that faster gait speed was associated with lower decline in EF, visuospatial skills and global cognition, but found no association between baseline cognition and changes in gait speed (Mielke et al. 2013). Another study indicated a decline in gait speed as a precursor of decline in cognitive function but not the other way around (Best et al. 2016). On the other hand, one study using gait speed, chair stand and grip strength as physical functioning measures found that global cognition was the domain that most consistently preceded physical performance decline among older women (Atkinson et al. 2009). Further, a study of 55- to 90 -year-olds found that the temporal relationship between cognitive and physical performance differed across domains and age, although poor EF was found to be associated with a steeper decline in gait speed across all the age groups (Stijntjes et al. 2016). There is also evidence that these associations might be bidirectional (Watson et al. 2010, Gale et al. 2014, Tian et al. 2017).

Older people have difficulties in coordination (Seidler et al. 2002) and their movements are slower (Demnitz et al. 2017). People with mild cognitive impairment (MCI) have worse mobility performance (Petersen et al. 2014). It has also been suggested that declines in cognitive performance and mobility are driven by a unifying process (Christensen 2001). Mobility deficits appear to be due to dysfunction of the neuromuscular system as well as dysfunctioning of the central nervous system (Seidler et al. 2010, Ren et al. 2013). The central nervous system plays an important role in mobility decline in old age (Rosso et al. 2013). It has been shown that the central nervous system is involved in the preparation and performance of complex walking tasks among older adults (Clark et al. 2014). Results of neuroimaging studies have suggested that shared underlying structural changes in the prefrontal and median lobes might be related to changes in mobility and cognitive performance (Holtzer et al. 2014). A smaller prefrontal area of the brain may contribute to slower gait through slower processing speed (Rosano et al. 2005). The recently presented pre-dementia syndrome, the motoric cognitive risk syndrome (MCR), describes a situation where the individual has cognitive complaints and slow gait speed but shows no functional limitations (Verghese et al. 2012). The MCR syndrome may identify older people at high risk for transitioning to dementia and disability (Shimada et al. 2017).

Several studies have found that EF plays a key role in the ability of older adults to manage complex performance-based instrumental activities of daily living (Vaughan & Giovanello 2010, Marshall et al. 2011) and is a significant predictor of functional status (Bell-McGinty et al. 2002, Cahn-Weiner, Boyle & Malloy 2002, Royall et al. 2004). EF is also required for safe driving (Anstey et al. 2005). In addition, EF plays an important role in lower extremity motor tasks (Ble et al. 2005, van Iersel et al. 2008, Liu-Ambrose et al. 2008, Yogev-Seligmann, Hausdorff & Giladi 2008, Demnitz et al. 2017). It has also been suggested that executive function may be a stronger predictor of functional declines than global cognition (Johnson, Lui & Yaffe 2007).

2.4 A life course approach to later life functioning

2.4.1 A life course approach to aging

The life course approach to aging provides a framework for studying the impacts of early life development, experiences and exposures on later life health and functioning (Kuh et al. 2003). In epidemiology, a life course approach can be utilized to examine the biological, behavioral and social pathways that link physical and social exposures and experiences during gestation, childhood, adolescence, and adult life, and across generations, to changes in health and disease risk in later life (Ben-Shlomo & Kuh 2002). Originally, in epidemiology, a life course approach was used primarily in research on “fetal programming”, i.e. the influence of prenatal factors on adult chronic diseases (Barker 1998), the hypothesis being that environmental exposures during critical or sensitive periods of growth and development in utero may be associated with adult chronic disease risk. The developmental origins of health and disease framework (Gluckman, Hanson & Beedle 2007), in turn, focuses on potential sensitive periods in childhood and adolescence and their effects on health and aging (Eriksson et al. 2001).

Various life course models have been developed to postulate pathways linking exposures across the life course to health in later life (Kuh et al. 2003). The critical or sensitive period model proposes that exposures during times of rapid growth and fetal development affect the risk for later-life diseases. This implies that the rate of aging might in part already be determined by early developmental programming. The risk accumulation model proposes that exposures and their effects accumulate over the life course and influence health in adulthood (Kuh et al. 2014).

2.4.2 Developmental origins in early life of functioning in later life

Developmental epidemiological findings suggest that their specific circumstances in early life put individuals on trajectories that determine their physical and psychological functioning in older age (Kuh & Shlomo 2004). Critical developmental periods during early life render individuals sensitive to experiences and exposures. Neurodevelopment, i.e. neural growth and synaptic network formation, is at its most active in childhood at the time of fast cognitive and motoric development (Wright & Christiani 2010). This could have far-reaching consequences on both cognitive and physical functioning in later life, as the prefrontal areas of the brain that deteriorate first in older age seem to be the same as the ones that are involved in both motor development and cognitive development (Diamond 2000).

The Northern Finland Birth Cohort study has reported that earlier infant motor development predicts higher levels of physical strength, muscle endurance and aerobic fitness in adulthood (Ridgway et al. 2009) and is associated with better educational outcomes in adolescence and adulthood (Taanila et al. 2005). Age at first walking has been shown to be associated with adult physical performance at age 53 years. Reaching a motor milestone at the modal age has been shown to have long-term benefits for functional performance in middle age (Kuh et al. 2006). Earlier age of learning to stand is associated with better executive functioning (Murray et al. 2006) and level of intelligence (Murray et al. 2007) in adulthood. Further, motor development was found to be associated with brain structure. Earlier timing of learning to stand and walk increased the gray and white matter densities and was linked with better executive function in adulthood (Ridler et al. 2006). Infancy has been suggested to be one of the critical periods of development for intellectual abilities in subsequent life (Gale et al. 2004, Räikkönen et al. 2009). Early adulthood, the period when brain development peaks, is a critical milestone in the development of intellectual abilities (Salthouse 2009).

A few studies have also examined early mental abilities as predictors of physical functioning and health in later life. A study using Scottish Mental Surveys data from 1932 and 1947 found that lower childhood mental ability at age 11 years was associated with increased risk for premature mortality, morbidity and frailty in later life (Deary et al. 2004) whereas high intellectual ability predicted functional independence at the mean age of 77 years (Starr et al. 2000). In the 1946 British birth cohort higher scores on cognitive tests in childhood were associated with better physical performance at age 53 years (Kuh et al. 2006). Lower weight and slower weight gain in infancy are associated with lower physical functioning (von Bonsdorff et al. 2011), lower cognitive ability (Räikkönen et al. 2013) and decreased muscle strength (Ylihärsilä et al. 2007) in later life. It has been suggested that physiological characteristics early in life, aging, and intervening health conditions have cumulative and interactive effects over a long period that shape the trajectories of mobility loss with aging (Ferrucci et al. 2016).

2.4.3 The concept of cognitive reserve

The concept of cognitive reserve in neuroscience refers to individual differences in brain structure and functioning that can help in coping with age-related brain changes in old age (Richards & Deary 2005, Stern 2009). The greater the reserve, the more severe the effects of neuropathology are required to be to cause functional impairment (Richards & Deary 2005). Two models of cognitive reserve have been proposed. The passive model of brain reserve posits that a larger brain might tolerate more brain pathology before clinical symptoms appear (Stern 2012). The active model of cognitive reserve refers to brain function (Stern 2012). Functional cognitive reserve comprises the ability to optimize or maximize performance through the differential recruitment of brain networks and active compensation by alternative cognitive strategies (Stern 2002, Richards & Deary 2005). The more cognitive reserve a person has the better he or she can cope with possible brain damage and still effectively function in everyday situations (Stern 2002).

Intelligence, education and occupational level are the major active components of cognitive reserve (Whalley et al. 2004). Schooler's (1984) environmental complexity theory proposes that the complexity of an individual's environment, i.e. one with diverse stimuli and demanding characteristics, may buffer against cognitive decline in later life (Schooler 1984, Hultsch et al. 1999). More stimulating environments, such as occupational complexity, may improve brain structure by increasing neural efficacy and networks, and thus affect a person's cognitive ability (Smart, Gow & Deary 2014).

Cognitive reserve can be measured using anatomical measures such as brain size, head circumference, synaptic count or dendritic branching. Even demographic features such as socioeconomic status, occupational attainment or educational attainment may reflect cognitive reserve. Some specific attributes such as literacy, intellectual quotient (IQ) or measures of specific cognitive functions have also been used to indicate cognitive reserve (Stern 2002, Brewster et al. 2014).

2.5 Study framework

A life course approach framework was used in this study to investigate the linkage between early life development from infancy and early adulthood and functioning in old age (Kuh & Shlomo 2004). The period of rapid growth and development in the early years of life peaks at maturity after which functional capacity begins to decline, at different rates in different individuals, with older age (Figure 1). People grow old very heterogeneously and therefore old age is not a definite stage but rather a diverse concept. Old age refers to ages nearing the end of human life course. The years of retirement and early old age (aged + 65 y) is a time period when people are still quite fit and usually live independent life. In old age (aged +75 y) the rate of functional decline usually increase and people become frailer. Wide variation exists in the range of functioning in old age. In part, this is due to changes in both the central nervous system and physiological systems. The functional capacity that one acquires during the growth period and the rate of decline in older age may determine how long an individual remains above the disability threshold, the level under which limitations in function start to occur (Kuh 2007).

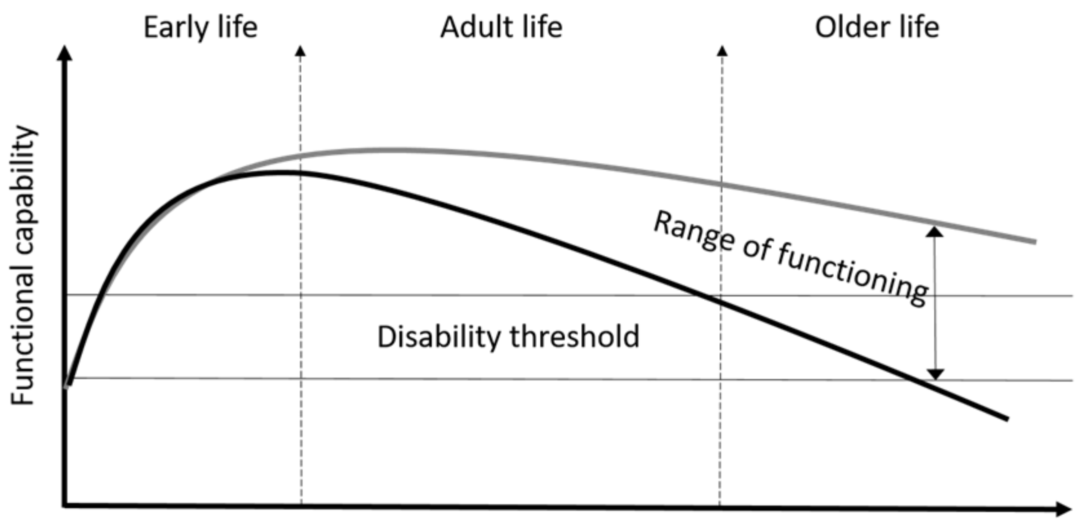


Figure 1 Conceptual framework of the study. Life course functional trajectories (adapted from Kuh et al. 2014).

3 AIMS OF THE STUDY

The purpose of the study was to explore how cognitive function and mobility are related over the life course. From the life course perspective this study addressed some of the critical time periods in perspective of the brain development: the rapid brain development in infancy is involved in early motor development, the early adulthood is the time when brain development peaks possibly affecting later life functioning, and the old age is the time when inevitable brain deterioration starts to appear possibly affecting mobility as well. The first aim was to study how executive function is associated with life-space mobility in old age. The second aim was to investigate whether early developmental factors are related to later life functioning. The analytic framework of this study is illustrated in Figure 2.

The specific research questions were:

1. Is executive function associated with life-space mobility among community-dwelling older people, and if so, do perceived walking difficulties, lower extremity performance or transportation difficulties explain the association (Study I)?

2. What is the temporal association between executive function and life-space mobility among community-dwelling older people (Study II)?

3. Is intellectual ability in early adulthood associated with physical functioning in older age (Study III)?

4. Is infant motor development associated with cognitive functioning in early old age (Study IV)?

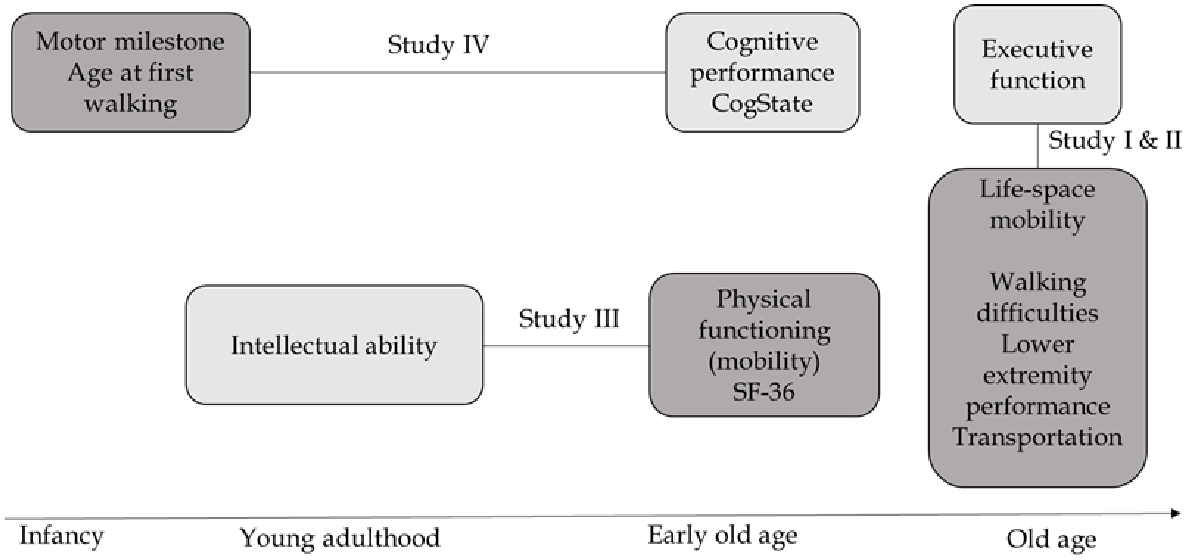


Figure 2 The analytical framework of the study.

4 DATA AND METHODS

4.1 Study design and participants

The data for this study were drawn from two projects: Life-Space Mobility in Old Age (LISPE) and the Helsinki Birth Cohort Sudy (HBCS). The LISPE study is a prospective cohort study of 848 community-dwelling older people aged 75 to 90 years residing in the areas of Jyväskylä and Muurame (Rantanen et al. 2012). The original epidemiological study cohort of the HBCS comprised 8 760 persons born between the years 1934-1944 in Helsinki (Barker et al. 2005). The study samples analyzed here were drawn from the original studies based on the availability of relevant data collected in substudies. The participants and study designs reported in this study are summarized in Table 1.

Table 1 Summary of study designs and populations.

Study	Dataset	Design	Participants	Age, years (M±SD)	Average Follow-up
I & II	LISPE	longitudinal prospective cohort study	n=157*	82.6±4.2	2 years
III	HBCS	epidemiological cohort study	n=360	20.3±1.6	51 years
IV	HBCS	epidemiological cohort study	n=398	12.1 ±2.1 months	63 years

M = Mean
SD = Standard deviation
*n=157 cross-sectional analysis

4.1.1 Life-Space Mobility in Old Age (LISPE)

LISPE is a population-based study conducted in year 2012 comprising 848 community-dwelling people aged 75-90 years (Rantanen et al. 2012). Random number tables were used to select 230 individuals for a Hearing, Cognition and Wellbeing sub-study in which sensory, physical and cognitive tests were conducted (Polku et al. 2015). Of these, 169 persons who did not experience severe problems in communicating and were willing to participate underwent the relevant examinations and interviews during spring 2014. Participants who had valid data on EF and life-space mobility (n=157) formed the analytic sample for the cross-sectional study (Study I). In the year 2016, the 169 participants studied in spring 2014 were invited to participate in the Mobility and Active Aging sub-study; 108 of them underwent the relevant examinations and interviews in spring 2016 and formed the analytic sample for the longitudinal analysis (Studies I and II). The Hearing, Cognition and Wellbeing sub-study sample (n=169) did not differ from the initial LISPE study sample (n=848) in sex, age, years of education, number of chronic conditions or lower extremity functioning measured with the Short Physical Performance Battery (SPPB), or cognitive functioning measured with Mini-Mental State Examination (MMSE) (p values >0.127).

4.1.2 Helsinki Birth Cohort Study (HBCS)

The original birth cohort used in the HBCS comprised 8 760 persons who were born in Helsinki University Central Hospital between the years 1934-1944 and were resident in Finland in 1971. All the participants had attended child welfare clinics in the city of Helsinki, and the majority also went to school in Helsinki (Eriksson et al. 2001). Of the original study population of 8 760 people, 2 786 men who served in the Finnish Defence Forces between 1952 and 1972 took an intellectual ability test during their mandatory military service (Räikkönen et al. 2009). Of these, 640 participated in the baseline clinical examinations between 2001 and 2004, and 478 in the follow-up clinical examinations in 2011 and 2013 (Eriksson et al. 2015). Complete data, i.e., military ability test score measured in early adulthood and both physical functioning assessments at the average ages of 61 and 71 years were available for 360 persons. These individuals formed the analytic sample of Study III. Those with missing data on follow-up examinations for physical functioning in 2013 were more likely to be older (p<0.001) and to have a father who had lower occupational status (p=0.003). They also had lower physical functioning scores at the first assessment (p<0.001) and lower military intellectual ability test scores in early adulthood (p<0.001).

Random number tables were used to select a subset of 2 902 persons for a further clinical study from the original birth cohort (n= 8760). Of the 2003 persons who had participated in the clinical study between 2001 and 2004, 1 586 living in the greater Helsinki area, were invited to participate in clinical performance tests. Of these, 1 279 persons participated in the cognitive performance tests (Paile-Hyvärinen et al. 2009). Among this group, 398 individuals had valid data on age at first walking, and thus formed the analytic sample of

Study IV. Among the participants of cognitive tests, we compared those with and without data on age at first walking. There were no differences between them in birth weight (p=0.847), but slightly more men (p=0.040) had missing data on age at first walking. Participants with missing data on age at first walking were also younger at the time of cognitive testing (p=0.002) and their fathers' had more likely higher occupational status (p<0.001) compared with those who had data available. The groups did not differ in adult occupational status (p=0.641) or cognitive performance (p>0.280).

4.2 Ethics

Both studies the LISPE and HBCS studies were conducted following the guidelines of the Declaration of Helsinki. The LISPE study and both the Hearing, Cognition and Wellbeing and the Mobility and Active Aging sub-studies were approved by the ethical committee of the University of Jyväskylä. The HBCS was approved by the ethical committee of the Hospital District of Helsinki and Uusimaa. Child welfare clinic records we reviewed with the permission of the Ministry of Social Affairs and Health, and military service data were linked with the permission of the Finnish Defence Command. All participants have given a written informed consent.

4.3 Measurements

4.3.1 Life-space mobility

Life- space mobility was measured with the 15-item University of Alabama at Birmingham Study of Aging Life-Space Assessment (LSA) (Baker, Bodner & Allman 2003), which was translated into Finnish (Portegijs et al. 2014a) in Studies I and II. Previous studies have established the validity and reliability of the LSA scale as well as its responsiveness for change (Baker, Bodner & Allman 2003, Peel et al. 2005, Allman, Sawyer & Roseman 2006, Portegijs et al. 2014a). The LSA measures a person's actual mobility during the four weeks preceding the assessment on the following life-space levels (=level score): bedroom (score 0), other rooms (1), outside home (2), neighborhood (3), town (4), beyond town (5). Participants were also asked how many times they attained each life-space level (=frequency score); daily (score 4), 4-6 times/ week (3), 1-3 times/ week (2), less than once a week (1), and whether they needed help from another person or used an assistive device (=assistance score): no assistance (2), use of device only (1.5), personal assistance (1). A composite score was calculated for each level as follows: level score x frequency score x assistance score, and then summed for all levels. Thus, the summed score reflects distance, frequency, and independence of movement, and was used as an indicator of life-space mobility.

The score ranges between 0 and 120, with higher scores indicating higher life-space mobility (Rantanen et al. 2012, Portegijs et al. 2014b).

4.3.2 Lower extremity performance

Lower extremity performance was assessed with the Short Physical Performance Battery (SPPB) (Guralnik et al. 1994) in Study I and II. The test battery comprises three tests assessing standing balance, walking speed over 2.44 meters and time taken to complete five chair rises. Each test is rated from 0 to 4 points according to established age- and gender-specific cut-off points (Guralnik et al. 1994, Mänty 2007). A SPPB sum score was calculated (range 0-12) when at least two of the tests were completed (Portegijs et al. 2014b). If one of the tests was missing, the sum score of the two tests was transformed by using a proportion equation formula to reflect the maximum possible test score, i.e., the sum score was first multiplied by the maximum possible test score (12) and then divided by the maximum possible performed test score (8). Higher scores indicate better physical performance.

4.3.3 Perceived difficulties in walking 500 meters

Perceived difficulties in walking 500 meters were self-reported in Study I. Participants were asked, "Are you able to walk about 500 meters?" The response options were "able without difficulty", "able with minor difficulty", "able with a great deal of difficulty", "unable without the help of another person", and "unable to manage even with help".

4.3.4 Transportation difficulties

Transportation difficulties were assessed based on perceived difficulties using public transportation, and frequency of driving in Study I. The question pertaining to public transportation was drawn from an 11-item self-report questionnaire for Instrumental Activities of Daily Living (IADL) (Lawton & Brody 1969). Participants were asked how well they managed to use public transportation. Response options were "able without difficulty", "able with minor difficulty", "able with a great deal of difficulty", "unable without the help of another person", and "unable to manage even with help". Driving was assessed by asking "How often do you drive a car?" Response options were "Daily or nearly daily", "Once or twice a week", "Once or twice a month", "Once or twice a year", "Less than once a year", "Never, I have never driven a car" and "Never, I have stopped driving a car". People who did not drive regularly i.e., at least once or twice a month, and had difficulties in using public transportation were categorized as having transportation difficulties, while those who did not have difficulties in using transportation or who drove a car at least once or twice a month were categorized as not having transportation difficulties (Study I).

4.3.5 Physical functioning

Physical functioning was assessed using the Finnish validated version of the RAND 36-Item Health Survey 1.0 [Short Form (SF-36)] in Study III. The SF-36 has been found to be a reliable and valid measure of physical functioning in the Finnish older population (Aalto, Aro & Teperi 1999). We used the ten-item sub-scale on physical functioning. The items are the following: vigorous activities, moderate activities, lifting and carrying groceries, climbing stairs, climbing one flight of stairs, flexibility, walking two kilometers, walking 500 meters, walking 100 meters, and bathing and dressing oneself. The items were coded into 0 = great deal of difficulty or unable to perform, 50 = some difficulty, 100 = no difficulty, and the sum score was divided by 10. Higher scores indicate better physical functioning.

4.3.6 Age at first walking

The data for age at first walking used in Study IV were obtained from child welfare clinic records retrieved from the Helsinki City archives. During their visits to the child welfare clinics, mothers were asked to report the age at which their child learned to walk without support. Age at first walking was recorded in months. The children visited the welfare clinics on average 11 times between their birth and the age of 2 years.

4.3.7 Executive function

EF was measured with the Trail Making Test (TMT) in Studies I and II. The TMT is a paper-and-pencil task providing information on visual search, scanning, processing speed, mental flexibility and executive function (Reitan & Wolfson 1993). The TMT has shown an excellent reliability (Strauss, Sherman & Spreen 2006). The TMT consists of two parts. In the TMT-A task, participants were required to draw lines sequentially connecting randomly arranged encircled numbers (from 1 to 25) spread across a sheet of paper. In the TMT-B task, participants were required to draw lines in numeric and alphabetical order (1-A-2-B-3-C, etc.) connecting randomly arranged circles containing numbers (from 1 to 13) and letters (from A to L) spread across a sheet of paper. If an error occurred, the examiner pointed it out immediately. Participants were then asked to revert to the last correct number or letter and continue from there to complete the task at the cost of additional time. Time to complete each task was measured in seconds. The acceptable maximum time taken to complete each part of the test was 240 seconds and the acceptable maximum number of errors was 4 (Lezak 1995, Bowie & Harvey 2006). To control for the effects of motor function, visual scanning and processing speed, Delta-TMT was calculated by subtracting time to perform TMT-A from time to perform TMT-B. Delta-TMT has been used in previous studies to indicate executive functioning (Drane et al. 2002, Ble et al. 2005).

EF was categorized into three approximately equal distribution-based groups as follows. Poor EF included those who did not perform TMT-A or TMT-B tasks within the acceptable time, or made more than 4 errors, or who failed to complete the task so that Delta-TMT could be calculated. Intermediate EF included those whose Delta-TMT was between 95 and 179 seconds at baseline and between 97 and 180 seconds at follow-up. Good EF included those whose Delta-TMT was 94 seconds or less at baseline and 97 seconds or less at follow-up. The cut-off between intermediate and good EF was defined as the median value of Delta-TMT among those who completed the tests within the acceptable time and with the acceptable accuracy.

4.3.8 Intellectual ability

The Finnish Defence Forces Basic Intellectual Ability Test was used to assess intellectual ability in early adulthood in Study III. The test was developed by the Finnish Defence Forces Educational Development Centre. This test was compulsory for all new recruits during the two first weeks of their military service. The test battery was developed to measure general cognitive ability and logical thinking and included verbal, arithmetic and visuospatial reasoning subtests. Each subtest comprises 40 multiple-choice questions in a series proceeding from the easiest to the most difficult (range of the scores 0-9 points).

The verbal reasoning sub-test includes four types of questions: the subject has to choose synonyms or antonyms of a given word, select a word belonging to the same category as a given word pair, identify which word on a word list does not belong to the group, and discern similar relationships between two word pairs. The arithmetic reasoning test also includes four types of questions: the subject has to complete a sequence of numbers that follow a certain pattern, to solve short verbal arithmetic problems, to compute simple arithmetic operations and to choose similar relationships between two pairs of numbers. The visuospatial reasoning sub-test comprises a set of matrices containing a pattern problem with one component removed. The subject is asked to decide which of the given single figures completes the matrix. The test requires the subject to conceptualize spatial relationships ranging from the very obvious to the very abstract. Correct answers in each subtest were summed, and the arithmetic mean (range 0-40 points) was used as an index of intellectual ability (Tiihonen et al. 2005, Räikkönen et al. 2009, Räikkönen et al. 2013).

4.3.9 Cognitive performance

Cognitive performance was measured using the CogState (CogState®, version 3.0.5) computerized cognitive test battery in Study IV. The CogState cognitive test battery has been designed to be an efficient and sensitive method of identifying problems in major cognitive domains such as psychomotor speed, visual attention, working memory, divided attention and associated learning (Darby et al. 2002). CogState battery has shown good reliability with minimal practice effects (Felleti et al. 2006). The five different tasks included in the battery are based on playing cards presented on a computer screen. Each of the five tasks consists of 30 to 50 repeated stimuli, and the time taken to complete the whole teat battery approximately 15 min. Reaction times were measured in milliseconds and mean reaction times were calculated for each task. Accuracy of responses was recorded as the number of correct answers divided by the total number of answers given.

The five tasks were as follows: in the simple reaction time task (SRT) measuring psychomotor speed, participants had to react by pressing the spacebar as quickly as possible whenever a card faced down on the screen was turned face up. This task was repeated 35 times at random intervals. The SRT task was administrated twice, at the beginning and end of the test session, and the mean reaction time of the two performances was calculated. In the choice reaction time task (CRT), measuring visual attention and psychomotor speed, participants had to react as quickly as possible by pressing K ("yes") or D ("no") if the card to be turning on the screen was red. This task was repeated 30 times. In the working memory task (WM), measuring working memory, psychomotor speed and visual attention, participants had to react as quickly as possible by pressing K ("yes") or D ("no") if the card shown on the screen was identical to the previous card. This task was repeated 30 times. In the divided attention task (DA), measuring divided attention, participants had to monitor five cards on the screen moving randomly between two horizontal lines above and below the cards. Participants were asked to press the spacebar as quickly as possible if one of the cards touched the lines. This test was repeated 30 times. In the associate learning task (AL), measuring visual learning and memory, participants had to match pairs of cards on the screen. Five pairs of cards were shown on the top half of the screen and one random pair face down on the bottom half of the screen. When the card pair below these five pairs turned face up, the participants had to press K ("yes") or D ("no") if the pair was identical with one of the pairs above. After matching the pair, the random pair on the bottom half of the screen was turned face down and after this the participants had to use their memory to be able to produce the right matching. After every match, the pair of cards was turned face up, allowing learning during the task. This task was repeated 50 times.

4.3.10 Covariates and descriptive variables

The age and gender of the participants were retrieved from the National Population Register in Studies I and II. In Study III, age at clinical examination, and in Study II age at military service and ages at the clinical examinations, were used. Total number of years of education was elicited with the question "How many years of education have you had in total?" (Study I & II). Childhood socioeconomic status was determined by father's occupational status as indicated by the highest recorded occupational class. This information was extracted from birth records, child welfare and school healthcare records and was coded as upper middle class, lower middle class, laborer or unknown occupation (Central Statistical Office of Finland 1989) (Study III & IV). Highest attained education was recorded at five-year intervals between the years 1970 and 2000 by Statistics of Finland, and was categorized into basic, less or unknown, upper secondary, lower tertiary, and upper tertiary (Study IV). Data on adult occupational status was extracted from the Finnish Population Register Center, and was categorized into upper middle class, lower middle class, self-employed, and laborer according to the highest recorded occupational class extracted at 5-year intervals between 1970 and 2000 (Study IV). To calculate participants' adult body mass index (BMI), weight and height were measured at the clinical examinations (kg/m^2) (Study III). Main chronic diseases (heart failure, myocardial infarction, angina pectoris, hypertension, diabetes) were elicited with questionnaires at the clinical examinations (Study III). Number of self-reported physician-diagnosed chronic conditions was calculated from a list of 22 chronic diseases (Study I & II). Global cognitive functioning was assessed with the Mini Mental State Examination (MMSE, range 0-30) (Folstein, Folstein & McHugh 1975) (Study I). The study variables are summarized in Table 2.

Table 2 Summary of the study variables.

Variables	Study	Methods and reference
Mobility		
Life-Space Mobility (composite score)	I, II	University of Alabama at Birmingham Study of Aging Life-Space Assessment; Baker et al., 2003
Lower extremity performance	I,II	Short Physical Performance Battery; Guralnik et al., 1994
Perceived difficulties in walking 500 meters	I	Self-reported; Leinonen et al. 2007
Transportation difficulties (cat)	I	Self-reported, IADL; Lawton & Brody, 1969
Physical functioning	III	Short Form (SF-36)]; Aalto et al., 1999
Age at first walking	IV	Child welfare clinic reports
Cognition		
Executive function	I, II	Trail Making Test; Reitan 1993
Intellectual ability	III	The Finnish Defence Forces Intellectual Ability Test
Cognitive performance	IV	CogState; Darby et al., 2002
Covariates		
Age (years)	I-IV	National registers
Gender	I-IV	National registers
Father's occupational status	III, IV	Extracted from birth records, child welfare records and school healthcare records
Education (years)	I	Self-reported; Pohjolainen et al. 1997
Highest attained education	IV	Statistics of Finland
Occupational status	IV	The Finnish Register Center, Statistics Finland
Body mass index	III	Measured and calculated (kg/m^2)
Number of chronic conditions	I	Self-reported
Main chronic diseases	III	Self-reported
Cognitive functioning	I	Mini Mental State Examination; Folstein et al., 1975

4.4 Statistical analysis

Descriptive statistics: The descriptive measures were computed using means and standard deviations (SD) for continuous variables and percentages for categorical variables in all studies. Student's *t*-test was used for comparing means for normally distributed variables (Study I, III, IV), and Mann-Whitney U test (Study IV) and Kruskall-Wallis H test (Study I, III, IV) were used for non-normally distributed variables. Pearson's chi-squared test was used for comparing proportions in categorical variables (Study I, III, IV). One-way analysis of variance (ANOVA) was used in Study I for comparing different EF groups.

Generalized linear regression models (GLM) were used in Study I to investigate the cross-sectional associations between EF and life-space mobility. The base model was adjusted for age and gender. We then included perceived difficulties walking 500 meters, lower extremity performance and transportation difficulties in the model one at the time to examine if the association between EF and life-space mobility was explained by these covariates. Finally, all the factors were included in the model simultaneously. Additionally, in the fully adjusted model we included the number of chronic conditions and years of education as covariates. The analyses were carried out with SPSS IBM version 24.0 (SPSS, IBM Corp., Armonk, NY).

A *Generalized estimating equations model (GEE)* was constructed in Study I to investigate the longitudinal associations between EF and life-space mobility by specifying an unstructured outcome covariance matrix. The main effects of EF on life-space mobility and time interaction effects (group by time) for the two-year follow-up were estimated. Models were adjusted for age and gender. The analyses was carried out with SPSS IBM version 24.0 (SPSS, IBM Corp., Armonk, NY).

Cross-lagged modelling was used to estimate the longitudinal associations between EF and life-space mobility in Study II. Unstandardized values were used in the analyses. The weighted least square estimator (WLSMV) was used to obtain parameter estimates. The model was adjusted for age and gender. The analyses were performed with MPLUS version 5.21 (Muthén & Muthén 1998). Full Information Maximum Likelihood procedure was used for handling missing values (<4.6%).

Longitudinal path modelling was used in Study III to explore the effect of intellectual ability in young adulthood on physical functioning in older age. Due to the noticeable ceiling effect of the physical functioning summary score at both measurements, we treated this variable as censored. We used standardized values of the intellectual ability test scores in the path models. The models were adjusted for age at each measurement and additionally for childhood socioeconomic status, adult BMI, and main chronic diseases. The analyses were performed with MPLUS version 7 (Muthén & Muthén 2012).

The conceptual model of the effect of intellectual ability on the longitudinal censored measurements of physical functioning is presented in Figure 3. The model includes paths for intellectual ability predicting physical functioning at the first assessment between years 2001 to 2004 (β_1) and physical functioning at the follow-up in 2013 (β2), and a path from the first assessment of physical functioning to follow-up (β_3). Additionally, the indirect effect of intellectual ability on follow-up physical functioning via the first assessment of physical functioning (β1 x β3) and total effect of β2 + (β1 x β3) was calculated (Figure 3).

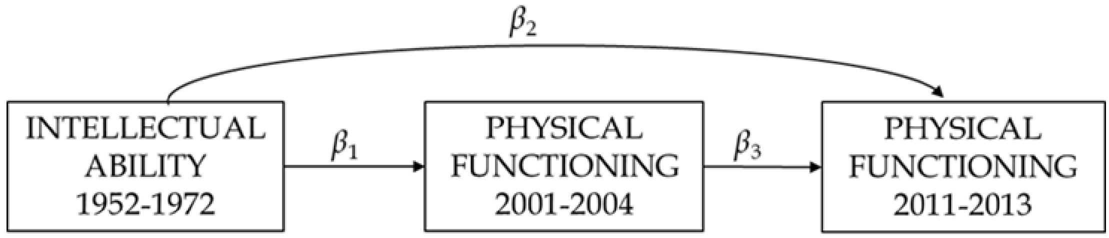


Figure 3 Conceptual model of the effect of intellectual ability on longitudinal censored measurements of physical functioning.

Linear regression models were used to investigate the association between age at first walking and cognitive performance in early old age (Study IV). To normalize the distribution of the cognitive performance reaction times, they were $\log_{10}$ transformed. We used standardized values of $\log_{10}$ transformed cognitive performance times in the regression models. The regression coefficients were expressed as percent changes per month in the age of learning to walk with 95% confidence intervals (CI). The effect on cognitive performance of the interaction of gender with age at first walking was tested. A statistically significant association was observed for the associated learning task ($p = 0.042$) but not for the other cognitive tasks ($p > 0.172$). Based on these findings, we performed gender-stratified analyses, which revealed that the associations between age at first walking and the cognitive tasks were parallel except with the associated learning task. Thus, we performed separate analyses for men and women for the associated learning task and analyses pooled by gender for the other cognitive tasks. Model I was adjusted for gender and age at cognitive testing; Model II was additionally adjusted for father's occupational status and the participant's highest attained education, and Model III additionally adjusted for adult occupational status. The analyses were carried out with SPSS IBM version 22.0 (SPSS, IBM Corp., Armonk, NY).

Multi-nominal regression analysis was used in Study IV to investigate the association between age at first walking and number of errors made in the cognitive performance tests. The analyses was carried out with SPSS IBM version 22.0 (SPSS, IBM Corp., Armonk, NY).

5 RESULTS

5.1 Characteristics of participants

Baseline and follow-up characteristics of the participants from the LISPE Study (Study I and II) are presented in Table 3.

Table 3 Participant characteristics at baseline and follow-up in Study I and II.

Characteristics	Baseline	Follow-up
	n=157	n=108
	Mean (SD)	Mean (SD)
Age (years)	82.6 (4.2)	84.3(4.1)
Education (years)	9.6 (4.3)	9.4 (4.5)
Number of chronic conditions	3.3 (1.6)	3.4 (1.7)
Life-space mobility composite score	59.0 (21.0)	61.5 (21.2)
Lower extremity functioning (SPPB)	8.5 (2.8)	9.1 (2.2)
Cognitive functioning (MMSE)	26.1 (2.6)	26.2 (3.0)
	%	%
Women	61.1	59.2
Executive function		
Good	33.8	37.1
Intermediate	31.8	33.0
Poor	34.4	29.5

SD= Standard deviation
SPPB= Short Physical Performance Battery
MMSE= Mini-Mental State Examination

Characteristics of the participants from HBCS in Study III and IV are presented in Table 4. 172 men and 226 women for whom data on age at learning to walk were available from child welfare clinic records participated in the clinical examinations during 2001-2004 at the mean age of 64.2 years. Average age at learning to walk was 12.1 (2.1) months. Mean age at military service was 20.3 years (SD 1.6, range 17.1 to 26.9 years). Mean age was 60.9 years (SD 2.3, range 57.1-67.9 years) at the time of the physical functioning assessment in 2001-2004 and 71.4 years (SD 2.2, range 69.0-78.0 years) at the follow-up in 2011-2013 (Table 4).

Table 4 Participant characteristics of Study III and IV.

Characteristics	Study III	Study IV
	Mean (SD)	Mean (SD)
Age at first walking (months)		12.1 (2.1)
Age at military service (years)	20.3 (1.6)	
Age at clinical testing 2001-06	60.9 (2.3)	64.2 (3.0)
Age at clinical testing 2013	71.4 (2.2)	
	%	%
Women	0	56.8
Father's occupational status		
Upper middle class	23.7	8.8
Lower middle class	24.8	23.5
Labourer	51.5	67.7

5.2 Executive function and life-space mobility (Study I and II)

Baseline characteristics of the participants according to EF are presented in Table 5 (Study I). Persons with poor or intermediate EF were older, less educated, had lower life-space mobility, and poorer lower extremity functioning compared to those with good EF. Those with poor EF had the most transportation difficulties (Table 5).

Table 5 Participant characteristics by executive function in Study I (n=157).

Characteristics	Executive function			*p* value
	Good n=53 Mean (SD)	Intermediate n=50 Mean (SD)	Poor n=54 Mean (SD)	
Age (years)	81.5 (4.2)	82.2 (4.1)	84.1 (4.0)	0.003[a]
Education (years)	11.3 (4.0)	9.8 (4.8)	7.9 (3.4)	<0.001[a]
Number of chronic conditions	3.1 (1.8)	3.4 (1.5)	3.4 (1.6)	0.493[a]
Life-space mobility (composite score)	64.2 (21.2)	62.9 (18.2)	50.3 (1.6)	0.001[a]
SPPB (total score)	9.5 (2.6)	8.6 (2.6)	7.5 (2.8)	0.001[a]
MMSE (total score)	27.6 (1.6)	26.5 (2.4)	24.4 (2.6)	0.001[a]
	%	%	%	
Women	58.5	60.0	64.8	0.782[b]
Difficulties in walking 500m				0.667[b]
No difficulties	77.4	80.0	66.7	
Minor difficulties	9.4	10.0	14.8	
A great deal of difficulties	3.8	6.0	9.3	
Unable even with help	7.1	9.4	3.2	
Transportation difficulties				0.002[b]
No difficulties	83.0	80.0	55.6	
Difficulties	17.0	20.0	44.4	

Executive function categories: Good delta-TMT ≤94s, *Intermediate* delta-TMT 95-179s, *Poor* unable to complete either the TMT-A or TMT-B task <240s, or made more than 4 mistakes or did not complete the task.
SD= Standard deviation
SPPB= Short Physical Performance Battery
MMSE= Mini-Mental State Examination
[a] = Analysis of variance (ANOVA)
[b] = Chi-square test

Persons with poor EF had lower life-space mobility compared to those with good EF (β= -13.94, 95%CI -21.61, -6.27). When either lower extremity performance (β= -4.80, 95%CI -11.35, 1.76) or transportation difficulties (β= -6.50, 95%CI -13.39, 0.40) was included in the age- and gender adjusted model, the association between EF and life-space mobility was attenuated, rendering the differences statistically non-significant, and thus partially explaining the association between EF and life-space mobility.

Table 6 shows the mean values for life-space mobility at baseline and at the 2-year follow-up according to EF. Decreases life-space mobility during the two-year follow-up was highest among those with poor EF at baseline, but the difference did not quite reach statistical significance (Table 6).

Table 6 Means and standard deviations (SD) and model parameters of general estimation equations (GEE) for group-by-time interactions for life-space mobility scores by executive function tertiles at baseline and 2-year follow-up.

Executive function	Baseline		2-year follow-up		Group x time interaction*		
	Mean	SD	Mean	SD	β	SE	*p* value*
Good (n=43)	68.3	19.3	67.5	18.5	Ref.		
Intermediate (n=35)	64.3	16.8	65.7	16.5	2.188	3.110	0.482
Poor (n=25)	53.8	20.1	46.8	20.4	-6.198	3.396	0.068

Good = Delta-TMT ≤ 95 seconds, *Intermediate* = Delta-TMT 95-179 seconds, *Poor* = unable to complete either the TMT A or TMT B task < 240 seconds, or made more than 4 mistakes or did not complete the task.
SE = standard error
* = GEE model group x time interaction adjusted for age and gender, good EF as reference group.
β= sample estimate for GEE regression coefficient.

Figure 4 shows the unstandardized coefficients of the cross-lagged model at the two-year follow-up for EF and life-space mobility (Study II, n=108). The analysis showed that better EF was associated with higher life-space mobility at study baseline. Between the baseline and follow-up assessments both EF and life-space mobility remained relatively stable. The cross-lagged model enabled simultaneous examination of longitudinal associations between EF and life-space mobility, while controlling for contemporary measurement and the stability of each factor over time. The model was adjusted for age and gender. The analysis revealed that better EF at baseline predicted higher life-space mobility at follow-up whereas baseline life-space mobility did not predict EF at follow-up (Figure 4).

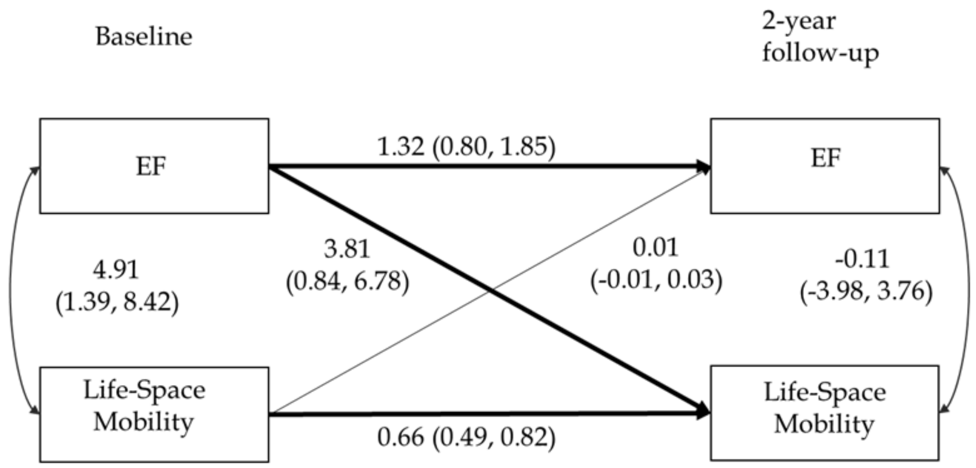


Figure 4 Unstandardized coefficients (95% confidence intervals of a cross-lagged model with two-year follow-up for executive function and life-space mobility adjusted for age and gender (n=108). Path coefficients are statistically significant if zero is not included in the confidence intervals.

5.3 Early adult life intellectual ability and physical functioning in older age (Study III)

The longitudinal path model adjusted for age at each measurement point including the censored physical functioning variables revealed a direct positive association between higher scores for total intellectual ability, arithmetic reasoning and verbal reasoning in early adulthood and better self-reported physical functioning at the first assessment in early old age conducted in 2001-04. Better physical functioning at the first assessment predicted better physical functioning at the 10-year follow-up. Intellectual ability total score, arithmetic reasoning and verbal reasoning in early adulthood also had an indirect effect on physical functioning at the mean age of 71 years through better physical functioning at the mean age of 61 years (Table 7). Further adjustments for childhood socioeconomic status, adult BMI, and main chronic diseases did not attenuate the results. All models showed good fit: total score; $X^2(df=14) = 3.27$, $p = 0.999$, arithmetic reasoning; $X^2(df=14) = 4.97$, $p = 0.986$, verbal reasoning; $X^2(df=14) = 2.96$, $P = 0.99$, visuospatial reasoning ; $X^2(df=14) = 3.02$, $p = 0.999$. For all models, Comparative Fit Index = 1, Tucker Lewis Index = 1 and Root Mean Square Error of Approximation = 0 (90%confidence interval: 0,0).

Table 7 Associations between intellectual ability in early adulthood and physical functioning at ages 61 and 71 years (n=360).

Path	Physical functioning		
	Path coefficients	SE	*p* value
Total Score (AI)			
Direct effects			
IA → PF1	2.26	0.84	0.007
IA → PF2	-0.05	0.87	0.956
PF1 → PF2	0.81	0.05	<0.001
Indirect effects			
IA → PF1 → PF2	1.83	0.68	0.007
Total effect			
IA → PF2	1.78	1.11	0.107
Arithmetic reasoning (AR)			
Direct effects			
AR → PF1	2.35	0.81	0.004
AR → PF2	-0.06	0.92	0.951
PF1 → PF2	0.82	0.05	<0.001
Indirect effects			
AR → PF1 → PF2	1.92	0.66	0.004
Total effect			
AR → PF2	1.86	1.15	0.106
Verbal reasoning (VR)			
Direct effects			
VR → PF1	1.94	0.84	0.021
VR → PF2	0.10	0.89	0.910
PF1 → PF2	0.81	0.05	<0.001
Indirect effects			
VR → PF1 → PF2	1.57	0.69	0.022
Total effect			
VR → PF2	1.66	1.09	0.127
Visuospatial reasoning (VSR)			
Direct effects			
VSR → PF1	1.56	0.86	0.072
VSR → PF2	-0.17	0.96	0.859
PF1 → PF2	0.81	0.05	<0.001
Indirect effects			
VSR → PF1 → PF2	1.26	0.71	0.073
Total effect			
VSR → PF2	1.09	1.18	0.356

β= path coefficient for the associations between intellectual ability test scores and physical functioning adjusted for age at each measurement, childhood SES and BMI;
SE = standard error; IA= standardized intellectual ability test total score in 1952-72; AR = standardized arithmetic reasoning; VR = standardized verbal reasoning, VSR = standardized visuospatial reasoning; PF1=Physical functioning in 2001-04; PF2=Physical functioning in 2013.

5.4 Motor development and cognitive performance in early old age (Study IV)

Median reaction times in cognitive tests are presented in Table 8.

Table 8 Median reaction times in completing the cognitive performance tests and their interquartile ranges.

	Median %	25^{th} percentile	75^{th} percentile
Simple reaction time (ms)	332	295	373
Choice reaction time (ms)	564	508	631
Working memory (ms)	848	761	1031
Divided attention (ms)	482	418	569
Associated learning (ms)	1825	1552	2200

Later age of learning to walk was associated with worse performance in cognitive tasks in early old age. The age- and gender-adjusted models revealed that each additional month before attainment of learning to walk lengthened reaction times in all the cognitive performance tasks: simple reaction time task (11.0% per month, 95% CI 1.14- 21.89, p = 0.028); choice reaction task (14.8% per month, 95% CI 4.43- 26.18, p = 0.004); working memory task (14.8% per month, 95% CI 4.77- 25.84, p = 0.003); and associated learning task for women (18.35% per month, 95% CI 3.94- 34.77, p = 0.011). The associations between age at first walking and divided attention, and for men between age at first walking and the associated learning task were not statistically significant (Table 9).

Table 9 Increase (%) in reaction times on cognitive performance tasks (CogState) according to each additional month in age at first walking.

	Model 1			Model 2			Model 3		
	%	95% CI	*p* value	%	95% CI	*p* value	%	95% CI	*p* value
SRT	11.03	1.14, 21.89	0.028	10.68	0.88, 21.43	0.032	10.32	0.48, 21.12	0.039
CRT	14.79	4.43, 26.18	0.004	14.74	4.32, 26.17	0.005	14.17	3.75, 25.63	0.007
WM	14.82	4.77, 25.84	0.003	15.40	5.26, 26.53	0.002	15.14	4.95, 26.32	0.003
DA	7.51	-1.87, 17.77	0.120	7.07	-2.28, 17.31	0.143	7.26	-2.17, 17.59	0.135
AL									
men	-3.43	-15.61, 10.71	0.610	-3.52	-15.93, 10.71	0.608	-3.73	-16.33, 10.76	0.593
women	17.15	3.25, 32.92	0.014	17.46	3.33, 33.51	0.014	18.35	3.94, 34.77	0.011

Note, longer reaction times indicate poorer performance on the task
SRT= simple reaction time task, CRT= choice reaction time task, WM= working memory task, DA= divided attention task, AL= associated learning task
Model 1 adjusted for age and gender, *Model 2* adjusted for model 1 and father's occupational status and highest attained education, *Model 3* adjusted for model 2 and adult occupational status.

6 DISCUSSION

Based on the results of this study, cognition and mobility are closely related across the life course from infancy to old age. Executive function was a determinant of life-space mobility in old age. Better executive function correlated with higher life-space mobility, and this was explained by the better lower extremity performance and absence of transportation difficulties among those with better EF. Early life motor and cognitive development were both associated with functioning in later life. Earlier attainment of learning to walk was associated with better cognitive performance in early old age. Better intellectual ability in young adulthood had an indirect effect on physical functioning in old age at the ten-year follow-up through the first assessment of physical functioning.

The present findings expand the earlier knowledge of the relationship between cognitive performance and mobility. First, in this study, by using the higher order cognitive measure, EF, and the wide-ranging life-space mobility measure, we were obtained new evidence on the association between cognitive performance and mobility. Second, this study contributes new knowledge on the early life determinants of late life functioning. We were able to extend the existing evidence on these associations, which have been observed from childhood to midlife in previous studies, to later stages in the life span. We were also able to use data on important human developmental milestones, i.e., learning to walk in infancy and peak brain development in early adulthood, both of which seem to be relevant for functioning in later life.

6.1 Executive function as a determinant of life-space mobility

The results of present study demonstrated not only that executive function and life-space mobility are related, but also that a temporal relationship exists between these two factors. Executive function was a stronger predictor of life-space mobility than vice versa. Our results are in line with some of the previous longitudinal studies which have suggested that EF is a predictor of decline in mobility (Royall et al. 2004, Johnson, Lui & Yaffe 2007, Vazzana et al. 2010). Conversely, two previous studies that have used life-space mobility as a measure of mobility have shown that greater life-space mobility may protect from cognitive decline (Crowe et al. 2008, Silberschmidt et al. 2017). Moreover, restricted life-space mobility has been reported to increase the risk for Alzheimer's disease and cognitive impairment (James et al. 2011). However, neither of these two studies used EF, a higher order cognitive domain, as a measure of cognition. It should be kept in mind that EF may be impaired among community-dwelling older adults even in the absence of a diagnosis of cognitive impairment (James et al. 2011). This fact may partially explain the conflict between the direction of the associations in our study and those described above, where global cognition was used as a measure of cognitive function. Apart from the types of measures used the inconsistency in the findings studies that have assessed the temporal relationship between cognitive performance and mobility (Atkinson et al. 2010, Mielke et al. 2013, Gale et al. 2014, Best et al. 2016, Tian et al. 2017) may also be due to other methodological differences such as sample size and duration of follow-up.

This study showed that objectively measured lower extremity functioning and the ability to use transportation explained the association between EF and life-space mobility. Gait requires cognitive investment as well as physiological capacity (Hausdorff et al. 2005). Lower extremity functioning is often a prerequisite for independent use of transportation (Rantanen 2013). Cognitive flexibility and inhibition, both cognitive processes needed for EF, are known to moderate the role of muscular fitness in determining mobility in older age (Forte et al. 2013). Among women, driving cessation may occur even before any physical hindrance has appeared (Siren, Hakamies-Blomqvist & Lindeman 2004). In fact, cognitive functioning has been proposed to be one of the main reasons for driving cessation among older adults (Anstey et al. 2006, Keay et al. 2009).

Motor control and cognitive performance share the same neural network (Rosano et al. 2012). The neural networks that support perceptual, motor, and cognitive processes are widely and densely interconnected (Thelen 2000). Motor control and cognitive processes for EF are located in the prefrontal areas of the brain, the areas that are the most vulnerable in the normal aging process (Seidler et al. 2010). Mobility performance in old age correlates with gray and white matter densities in the brain (Holtzer et al. 2014). Losses in gray matter (Zimmerman et al. 2006) and white matter (Gunning‐Dixon et al. 2009) are related to deterioration in executive control and other cognitive processes that support executive functions (Ren et al. 2013). Age-related white and gray matter losses in frontal areas of the brain might explain why the higher-order cognitive functions needed for mobility are more disrupted during aging (Resnick et al. 2003).

The inevitable aging of brain results in decline in cognitive performance (Raz & Rodrigue 2006). Cognitive reserve seems to play a key role in functional capability in old age. The simultaneous occurrence of deficits in mobility and cognitive performance in older age might be explained by general degeneration of the central nervous system (Seidler et al. 2010). Motoric cognitive syndrome, characterized by presence of cognitive problems and slow gait, is described as an early risk factor for cognitive decline (Verghese et al. 2014). Frontal lobe function has generally been linked to the higher order cognitive functions that are needed for EF (Demakis 2004). EF mediates the relationship between cognitive reserve and functional ability (Puente, Lindbergh & Miller 2015), and is needed for all purposeful movements (Diamond 2000).

6.2 Early development as a modifier of later life functioning

In this study, we found that mobility and cognitive performance were related across the life course from infancy to older age. Reaching certain developmental milestones, such as independent walking, seems to have long-term influences on cognitive performance in later life. Furthermore, intellectual ability in early adulthood, a period when brain maturation peaks, may track over to physical functioning in later life. Earlier attainment of motor development milestones in infancy and a higher level of intellectual ability in early adulthood may set an individual on a trajectory that partially determines functioning later in life.

While cross-sectional findings on the association between cognitive and physical functioning in old age are relatively abundant (Demnitz et al. 2016), less evidence exists on these associations over the life course. Previous studies in the field of cognitive epidemiology suggest that better cognitive ability at a young age is associated with better health in later life and lower risk for premature mortality (Hurst et al. 2013, Deary et al. 2004). Our findings are consistent with previous findings on the association between prior intellectual ability and physical functioning in later life (Starr et al. 2000, Kuh et al. 2006, Kuh et al. 2009). In the 1932 Scottish Mental Survey, mental ability at the age of 11 years was identified as an important independent predictor of late-life functional independence at the age of 77 years (Starr et al. 2000). In the 1946 British birth cohort, higher cognitive test scores at the age of 8 years were associated with better standing balance and chair rising time at the age of 53 years (Kuh et al. 2009, Kuh et al. 2006). People with higher early-life intellectual ability seem to live longer and healthier lives (Batty, Deary & Gottfredson 2007). Higher intellectual ability in early adulthood might also set an individual on a trajectory of better cognitive development that leads to a healthier and longer life. A possible explanation for this is that people with higher intellectual ability are better able to make choices in life that are beneficial for later life health and functioning.

Our results extend previous observations on the associations between motor development and cognition from infancy through adolescence and midlife (Taanila et al. 2005, Murray et al. 2007) to older age. Earlier studies have reported a linkage between motor development and brain structure and functioning (Ridler et al. 2006). Infancy and early childhood are the important periods in the life course when the brain, the central nervous system and motor development all undergo rapid growth (Malina 2004). Infancy and early childhood are stages during which modifications take place simultaneously in neuromuscular maturation, physical growth, biological maturation and behavioral development (Malina 2004). Already in early childhood brain development plays a key role in the acquisition of new motor skills (Thelen 1995). For instance, to learn to walk requires complex interactions between the movements of the legs, the center of gravity of the body, and the support surface (Thelen 2000). Alongside brain maturation, exploration and selection are fundamental processes in motor development (Thelen 1995). As a child learns new motor skills, the environment in which the movement takes place expands. This helps the child to sample the word more completely (Thelen 2000). Environmental experiences that interact with growth and maturation also influence motor development (Malina 2004). The environmental complexity theory suggests that the more demanding the environment the greater the cognitive investment needed to cope with it (Schooler 1984). Being able to expand one's environment and explore more than one's immediate surroundings, may be beneficial for a child's cognitive development.

Better development of the frontal areas of the brain may play a key role in determining functional capability in old age. The timing of motor development and of rapid growth of the brain may result in better development of the central nervous system. Further, having a higher peak level of cognitive functioning in early adulthood may lead to better cognitive reserve capacity in old age. The life course perspective on cognitive aging proposes that cognitive functioning in old age is shaped by factors operating across the life course resulting in high-er cognitive reserve (Whalley et al. 2004). Age at first learning to walk may set an individual on a trajectory that determines the level of cognitive capability, and this may track over to physical functioning as well. Intellectual ability in early adulthood, when brain development peaks and reaches full maturation, may predict an individual's later cognitive ability for later years (Giedd et al. 1999). In early adulthood, when the critical developmental periods that oc-curred in the early years of life have shaped brain structure and function, it is unlikely that cognitive decline is already present (Hedden & Gabrieli 2004). The life course model of risk accumulation suggests that exposures across the life course influence physical and cognitive development and might manifest as lower functional reserve in later life (Kuh et al. 2014). Early development, childhood socioeconomic status, education, and choices made regarding adult occupational status and lifestyle, are factors that along with cognitive function itself, have an influence on subsequent cognition. These determinants track across the life course as building blocks for cognitive reserve (Richards & Deary 2005). Higher cognitive reserve can protect against the consequences of cogni-tive decline (Richards & Deary 2005) that accompanies with decline in function-al status in old age (Auyeung et al. 2008).

6.3 Methodological considerations

The original LISPE study data, from which data for Studies I and II were drawn, were gathered from a rather large sample of well-functioning community-dwelling older adults. Using this registered database to recruit the participants ensured that individuals from all social strata were included in the study. The computer-assisted face-to-face data collection in the LISPE study was done at participants' homes by trained research assistants, thereby ensuring good quality of data. The data for Studies III and IV were drawn from the longitudinal HBCS dataset gathered from people born in Helsinki between 1934 and 1944 who had voluntary attended free- of -charge child welfare clinics in the city. They were all alive and resident in Helsinki in 1971, the year when all Finns were issued with a personal identification code. The participants who took part in the clinical examinations in 2001-13 were born in Helsinki University Central Hospital and therefore may not be representative of all the people born in Helsinki during that period. However, the distribution of socioeconomic status of the participants at the time of their birth was similar to that across the city in general.

Cross-sectional, longitudinal and temporal study designs were all used in this study in pursuit of the aim of providing comprehensive understanding of the relationship between cognitive performance and mobility over the life course. A longitudinal study design is challenging when studying older adults. Poorer functioning individuals are more likely to drop out potentially inducing bias in the results. In Study I, therefore, the longitudinal associations between EF and life-space mobility might be underestimated. Attrition might also have reduced statistical power. Long-running longitudinal cohort studies such as the HBCS, in which large samples of individuals have been followed up over a long period, need good study management. Missing data are also likely to be present in longitudinal studies. In Studies III and IV, we only included individuals for whom complete data were available for the variables used in the analysis; this affected the sample sizes. It is possible that, owing to small sample sizes used in this research the strength of the associations are underestimated. Moreover, we were not able to control for all the possible factors that might have affected the associations between early life and later life functioning, and therefore cannot rule out residual confounding.

Due to time constraints in the study protocol and the fact that participants were elderly, we were only able to use a single test as a measure of EF. Although the TMT is one of the tests most widely used to assess executive function, future studies should use multiple measures of EF to gain a more comprehensive picture of cognitive performance. Thus, the evaluation of executive function used in this study might not be most comprehensive possible. We used several mobility measures including objectively measured, self-reported and register-based data. Walking difficulties, physical functioning and transportation difficulties were self-reported. Self-reported measurements may under- or over-estimate participants' true difficulties. Our participants did not experience severe cognitive impairment, and previous studies have reported that people with mild cognitive impairment are able to give a fairly accurate report of their functional status (Farias, Mungas & Jagust 2005). Hence, it is unlikely that the self-reported measures were biased by cognitive dysfunctions. Self-reported measures of functional capability among older people have been shown to correlate with objective measurements (Guralnik et al. 1994, Syddall et al. 2015, Tsai et al. 2015). Further, self-reported measures provide valuable information on how individuals manage everyday tasks in their living environment, and are an economical way of assessing mobility in large groups of people (Mänty 2007).

The life course framework used in this study enabled a comprehensive perspective on the relationship between cognitive performance and mobility across the life course. The use of the unique longitudinal HBCS data, in which data are available of participants for over 70 years from birth to old age, made it possible to extend research on the topic to later ages than hitherto. The fact that the HBCS participants were born and grew up in one specific area in Finland during the post-war period needs to be considered when generalizing the findings. It may be that the exposures influencing development across the life course at that time are different from those that are influential today. Moreover, the data from the LISPE study, which included old people, enabled us also to examine the relationship between cognitive performance and mobility at the very end of the life span.

6.4 Implications and future directions

As people grow older, they start walking slower and processing information slower, and thus experience decline in both cognitive performance and mobility (Auyeung et al. 2008). Dual task situations, where a person needs to perform two or more activities concurrently (Pashler 1994), are a constant feature of everyday mobility. Motor performance decreases in dual task situations among cognitively impaired people (Hauer et al. 2003). Cognitive investment for mobility increases the further a person moves away from familiar surroundings (Schooler 1984). Life- space mobility in old age is related to autonomy (Portegijs et al. 2014b) and quality of life (Rantakokko et al. 2010). To enhance older people's chances to participate in the society and maintain independence for as long as possible, we need to further identify the factors during the life course that could affect older people's life-space mobility.

This research confirmed the association previously found between cognition and mobility in old age. The results reveald further that cognitive performance predicts mobility rather than the other way around. This study thus paves the way for future studies on the topic. These studies should use larger sample sizes and longer follow-ups with several follow-up points to further clearify whether it is cognitive performance or mobility that declines first in older age. This knowledge would be important for planning interventions. The fact that EF might be a more sensitive measure than the MMSE in detecting early cognitive dysfunction (Juby, Tench & Baker 2002) should also be acknowledged in health care. Assessment of executive function among older adults could help in preventing further disability and promoting older people's possibilities for independent mobility.

Examining functioning in old age from a life course perspective allows consideration of what aspects of an individual's whole life history could potentially interfare with functioning in old age. Future studies should include more possible mediating factors when studying the association between early life development and functioning in old age. The association between early development and cognitive and physical functioning in old age provides valuable information which can help in planning preventive interventions aiming at reducing the risks for cognitive and physical decline in older age. The contribution of early life development as an early predictor of cognitive decline and accompanying mobility limitations should be further examined. For example, physical activity may be beneficial in childhood (8-11y) during the time of fast growth of the frontal lobes of the brain (Romine & Reynolds 2005). The results of this study also suggest that early life development should be well supported to buffer against the possible accumulation of developmental disorders during the life course that increas the risks for functional limitations later in life. Poor intellectual ability, manifesting in, for example, lack of knowledge and the inability to follow health recommendations may affect later life health and functioning. Thus, promoting health literacy at an early age in society might help people to take better care of their health and functioning during the life course.

An active and socially integrated lifestyle seems to protect ageainst dementia (Fratiglioni, Paillard-Borg & Winblad 2004, Kulmala 2016). Mobility decline in old age is associated with reduced quality of life (Netuveli et al. 2006), increased risk for falls (Mänty et al. 2010), hospitalization (von Bonsdorff et al. 2006) loss of independency, and mortality (Hirvensalo, Rantanen & Heikkinen 2000, Lyyra, Leskinen & Heikkinen 2005). Age, female sex, socioeconomic status, injuries, inactivity and environmental barriers all have been found to be important risk factors for mobility limitations (Satariano et al. 2012). Impairment in EF predicts mobility impairment (Johnson, Lui & Yaffe 2007, Gross et al. 2016) and mortality in older community-living adults (Vazzana et al. 2010). Further, EF is associated with health related quality of life (Davis et al. 2010). Decline in EF may result in a narrowing of life-space mobility among older adults even before any other signs of cognitive impairment become apparent. Thus, to build up cognitive reserve for the latter part of lifespan, cognitive processes needed for executive function should be supported throughout the whole lifecourse.

The findings of this research indicate the importance of recognizing the role of interventions to promote cognitive health (Kivipelto et al. 2013), as this is likely to be a determinant of functional capability in old age. EF should be assessed regularly among aging population with aim of predicting possible problems in functional independence. The results of previous cognitive intervention studies suggest that EF can be improved among older adults (Dahlin et al. 2008). There is also evidence from previous studies that changes in EF have improved gait speed (Liu-Ambrose et al. 2010) and functioning (Kelly et al. 2014) among older people. Thus, cognitive training interventions may also promote quality of life and active participation in old age (Giuli et al. 2016).

7 MAIN FINDINGS AND CONCLUSIONS

The main findings and conclusions of the present study can be summarized as follows:

1. People with better executive function had higher life-space mobility. The association was explained by better lower extremity functioning and absence of transportation difficulties.

2. Executive functioning is a determinant of life-space mobility. Supporting executive function may help in maintaining higher life-space mobility.

3. People with better intellectual ability in early adulthood showed better physical functioning in old age. Better early-life intellectual ability may help in maintaining better physical functioning in older age.

4. Children who learned to walk earlier had better cognitive performance in early old age. The earlier attainment of motor skills may track over to cognitive functioning in early old age possibly reflecting greater cognitive reserve in older age.

YHTEENVETO (FINNISH SUMMARY)

Kognitiivisen suorituskyvyn yhteys liikkumiseen läpi elämänkaaren

Kognitiivinen suorituskyky ja liikkumiskyky ovat tärkeitä tekijöitä itsenäisen elämän sekä elämänlaadun kannalta vanhuudessa. Lapsuudessa kävelemään oppiminen on merkittävä virstanpylväs sekä motorisen että keskushermoston kehittymisen kannalta. Kun lapsi kehittyy ja omaksuu uusia fyysisiä ja kognitiivisia valmiuksia, hänen elinpiirinsä laajentuu. Vanhuudessa liikkumiskyky, eli kyky liikkua paikasta toiseen, milloin ja miten haluaa, on edellytys mahdollisuudelle elää aktiivista elämää vuorovaikutuksessa ympäröivän yhteiskunnan kanssa. Liikkumisaktiivisuus elinpiirissä mittarilla voidaan kuvata henkilön toteutunutta liikkumista omassa elinpiirissään huomioiden liikkumisen laajuuden, määrän sekä mahdollisen avun tarpeen liikkumiseen. Liikkumiskyky edellyttää fyysisen toimintakyvyn lisäksi myös kognitiivista prosessointia. Kognitiivista toiminnanohjausta tarvitaan tavoitteellisen toiminnan suunnitteluun ja toteuttamiseen. Samat aivoalueet ovat osallisena sekä kognitiivisessa toiminnanohjauksessa että motoristen toimintojen ohjauksessa.

Elämänkulkututkimus lähestymistapana vanhuustutkimukseen mahdollistaa elämän alkuvaiheen virstanpylväiden yhteyksien tarkastelemisen suhteessa vanhuuden toimintakykyyn. Tässä tutkimuksessa selvitettiin kognitiivisen suorituskyvyn ja liikkumisen välisiä yhteyksiä läpi elämänkaaren. Tarkastelimme kognitiivisen toiminnanohjauksen ja liikkumisaktiivisuuden elinpiirissä välistä yhteyttä vanhuudessa, sekä sitä selittävätkö liikkumisvaikeudet, alaraajojen toimintakyky tai kulkuneuvoilla kulkemisen vaikeudet tätä yhteyttä. Selvitimme myös kumpi näistä tekijöistä, kognitiivinen toiminnanohjaus vai liikkumisaktiivisuus elinpiirissä, on voimakkaampi ennustaja kahden vuoden seurannassa. Lisäksi tutkimme, onko varhaisen aikuisuuden kognitiivinen kyvykkyys yhteydessä fyysiseen toimintakykyyn vanhuudessa, sekä sitä, onko varhainen motorinen kehitys, kävelemään oppimisikä, yhteydessä kognitiiviseen suorituskykyyn varhaisessa vanhuudessa.

Tutkimusaineistoina käytettiin kahden eri tutkimusprojektin aineistoja. Life-Space Mobility in Old Age (LISPE) –projektista tutkimukseen osallistui 157 henkilöä, joilta oli mitattu kognitiivinen suorituskyky Trail Making Testillä sekä liikkumisaktiivisuus elinpiirissä Life-Space Assessmentillä. Helsinki Birth Cohort Study –aineistosta tutkimuksessa käytettiin kahta osatutkimusaineistoa. Kognitiivinen kyvykkyys oli mitattu 360 varusmieheltä varhaisessa aikuisuudessa. Myöhemmin he osallistuivat kliinisiin tutkimuksiin, jolloin heidän fyysistä suorituskykyä arvioitiin Short Form 36 kyselyllä kahdesti keskimäärin 61 vuoden sekä 71 vuoden iässä. Neuvolakorteista saatu kävelemään oppimisikä oli tiedossa 368 mieheltä ja naiselta, jotka osallistuivat myöhemmin kognitiivisiin testeihin varhaisessa vanhuudessa 64 vuoden iässä. Kognitiivista suorituskykyä mitattiin tietokonepohjaisella CogState-testistöllä.

Henkilöillä, joilla oli parempi kognitiivinen toiminnanohjaus, oli myös laajempi liikkumisaktiivisuus elinpiirissä. Tätä yhteyttä selitti parempi alaraajojen toimintakyky ja se, että heillä ei ollut vaikeuksia käyttää kulkuneuvoja liikkumiseensa. Kahden vuoden seurannassa kognitiivinen toiminnanohjaus ennustaa voimakkaammin liikkumisaktiivisuutta elinpiirissä. Toiseen suuntaan yhteyttä ei havaittu. Parempi kognitiivinen kyvykkyys varhaisessa aikuisuudessa on yhteydessä parempaan fyysiseen suorituskykyyn varhaisessa vanhuudessa, jonka kautta välittyy myös epäsuora yhteys 10 vuotta myöhemmin mitattuun fyysiseen toimintakykyyn. Henkilöt, jotka oppivat aikaisemmin kävelemään varhaisessa lapsuudessa, suoriutuivat paremmin kognitiivisesta testistä varhaisessa vanhuudessa.

Tutkimuksen tulokset osoittivat, että kognitiivinen suorituskyky ja liikkumiskyky ovat kiinteästi yhteydessä toisiinsa läpi elämänkaaren. Väistämättömällä ikääntymiseen liittyvällä aivojen toiminnan heikentymisellä saattaa olla vaikutusta myös motoristen toimintojen heikentymiseen. Erityisesti kognitiivisen toiminnanohjauksen heikentyminen vanhuudessa saattaa ennustaa liikkumisaktiivisuuden vähenemistä elinpiirissä. Varhainen lapsuus on ajankohta, jolloin tapahtuu vilkasta aivotoiminnan kehitystä samanaikaisesti motorisen kehityksen kanssa. Varhainen aikuisuus on ajanjakso, jolloin aivojen kehitys on saavuttanut huippunsa. Aikaisempi kävelemään oppimisikä ja parempi kognitiivinen kyvykkyys nuoruudessa saattavat vaikuttaa myönteisesti henkilön kognitiiviseen reservikapasiteettiin ja tämän johdosta myös parempaan toimintakykyyn vanhuudessa. Kognitiivisia toimintoja, joita tarvitaan toiminnanohjauksessa, tulisi tukea koko elämänkaaren ajan. Kognitiivista toimintakykyä ylläpitävillä interventioilla voitaisiin mahdollisesti parantaa ikääntyvien henkilöiden toimintakykyä ja liikkumisaktiivisuutta elinpiirissä. Tutkimalla lisää vanhuuden liikkumiskykyyn elämäkulun aikana vaikuttavia tekijöitä, voisimme mahdollisesti lisätä ikääntyneiden henkilöiden mahdollisuuksia elää itsenäistä ja aktiivista elämää vanhuudessa.

Avainsanat: Kognitiivinen ikääntyminen, Kognitiivinen toiminnanohjaus, Liikkumiskyky, Fyysinen toimintakyky, Liikkumisaktiivisuus elinpiirissä, Kognitiivinen reservikapasiteetti, Elämänkulku

REFERENCES

Aalto, A., Aro, A. R. & Teperi, J. 1999. RAND-36 terveyteen liittyvän elämänlaadun mittarina: Mittarin luotettavuus ja suomalaiset väestöarvot. Stakes Helsinki.

Alfaro-Acha, A., Al Snih, S., Raji, M. A., Markides, K. S. & Ottenbacher, K. J. 2007. Does 8-Foot Walk Time Predict Cognitive Decline in Older Mexicans Americans? Journal of the American Geriatrics Society 55 (2), 245-251.

Allman, R. M., Sawyer, P. & Roseman, J. M. 2006. The UAB Study of Aging: Background and insights into life-space mobility among older Americans in rural and urban settings. Aging Health 2 (3), 417-429.

Anstey, K. J. & Low, L. 2004. Normal cognitive changes in aging. Australian Family Physician 33 (10), 783.

Anstey, K. J., Windsor, T. D., Luszcz, M. A. & Andrews, G. R. 2006. Predicting driving cessation over 5 years in older adults: Psychological well-being and cognitive competence are stronger predictors than physical health. Journal of the American Geriatrics Society 54 (1), 121-126.

Atkinson, H. H., Rapp, S. R., Williamson, J. D., Lovato, J., Absher, J. R., et al. 2010. The relationship between cognitive function and physical performance in older women: results from the women's health initiative memory study. The journals of gerontology. Series A, Biological sciences and medical sciences 65 (3), 300-306.

Auyeung, T. W., Kwok, T., Lee, J., Leung, P. C., Leung, J., et al. 2008. Functional decline in cognitive impairment--the relationship between physical and cognitive function. Neuroepidemiology 31 (3), 167-173.

Baker, P. S., Bodner, E. V. & Allman, R. M. 2003. Measuring life-space mobility in community-dwelling older adults. Journal of the American Geriatrics Society 51 (11), 1610-1614.

Ball, K., Berch, D. B., Helmers, K. F., Jobe, J. B., Leveck, M. D., et al. 2002. Effects of cognitive training interventions with older adults: a randomized controlled trial. JAMA: Journal of the American Medical Association 288 (18), 2271-2281.

Banich, M. T. 2009. Executive function the search for an integrated account. Current Directions in Psychological Science 18 (2), 89-94.

Barker, D. J. 1998. Programming baby. In Mothers, babies and health in later life. (2nd edition) Edinburg: Churchill Livingstone, 13-41.

Barker, D. J., Osmond, C., Forsen, T. J., Kajantie, E. & Eriksson, J. G. 2005. Trajectories of growth among children who have coronary events as adults. The New England Journal of Medicine 353 (17), 1802-1809.

Barnes, L. L., Wilson, R. S., Bienias, J. L., Mendes de Leon, Carlos F, Kim, H. N., et al. 2007. Correlates of life space in a volunteer cohort of older adults. Experimental Aging Research 33 (1), 77-93.

Bassuk, S. S., Glass, T. A. & Berkman, L. F. 1999. Social disengagement and incident cognitive decline in community-dwelling elderly persons. Annals of Internal Medicine 131 (3), 165-173.

Batty, G. D., Deary, I. J. & Gottfredson, L. S. 2007. Premorbid (early life) IQ and later mortality risk: systematic review. Annals of Epidemiology 17 (4), 278-288.

Beauchet, O., Annweiler, C., Callisaya, M. L., De Cock, A., Helbostad, J. L., et al. 2016. Poor gait performance and prediction of dementia: results from a meta-analysis. Journal of the American Medical Directors Association 17 (6), 482-490.

Bell-McGinty, S., Podell, K., Franzen, M., Baird, A. D. & Williams, M. J. 2002. Standard measures of executive function in predicting instrumental activities of daily living in older adults. International Journal of Geriatric Psychiatry 17 (9), 828-834.

Ben-Shlomo, Y. & Kuh, D. 2002. A life course approach to chronic disease epidemiology: conceptual models, empirical challenges and interdisciplinary perspectives. International Journal of epidemiology 31 (2), 285-293.

Best, J. R., Davis, J. C. & Liu-Ambrose, T. 2015. Longitudinal analysis of physical performance, functional status, physical activity, and mood in relation to executive function in older adults who fall. Journal of the American Geriatrics Society 63 (6), 1112-1120.

Best, J. R., Liu-Ambrose, T., Boudreau, R. M., Ayonayon, H. N., Satterfield, S., et al. 2016. An evaluation of the longitudinal, bidirectional associations between gait speed and cognition in older women and men. Journals of Gerontology Series A: Biomedical Sciences and Medical Sciences 71 (12), 1616-1623.

Best, J. R. & Miller, P. H. 2010. A developmental perspective on executive function. Child development 81 (6), 1641-1660.

Bishop, N. J., Eggum-Wilkens, N. D., Haas, S. A. & Kronenfeld, J. J. 2016. Estimating the co-development of cognitive decline and physical mobility limitations in older US adults. Demography 53 (2), 337-364.

Ble, A., Volpato, S., Zuliani, G., Guralnik, J. M., Bandinelli, S., et al. 2005. Executive function correlates with walking speed in older persons: the InCHIANTI study. Journal of the American Geriatrics Society 53 (3), 410-415.

von Bonsdorff, M. B., Rantanen, T., Sipila, S., Salonen, M. K., Kajantie, E., et al. 2011. Birth size and childhood growth as determinants of physical functioning in older age: the Helsinki Birth Cohort Study. American Journal of Epidemiology 174 (12), 1336-1344.

von Bonsdorff, M. B., Rantanen, T., Laukkanen, P., Suutama, T. & Heikkinen, E. 2006. Mobility limitations and cognitive deficits as predictors of institutionalization among community-dwelling older people. Gerontology 52 (6), 359-365.

Bowie, C. R. & Harvey, P. D. 2006. Administration and interpretation of the Trail Making Test. Nature protocols 1 (5), 2277-2281.

Braver, T. S. & West, R. 2008. Working memory, executive control, and aging. The handbook of aging and cognition (3rd edition) New York and Hove, Psychology Press, 311-372.

Brewster, P.W., Johnson, J.K., Marquine, M.J., Mungas, D.M., Reed, B., Nápoles, A. 2018. Aging and cognitive functioning. In Satariano, W.A. & Maus, M. (Eds.) Aging, place and health. Burlington, MA: Jones & Barlett Learning, 113-134.

Brewster, P. W., Melrose, R. J., Marquine, M. J., Johnson, J. K., Napoles, A., et al. 2014. Life experience and demographic influences on cognitive function in older adults. Neuropsychology 28 (6), 846.

Cahn-Weiner, D. A., Boyle, P. A. & Malloy, P. F. 2002. Tests of executive function predict instrumental activities of daily living in community-dwelling older individuals. Applied Neuropsychology 9 (3), 187-191.

Cahn-Weiner, D. A., Farias, S. T., Julian, L., Harvey, D. J., Kramer, J. H., et al. 2007. Cognitive and neuroimaging predictors of instrumental activities of daily living. Journal of the International Neuropsychological Society 13 (5), 747-757.

Callisaya, M. L., Blizzard, C. L., Wood, A. G., Thrift, A. G., Wardill, T., et al. 2015. Longitudinal relationships between cognitive decline and gait slowing: the Tasmanian Study of Cognition and Gait. Journals of Gerontology Series A: Biomedical Sciences and Medical Sciences 70 (10), 1226-1232.

Carlson, M. C., Fried, L. P., Xue, Q., Bandeen-Roche, K., Zeger, S. L., et al. 1999. Association between executive attention and physical functional performance in community-dwelling older women. The Journals of Gerontology Series B: Psychological Sciences and Social Sciences 54 (5), S270.

Central Statistical Office of Finland 1989. Classification of Socioeconomic Groups: Handbooks 17. Helsinki, Finland: Central Statistical Office of Finland.

Chodzko-Zajko, W. J. Moore, K.A. 1994. Physical fitness, cognitive performance, and aging. Exercise and Sport Science Reviews 22 (1), 195-220.

Chodzko-Zajko, W. J., Schuler, P., Solomon, J., Heinl, B. & Ellis, N. R. 1992. The influence of physical fitness on automatic and effortful memory changes in aging. The International Journal of Aging and Human Development 35 (4), 265-285.

Christensen, H. & Mackinnon, A. 1993. The association between mental, social and physical activity and cognitive performance in young and old subjects. Age and Ageing 22 (3), 175-182.

Christensen, H. 2001. What cognitive changes can be expected with normal ageing? Australian & New Zealand Journal of Psychiatry 35 (6), 768-775.

Clark, D. J., Rose, D. K., Ring, S. A. & Porges, E. C. 2014. Utilization of central nervous system resources for preparation and performance of complex walking tasks in older adults. Frontiers in Aging Neuroscience 6, 217.

Clouston, S. A., Brewster, P., Kuh, D., Richards, M., Cooper, R., et al. 2013. The Dynamic Relationship between Physical Function and Cognition in Longitudinal Aging Cohorts. Epidemiologic Reviews 35 (1), 33-50.

Colcombe, S. & Kramer, A. F. 2003. Fitness effects on the cognitive function of older adults: a meta-analytic study. Psychological Science 14 (2), 125-130.

Collie, A. & Maruff, P. 2003. Computerised neuropsychological testing. British Journal of Sports Medicine 37 (1), 2-3.

Craik, F. I. & Bialystok, E. 2006. Cognition through the lifespan: mechanisms of change. Trends in Cognitive Sciences 10 (3), 131-138.

Crowe, M., Andel, R., Wadley, V. G., Okonkwo, O. C., Sawyer, P., et al. 2008. Life-space and cognitive decline in a community-based sample of African American and Caucasian older adults. The Journals of Gerontology. Series A, Biological Sciences and Medical Sciences 63 (11), 1241-1245.

Curcio, C., Alvarado, B. E., Gomez, F., Guerra, R., Guralnik, J., et al. 2013. Life-Space Assessment scale to assess mobility: validation in Latin American older women and men. Aging Clinical and Experimental Research 25 (5), 553-560.

Dahlin, E., Nyberg, L., Bäckman, L. & Neely, A. S. 2008. Plasticity of executive functioning in young and older adults: immediate training gains, transfer, and long-term maintenance. Psychology and Aging 23 (4), 720.

Darby, D., Maruff, P., Collie, A. & McStephen, M. 2002. Mild cognitive impairment can be detected by multiple assessments in a single day. Neurology 59 (7), 1042-1046.

Davis, J. C., Marra, C. A., Najafzadeh, M. & Liu-Ambrose, T. 2010. The independent contribution of executive functions to health related quality of life in older women. BMC Geriatrics 10 (1), 16.

Davis, M. G., Fox, K. R., Hillsdon, M., Sharp, D. J., Coulson, J. C., et al. 2011. Objectively measured physical activity in a diverse sample of older urban UK adults. Medicine & Science in Sports & Exercise 43 (4), 647-654.

Deary, I. J., Whiteman, M. C., Starr, J. M., Whalley, L. J. & Fox, H. C. 2004. The impact of childhood intelligence on later life: following up the Scottish mental surveys of 1932 and 1947. Journal of Personality and Social Psychology 86 (1), 130-147.

Delis, D. C., Kaplan, E. & Kramer, J. H. 2001. Delis-Kaplan Executive function system: examiners manual. Psychological Corporation.

Demakis, G. J. 2004. Frontal lobe damage and tests of executive processing: a meta-analysis of the category test, stroop test, and trail-making test. Journal of Clinical and Experimental Neuropsychology 26 (3), 441-450.

Demnitz, N., Esser, P., Dawes, H., Valkanova, V., Johansen-Berg, H., et al. 2016. A systematic review and meta-analysis of cross-sectional studies examining the relationship between mobility and cognition in healthy older adults. Gait & Posture 50, 164-174.

Demnitz, N., Zsoldos, E., Mahmood, A., Mackay, C. E., Kivimäki, M., et al. 2017. Associations between mobility, cognition, and brain structure in healthy older adults. Frontiers in Aging Neuroscience 9, 155.

Diamond, A. 2000. Close interrelation of motor development and cognitive development and of the cerebellum and prefrontal cortex. Child Development 71 (1), 44-56.

Di Carlo, A., Balderreschi, M., Lamassa, M., Bovis, F., Inzitari, M., et al. 2016. Daily functions as predictors of dementia in cognitive impairment, nodementia (CIND) and mild cognitve impairment (MCI): an 8-year fllow-up in the ILSA Study. Journal of Alzheimer's disease 53, 505-515.

Drane, D. L., Yuspeh, R. L., Huthwaite, J. S. & Klingler, L. K. 2002. Demographic characteristics and normative observations for derived-trail making test indices. Neuropsychiatry, Neuropsychology, and Behavioral Neurology 15 (1), 39-43.

Eriksson, J. G., Forsen, T., Tuomilehto, J., Osmond, C. & Barker, D. J. 2001. Early growth and coronary heart disease in later life: longitudinal study. British Medical Journal (Clinical research ed.) 322 (7292), 949-953.

Eriksson, J. G., Osmond, C., Perala, M. M., Salonen, M. K., Simonen, M., et al. 2015. Prenatal and childhood growth and physical performance in old age--findings from the Helsinki Birth Cohort Study 1934-1944. Age (Dordrecht, Netherlands) 37 (6), 108.

Etnier, J. L. & Chang, Y. 2009. The effect of physical activity on executive function: a brief commentary on definitions, measurement issues, and the current state of the literature. Journal of Sport and Exercise Psychology 31 (4), 469-483.

Falleti, M.C., Maruff, P., Collie, A., Darby, D.G. 2006. Practice effects associated with the repeated assessment of cognitive function using CogState battery 10-minute, one week and one month test-retest intervals. Journal of Clinical and Experimental Neuropsychology 28, 1095-1112.

Farias, S. T., Mungas, D. & Jagust, W. 2005. Degree of discrepancy between self and other-reported everyday functioning by cognitive status: Dementia, mild cognitive impairment, and healthy elders. International journal of geriatric psychiatry 20 (9), 827-834.

Ferrucci, L., Cooper, R., Shardell, M., Simonsick, E. M., Schrack, J. A., et al. 2016. Age-related change in mobility: perspectives from life course epidemiology and geroscience. Journals of Gerontology Series A: Biomedical Sciences and Medical Sciences 71 (9), 1184-1194.

Folstein, M. F., Folstein, S. E. & McHugh, P. R. 1975. "Mini-mental state": A practical method for grading the cognitive state of patients for the clinician. Journal of Psychiatric Research 12 (3), 189-198.

Forte, R., Pesce, C., Leite, J. C., De Vito, G., Gibney, E. R., et al. 2013. Executive function moderates the role of muscular fitness in determining functional mobility in older adults. Aging Clinical and Experimental Research 25 (3), 291-298.

Fratiglioni, L., Paillard-Borg, S. & Winblad, B. 2004. An active and socially integrated lifestyle in late life might protect against dementia. The Lancet Neurology 3 (6), 343-353.

Gale, C. R., Allerhand, M., Sayer, A. A., Cooper, C. & Deary, I. J. 2014. The dynamic relationship between cognitive function and walking speed: the English Longitudinal Study of Ageing. Age 36 (4), 9682.

Gale, C. R., O'Callaghan, F. J., Godfrey, K. M., Law, C. M. & Martyn, C. N. 2004. Critical periods of brain growth and cognitive function in children. Brain 127 (2), 321-329.

Gallahue, D. L., Ozmun, J. C. & Goodway, J. D. 2012. Understanding motor development: Infants, Children, Adolescents, Adults. (7th edition) New York: McGraw-Hill International edition, 2-22.

Giedd, J. N., Blumenthal, J., Jeffries, N. O., Castellanos, F. X., Liu, H., et al. 1999. Brain development during childhood and adolescence: a longitudinal MRI study. Nature neuroscience 2 (10), 861-863.

Gilbert, S. J. & Burgess, P. W. 2008. Executive function. Current Biology 18 (3), R114.

Giuli, C., Papa, R., Lattanzio, F. & Postacchini, D. 2016. The effects of cognitive training for elderly: Results from My Mind Project. Rejuvenation Research 19 (6), 485-494.

Gluckman, P. D., Hanson, M. A. & Beedle, A. S. 2007. Early life events and their consequences for later disease: a life history and evolutionary perspective. American Journal of Human Biology 19 (1), 1-19.

Greiner, P. A., Snowdon, D. A. & Schmitt, F. A. 1996. The loss of independence in activities of daily living: the role of low normal cognitive function in elderly nuns. American Journal of Public Health 86 (1), 62-66.

Gross, A. L., Xue, Q. L., Bandeen-Roche, K., Fried, L. P., Varadhan, R., et al. 2016. Declines and Impairment in Executive Function Predict Onset of Physical Frailty. The journals of gerontology. Series A, Biological sciences and medical sciences 71 (12), 1624-1630.

Gunning-Dixon, F. M., Brickman, A. M., Cheng, J. C. & Alexopoulos, G. S. 2009. Aging of cerebral white matter: a review of MRI findings. International Journal of Geriatric Psychiatry 24 (2), 109-117.

Guralnik, J. M., Simonsick, E. M., Ferrucci, L., Glynn, R. J., Berkman, L. F., et al. 1994. A short physical performance battery assessing lower extremity function: association with self-reported disability and prediction of mortality and nursing home admission. Journal of Gerontology 49 (2), 85.

Guralnik, J. M. & Ferrucci, L. 2003. Assessing the building blocks of function: utilizing measures of functional limitation. American Journal of Preventive Medicine 25 (3), 112-121.

Guttmann, C. R., Jolesz, F. A., Kikinis, R., Killiany, R. J., Moss, M. B., et al. 1998. White matter changes with normal aging. Neurology 50 (4), 972-978.

Hausdorff, J. M., Yogev, G., Springer, S., Simon, E. S. & Giladi, N. 2005. Walking is more like catching than tapping: gait in the elderly as a complex cognitive task. Experimental Brain Research 164 (4), 541-548.

Hedden, T. & Gabrieli, J. D. 2004. Insights into the ageing mind: a view from cognitive neuroscience. Nature reviews. Neuroscience 5 (2), 87-96.

Hillman, C. H., Erickson, K. I. & Kramer, A. F. 2008. Be smart, exercise your heart: exercise effects on brain and cognition. Nature reviews neuroscience 9 (1), 58-65.

Hirvensalo, M., Rantanen, T. & Heikkinen, E. 2000. Mobility Difficulties and Physical Activity as Predictors of Mortality and Loss of Independence in the Community-Living Older Population. Journal of the American Geriatrics Society 48 (5), 493-498.

Holtzer, R., Epstein, N., Mahoney, J. R., Izzetoglu, M. & Blumen, H. M. 2014. Neuroimaging of mobility in aging: a targeted review. The journals of gerontology. Series A, Biological Sciences and Medical Sciences 69 (11), 1375-1388.

Holtzman, R. E., Rebok, G. W., Saczynski, J. S., Kouzis, A. C., Wilcox Doyle, K., et al. 2004. Social network characteristics and cognition in middle-aged and older adults. The Journals of Gerontology Series B: Psychological Sciences and Social Sciences 59 (6), P284.

Hultsch, D. F., Hertzog, C., Small, B. J. & Dixon, R. A. 1999. Use it or lose it: engaged lifestyle as a buffer of cognitive decline in aging? Psychology and aging 14 (2), 245.

Hurst, L., Stafford, M., Cooper, R., Hardy, R., Richards, M., et al. 2013. Lifetime socioeconomic inequalities in physical and cognitive aging. American Journal of Public Health 103 (9), 1641-1648.

Iersel, M. B. v., Kessels, R. P., Bloem, B. R., Verbeek, A. L. & Olde Rikkert, M. G. 2008. Executive functions are associated with gait and balance in community-living elderly people. The Journals of Gerontology Series A: Biological Sciences and Medical Sciences 63 (12), 1344-1349.

Inzitari, M., Baldereschi, M., Carlo, A. D., Bari, M. D., Marchionni, N., et al. 2007. Impaired attention predicts motor performance decline in older community-dwellers with normal baseline mobility: results from the Italian Longitudinal Study on Aging (ILSA). The Journals of Gerontology Series A: Biological Sciences and Medical Sciences 62 (8), 837-843.

Inzitari, M., Newman, A. B., Yaffe, K., Boudreau, R., De Rekeneire, N., et al. 2007. Gait speed predicts decline in attention and psychomotor speed in older adults: the health aging and body composition study. Neuroepidemiology 29 (3-4), 156-162.

James, B. D., Boyle, P. A., Buchman, A. S., Barnes, L. L. & Bennett, D. A. 2011. Life space and risk of Alzheimer disease, mild cognitive impairment, and cognitive decline in old age. The American Journal of Geriatric Psychiatry 19 (11), 961-969.

Jarchi, D., Pope, J., Lee, T.K.M., Tamjidi, L., MirZaei, A., et al. 2018. A review on accelerometry based gait analysis and emerging clinical applications. Reviews in Biomedical Engingeering. E-pub ahead of print.

Jenkins, J. J. 1979. Four points to remember: A tetrahedral model of memory experiments. Levels of processing in human memory Erlbaum Hillsdale, 429-446.

Jobe, J. B., Smith, D. M., Ball, K., Tennstedt, S. L., Marsiske, M., et al. 2001. ACTIVE: A cognitive intervention trial to promote independence in older adults. Controlled Clinical Trials 22 (4), 453-479.

Johnson, J. K., Lui, L. Y. & Yaffe, K. 2007. Executive function, more than global cognition, predicts functional decline and mortality in elderly women. The journals of gerontology.S eries A, Biological Sciences and Medical Sciences 62 (10), 1134-1141.

Jonker, C., Geerlings, M. I. & Schmand, B. 2000. Are memory complaints predictive for dementia? A review of clinical and population-based studies. International Journal of Geriatric Psychiatry 15 (11), 983-991.

Juby, A., Tench, S. & Baker, V. 2002. The value of clock drawing in identifying executive cognitive dysfunction in people with a normal Mini-Mental State Examination score. Canadian Medical Association Journal 167 (8), 859-864.

Keay, L., Munoz, B., Turano, K. A., Hassan, S. E., Munro, C. A., et al. 2009. Visual and cognitive deficits predict stopping or restricting driving: the Salisbury Eye Evaluation Driving Study (SEEDS). Investigative Ophthalmology & Visual Science 50 (1), 107-113.

Kelly, M. E., Loughrey, D., Lawlor, B. A., Robertson, I. H., Walsh, C., et al. 2014. The impact of cognitive training and mental stimulation on cognitive and everyday functioning of healthy older adults: a systematic review and meta-analysis. Ageing Research Reviews 15, 28-43.

Killane, I., Donoghue, O. A., Savva, G. M., Cronin, H., Kenny, R. A., et al. 2014. Relative association of processing speed, short-term memory and sustained attention with task on gait speed: a study of community-dwelling people 50 years and older. Journals of Gerontology Series A: Biomedical Sciences and Medical Sciences 69 (11), 1407-1414.

Kivipelto, M., Solomon, A., Ahtiluoto, S., Ngandu, T., Lehtisalo, J., et al. 2013. The Finnish geriatric intervention study to prevent cognitive impairment and disability (FINGER): study design and progress. Alzheimer's & Dementia: the Journal of the Alzheimer's Association 9 (6), 657-665.

Kramer, A. F., Bherer, L., Colcombe, S. J., Dong, W. & Greenough, W. T. 2004. Environmental influences on cognitive and brain plasticity during aging. The Journals of Gerontology Series A: Biological Sciences and Medical Sciences 59 (9), M957.

Kramer, A. F., Hahn, S., Cohen, N. J., Banich, M. T., McAuley, E., et al. 1999. Ageing, fitness and neurocognitive function. Nature 400 (6743), 418-419.

Kueper, J. K., Speechley, M., Lingum, N. R. & Montero-Odasso, M. 2017. Motor function and incident dementia: a systematic review and meta-analysis. Age and Ageing 46 (5), 729-738.

Kuh, D., Bassey, J., Hardy, R., Aihie Sayer, A., Wadsworth, M., et al. 2002. Birth weight, childhood size, and muscle strength in adult life: evidence from a birth cohort study. American Journal of Epidemiology 156 (7), 627-633.

Kuh, D., Cooper, R., Hardy, R., Guralnik, J., Richards, M., et al. 2009. Lifetime cognitive performance is associated with midlife physical performance in a prospective national birth cohort study. Psychosomatic Medicine 71 (1), 38-48.

Kuh, D., Hardy, R., Butterworth, S., Okell, L., Richards, M., et al. 2006. Developmental origins of midlife physical performance: evidence from a British birth cohort. American Journal of Epidemiology 164 (2), 110-121.

Kuh, D., Hardy, R., Butterworth, S., Okell, L., Wadsworth, M., et al. 2006. Developmental origins of midlife grip strength: findings from a birth cohort study. The journals of gerontology. Series A, Biological sciences and medical sciences 61 (7), 702-706.

Kuh, D. 2007. A life course approach to healthy aging, frailty, and capability. The Journals of Gerontology Series A: Biological Sciences and Medical Sciences 62 (7), 717-721.

Kuh, D., Ben-Shlomo, Y., Lynch, J., Hallqvist, J. & Power, C. 2003. Life course epidemiology. Journal of Epidemiology & Community Health 57 (10), 778-783.

Kuh, D., Cooper, R., Hardy, R., Richards, M. & Ben-Shlomo, Y. 2014. A life course epidemiology, aging research, and maturing cohort studies: a dynamic combination for understanding healthy aging. In Kuh, D., Cooper, R., Haedy, R., Richards M. & Ben-Shlomo (Eds.) A life course approach to healthy ageing. Oxford Oxford University Press, 3-15.

Kuh, D., Karunananthan, S., Bergman, H. & Cooper, R. 2014. A life course approach to healthy ageing: maintaining physical capability. Proceedings of the Nutrition Society 73 (2), 237-248.

Kuh, D. & Shlomo, Y. B. 2004. A life course approach to chronic disease epidemiology: tracing the origins of ill-health from early to adult life. (2nd Edition) Oxford Oxford University Press.

Kulmala, J. 2016. Physical activity in maintaining cognitive functioning in older age-mini-review of recent European studies. Social Inquiry into Well-being 2 (1), 45-50.

Latham, N. K., Mehta, V., Nguyen, A. M., Jette, A. M., Olarsch, S., et al. 2008. Performance-based or self-report measures of physical function: which should be used in clinical trials of hip fracture patients? Archives of Physical Medicine and Rehabilitation 89 (11), 2146-2155.

Lawton, M. & Brody, E. 1969. Assessment of older people: self-maintaining and instrumental activities of daily living. Gerontologist 9, 179-186.

Lezak, M. (Ed.) 1995. Neuropsychological Assessment. (3rd edition) Oxford Oxford University Press, 381-384.

Liu-Ambrose, T., Donaldson, M. G., Ahamed, Y., Graf, P., Cook, W. L., et al. 2008. Otago home-based strength and balance retraining improves executive functioning in older fallers: a randomized controlled trial. Journal of the American Geriatrics Society 56 (10), 1821-1830.

Liu-Ambrose, T., Davis, J. C., Nagamatsu, L. S., Hsu, C. L., Katarynych, L. A., et al. 2010. Changes in executive functions and self-efficacy are independently associated with improved usual gait speed in older women. BMC: Geriatrics 10 (1), 25.

Lytle, M. E., Vander Bilt, J., Pandav, R. S., Dodge, H. H. & Ganguli, M. 2004. Exercise level and cognitive decline: the MoVIES project. Alzheimer Disease & Associated Disorders 18 (2), 57-64.

Lyyra, T., Leskinen, E. & Heikkinen, E. 2005. A cohort study found good respiratory, sensory and motor functions decreased mortality risk in older people. Journal of Clinical Epidemiology 58 (5), 509-516.

Malina, R. M. 2004. Motor development during infancy and early childhood: overview and suggested directions for research. International Journal of Sport and Health Science 2, 50-66.

Marshall, G. A., Rentz, D. M., Frey, M. T., Locascio, J. J., Johnson, K. A., et al. 2011. Executive function and instrumental activities of daily living in mild cognitive impairment and Alzheimer's disease. Alzheimer's & dementia: the journal of the Alzheimer's Association 7 (3), 300-308.

May, D., Nayak, U. & Isaacs, B. 1985. The life-space diary: a measure of mobility in old people at home. International Rehabilitation Medicine 7 (4), 182-186.

McDonough, C. M., Goehring, L.A., Marino, M.E., Jette, A. M. 2018. Aging and late life mobility. In Satariano, W.A. & Maus, M. (Eds.) Aging, place and health. Burlington, MA: Jones & Barlett Learning, 91-112.

McGough, E. L., Kelly, V. E., Logsdon, R. G., McCurry, S. M., Cochrane, B. B., et al. 2011. Associations between physical performance and executive function in older adults with mild cognitive impairment: gait speed and the timed "up & go" test. Physical Therapy 91 (8), 1198-1207.

Mielke, M. M., Roberts, R. O., Savica, R., Cha, R., Drubach, D. I., et al. 2013. Assessing the temporal relationship between cognition and gait: slow gait predicts cognitive decline in the Mayo Clinic Study of Aging. The journals of gerontology. Series A, Biological Sciences and Medical Sciences 68 (8), 929-937.

Morris, J. C., Heyman, A., Mohs, R. C., Hughes, J. P., Van Belle, G., et al. 1989. The consortium to establish a registry for Alzheimer's disease (CERAD): I. Clinical and neuropsychological assessment of Alzheimer's disease. Neurology 39, 1159-1165.

Morris, M. C., Evans, D. A., Tangney, C. C., Bienias, J. L. & Wilson, R. S. 2006. Associations of vegetable and fruit consumption with age-related cognitive change. Neurology 67 (8), 1370-1376.

Moscovitch, M. & Winocur, G. 1995. Frontal lobes, memory, and aging. Annals of the New York Academy of Sciences 769 (1), 119-150.

Murray, G. K., Jones, P. B., Kuh, D. & Richards, M. 2007. Infant developmental milestones and subsequent cognitive function. Annals of Neurology 62 (2), 128-136.

Murray, G. K., Veijola, J., Moilanen, K., Miettunen, J., Glahn, D. C., et al. 2006. Infant motor development is associated with adult cognitive categorisation in a longitudinal birth cohort study. Journal of Child Psychology and psychiatry, and Allied Disciplines 47 (1), 25-29.

Muthén, L. K. & Muthén, B. O. 1998. Mplus user's guide: Statistical analysis with latent variables. Los Angeles, CA: Muthén & Muthén.

Muthén, L. K. & Muthén, B. O. 2012. Mplus Version 7 user’s guide. Los Angeles, CA: Muthén & Muthén.

Mäkilä, P., Hirvensalo, M. & Parkatti, T. 2010. Changes in physical activity involvement and attitude to physical activity in a 16-year follow-up study among the elderly. Journal of Aging Research, Article ID 174290, 7.

Mänty, M., Heinonen, A., Viljanen, A., Pajala, S., Koskenvuo, M., et al. 2010. Self-reported preclinical mobility limitation and fall history as predictors of future falls in older women: prospective cohort study. Osteoporosis International 21 (4), 689-693.

Mänty, M. 2007. Iäkkäiden henkilöiden kaatumistapaturmat: Opas kaatumisten ja murtumien ehkäisyyn. (2nd ed.) National Public Health Institute.

Nagi, S. Z. 1976. An epidemiology of disability among adults in the United States. The Milbank Memorial Fund Quarterly. Health and Society, 439-467.

Netuveli, G., Wiggins, R. D., Hildon, Z., Montgomery, S. M. & Blane, D. 2006. Quality of life at older ages: evidence from the English longitudinal study of aging (wave 1). Journal of Epidemiology & Community Health 60 (4), 357-363.

Oh-Park, M., Wang, C. & Verghese, J. 2011. Stair negotiation time in community-dwelling older adults: normative values and association with functional decline. Archives of Physical Medicine and Rehabilitation 92 (12), 2006-2011.

Paile-Hyvärinen, M., Räikkonen, K., Kajantie, E., Darby, D., Ylihärsilä, H., et al. 2009. Impact of glucose metabolism and birth size on cognitive performance in elderly subjects. Diabetes Research and Clinical Practice 83 (3), 379-386.

Park, D. C., Lautenschlager, G., Hedden, T., Davidson, N. S., Smith, A. D., et al. 2002. Models of visuospatial and verbal memory across the adult life span. Psychology and Aging 17 (2), 299.

Parker, M., Baker, P. S. & Allman, R. M. 2002. A life-space approach to functional assessment of mobility in the elderly. Journal of Gerontological Social Work 35 (4), 35-55.

Pashler, H. 1994. Dual-task interference in simple tasks: data and theory. Psychological Bulletin 116 (2), 220.

Peel, C., Sawyer Baker, P., Roth, D. L., Brown, C. J., Brodner, E. V., et al. 2005. Assessing mobility in older adults: the UAB Study of Aging Life-Space Assessment. Physical Therapy 85 (10), 1008-1119.

Petersen, R. C. 1995. Normal aging, mild cognitive impairment and Alzheimer's disease. The Neurologist 4, 326-344.

Petersen, R. C. 2011. Mild cognitive impairment. New England Journal of Medicine 364 (23), 2227-2234.

Petersen, R. C., Caracciolo, B., Brayne, C., Gauthier, S., Jelic, V., et al. 2014. Mild cognitive impairment: a concept in evolution. Journal of Internal Medicine 275 (3), 214-228.

Petersen, R. C., Smith, G. E., Waring, S. C., Ivnik, R. J., Tangalos, E. G., et al. 1999. Mild cognitive impairment: clinical characterization and outcome. Archives of Neurology 56 (3), 303-308.

Podsiadlo, D. & Richardson, S. 1991. The timed “Up & Go”: a test of basic functional mobility for frail elderly persons. Journal of the American Geriatrics Society 39 (2), 142-148.

Polku, H., Mikkola, T. M., Portegijs, E., Rantakokko, M., Kokko, K., et al. 2015. Life-space mobility and dimensions of depressive symptoms among community-dwelling older adults. Aging & Mental Health 19 (9), 781-789.

Portegijs, E., Iwarsson, S., Rantakokko, M., Viljanen, A. & Rantanen, T. 2014a. Life-space mobility assessment in older people in Finland; measurement properties in winter and spring. BMC Research Notes 7 (1), 323.

Portegijs, E., Rantakokko, M., Mikkola, T. M., Viljanen, A. & Rantanen, T. 2014b. Association Between Physical Performance and Sense of Autonomy in Outdoor Activities and Life-Space Mobility in Community-Dwelling Older People. Journal of the American Geriatrics Society 62 (4), 615-621.

Portegijs, E., Rantakokko, M., Viljanen, A., Sipilä, S. & Rantanen, T. 2016. Identification of older people at risk of ADL disability using the life-space assessment: a longitudinal cohort study. Journal of the American Medical Directors Association 17 (5), 410-414.

Pruitt, L. A., Glynn, N. W., King, A. C., Guralnik, J. M., Aiken, E. K., et al. 2008. Use of accelerometry to measure physical activity in older adults at risk for mobility disability. Journal of Aging and Physical Activity 16 (4), 416-434.

Puente, A. N., Lindbergh, C. A. & Miller, L. S. 2015. The Relationship between Cognitive Reserve and Functional Ability is mediated by Executive Functioning in Older Adults. The Clinical Neuropsychologist 29 (1), 67-81.

Rantakokko, M., Mänty, M. & Rantanen, T. 2013. Mobility decline in old age. Exercise and sport sciences reviews 41 (1), 19-25.

Rantakokko, M., Iwarsson, S., Kauppinen, M., Leinonen, R., Heikkinen, E., et al. 2010. Quality of life and barriers in the urban outdoor environment in old age. Journal of the American Geriatrics Society 58 (11), 2154-2159.

Rantakokko, M., Portegijs, E., Viljanen, A., Iwarsson, S., Kauppinen, M., et al. 2015. Changes in life-space mobility and quality of life among community-dwelling older people: a 2-year follow-up study. Quality of Life Research 25 (5), 1189-1197.

Rantakokko, M., Portegijs, E., Viljanen, A., Iwarsson, S. & Rantanen, T. 2017. Task modification in walking postpone decline in life-space mobility among community-dwelling older peoplea. a 2-year follow-up study. The Journals of Gerontology: Series A: Biomedical Sciences and Medical Sciences 72 (9), 1252-1256.

Rantanen, T., Portegijs, E., Viljanen, A., Eronen, J., Saajanaho, M., et al. 2012. Individual and environmental factors underlying life space of older people - study protocol and design of a cohort study on life-space mobility in old age (LISPE). BMC Public Health 12, 1018.

Rantanen, T. 2013. Promoting mobility in older people. Journal of Preventive Medicine and Public Health 46 (Suppl 1), S54.

Raz, N., Gunning-Dixon, F., Head, D., Rodrigue, K. M., Williamson, A., et al. 2004. Aging, sexual dimorphism, and hemispheric asymmetry of the cerebral cortex: replicability of regional differences in volume. Neurobiology of Aging 25 (3), 377-396.

Raz, N. & Rodrigue, K. M. 2006. Differential aging of the brain: patterns, cognitive correlates and modifiers. Neuroscience & Biobehavioral Reviews 30 (6), 730-748.

Reitan,R., Wolfson,D. (Ed.) 1993. The Halstead-Reitan Neutopsychologic Test Battery: Theory and clinical interpretation. Tucson, AZ: Neuropsychology Press.

Ren, J., Wu, Y. D., Chan, J. S. & Yan, J. H. 2013. Cognitive aging affects motor performance and learning. Geriatrics & Gerontology International 13 (1), 19-27.

Resnick, S. M., Pham, D. L., Kraut, M. A., Zonderman, A. B. & Davatzikos, C. 2003. Longitudinal magnetic resonance imaging studies of older adults: a shrinking brain. Journal of Neuroscience 23 (8), 3295-3301.

Reuben, D. B., Magasi, S., McCreath, H. E., Bohannon, R. W., Wang, Y., et al. 2013. Motor assessment using the NIH Toolbox. Neurology 80 (11 Supplement 3), S75.

Richards, M. & Deary, I. J. 2005. A life course approach to cognitive reserve: a model for cognitive aging and development? Annals of Neurology 58 (4), 617-622.

Ridgway, C. L., Ong, K. K., Tammelin, T., Sharp, S. J., Ekelund, U., et al. 2009. Birth size, infant weight gain, and motor development influence adult physical performance. Medicine and Science in Sports and Exercise 41 (6), 1212-1221.

Ridler, K., Veijola, J. M., Tanskanen, P., Miettunen, J., Chitnis, X., et al. 2006. Fronto-cerebellar systems are associated with infant motor and adult executive functions in healthy adults but not in schizophrenia. Proceedings of the National Academy of Sciences of the United States of America 103 (42), 15651-15656.

Rikli, R. E. & Edwards, D. J. 1991. Effects of a three-year exercise program on motor function and cognitive processing speed in older women. Research Quarterly for Exercise and Sport 62 (1), 61-67.

Romine, C. B. & Reynolds, C. R. 2005. A model of the development of frontal lobe functioning: Findings from a meta-analysis. Applied Neuropsychology 12 (4), 190-201.

Rosano, C., Simonsick, E. M., Harris, T. B., Kritchevsky, S. B., Brach, J., et al. 2005. Association between physical and cognitive function in healthy elderly: the health, aging and body composition study. Neuroepidemiology 24 (1-2), 8-14.

Rosano, C., Studenski, S. A., Aizenstein, H. J., Boudreau, R. M., Longstreth, W. T.,Jr, et al. 2012. Slower gait, slower information processing and smaller prefrontal area in older adults. Age and Ageing 41 (1), 58-64.

Rosano, C., Newman, A. B., Katz, R., Hirsch, C. H. & Kuller, L. H. 2008. Association between lower digit symbol substitution test score and slower gait and greater risk of mortality and of developing incident disability in well-functioning older adults. Journal of the American Geriatrics Society 56 (9), 1618-1625.

Rose, S. A., Feldman, J. F. & Jankowski, J. J. 2012. Implications of infant cognition for executive functions at age 11. Psychological Science 23 (11), 1345-1355.

Rosso, A. L., Studenski, S. A., Chen, W. G., Aizenstein, H. J., Alexander, N. B., et al. 2013. Aging, the central nervous system, and mobility. The journals of gerontology. Series A, Biological Sciences and Medical Sciences 68 (11), 1379-1386.

Royall, D. R., Palmer, R., Chiodo, L. K. & Polk, M. J. 2004. Declining executive control in normal aging predicts change in functional status: the Freedom House Study. Journal of the American Geriatrics Society 52 (3), 346-352.

Rudman, D. L., Friedland, J., Chipman, M. & Sciortino, P. 2006. Holding on and letting go: The perspectives of pre-seniors and seniors on driving self-regulation in later life. Canadian Journal on Aging/La Revue Canadienne du Vieillissement 25 (1), 65-76.

Räikkonen, K., Forsen, T., Henriksson, M., Kajantie, E., Heinonen, K., et al. 2009. Growth trajectories and intellectual abilities in young adulthood: The Helsinki Birth Cohort study. American Journal of Epidemiology 170 (4), 447-455.

Räikkonen, K., Kajantie, E., Pesonen, A. K., Heinonen, K., Alastalo, H., et al. 2013. Early life origins cognitive decline: findings in elderly men in the Helsinki Birth Cohort Study. PloS one 8 (1), e54707.

Sainio, P., Stenholm, S., Vaara, M., Rask, S., Valkeinen, H. & Rantanen, T. 2012. Fyysinen toimintakyky. In Koskinen, S., Lundqvist, A. & Ristiluoma, N. (Eds.), Health, functional capacity and welfare in Finland in 2011 (pp. 120-124). Helsinki: Natonal Institute for Health and Welfare (THL), Report 68/2012.

Salthouse, T. A. 2009. When does age-related cognitive decline begin? Neurobiology of Aging 30 (4), 507-514.

Salthouse, T. A. 2006. Mental exercise and mental aging: Evaluating the validity of the "use it or lose it" hypothesis. Perspectives on Psychological Science 1 (1), 68-87.

Salthouse, T. A. 1996. The processing-speed theory of adult age differences in cognition. Psychological Review 103 (3), 403.

Salthouse, T. A., Atkinson, T. M. & Berish, D. E. 2003. Executive functioning as a potential mediator of age-related cognitive decline in normal adults. Journal of Experimental Psychology: General 132 (4), 566.

Salthouse, T. A., Berish, D. E. & Miles, J. D. 2002. The role of cognitive stimulation on the relations between age and cognitive functioning. Psychology and Aging 17 (4), 548.

Sartori, A. C., Wadley, V. G., Clay, O. J., Parisi, J. M., Rebok, G. W., et al. 2012. The relationship between cognitive function and life space: the potential role of personal control beliefs. Psychology and Aging 27 (2), 364.

Satariano, W. A., Guralnik, J. M., Jackson, R. J., Marottoli, R. A., Phelan, E. A., et al. 2012. Mobility and aging: new directions for public health action. American Journal of Public Health 102 (8), 1508-1515.

Sawyer, P. & Allman, R. M. 2010. Resilience in mobility in the context of chronic disease and aging: cross-sectional and prospective findings from the University of Alabama at Birmingham (UAB) Study of Aging. In Fry, P.S.& Keyes, C.L.M. (Eds.) Frontiers of Resilient Aging: Life-strengths and Wellness in Late Life Cambridge Cambridge University Press, 310-339.

Schaie, K. W., Willis, S. L. & Caskie, G. I. 2004. The Seattle longitudinal study: Relationship between personality and cognition. Aging Neuropsychology and Cognition 11 (2-3), 304-324.

Schooler, C. 1984. Psychological effects of complex environments during the life span: A review and theory. Intelligence 8 (4), 259-281.

Seidler, R. D., Purushotham, A., Kim, S., Uğurbil, K., Willingham, D., et al. 2002. Cerebellum activation associated with performance change but not motor learning. Science 296 (5575), 2043-2046.

Seidler, R. D., Bernard, J. A., Burutolu, T. B., Fling, B. W., Gordon, M. T., et al. 2010. Motor control and aging: links to age-related brain structural, functional, and biochemical effects. Neuroscience & Biobehavioral Reviews 34 (5), 721-733.

Sheppard, K. D., Sawyer, P., Ritchie, C. S., Allman, R. M. & Brown, C. J. 2013. Life-space mobility predicts nursing home admission over 6 years. Journal of Aging and Health 25 (6), 907-920.

Shimada, H., Makizako, H., Tsutsumimoto, K., Verghese, J. & Suzuki, T. 2017. Motoric cognitive risk syndrome: association with incident dementia and disability. Journal of Alzheimer's disease 59 (1), 77-84.

Shumway-Cook, A., Guralnik, J.M., Phillips, C. L., Coppin, A.K., Ciol, M. A., et al. 2007. Age-associated declines in complex walking task performance: the InCHIANTI Toolkit. Journal of the American Geriatrics Society 55 (1), 58-65.

Silberschmidt, S., Kumar, A., Raji, M. M., Markides, K., Ottenbacher, K. J., et al. 2017. Life-Space mobility and cognitive decline among mexican americans aged 75 years and older. Journal of the American Geriatrics Society 65 (7), 1514-1520.

Singh-Manoux, A., Kivimaki, M., Glymour, M. M., Elbaz, A., Berr, C., et al. 2012. Timing of onset of cognitive decline: results from Whitehall II prospective cohort study. BMJ (Clinical research ed.) 344, d7622.

Siren, A., Hakamies-Blomqvist, L. & Lindeman, M. 2004. Driving cessation and health in older women. Journal of Applied Gerontology 23 (1), 58-69.

Smart, E. L., Gow, A. J. & Deary, I. J. 2014. Occupational complexity and lifetime cognitive abilities. Neurology 83 (24), 2285-2291.

Snih, S. A., Peek, K. M., Sawyer, P., Markides, K. S., Allman, R. M., et al. 2012. Life-Space Mobility in Mexican Americans Aged 75 and Older. Journal of the American Geriatrics Society 60 (3), 532-537.

Snowdon, D. A., Kemper, S. J., Mortimer, J. A., Greiner, L. H., Wekstein, D. R., et al. 1996. Linguistic ability in early life and cognitive function and Alzheimer's disease in late life: Findings from the Nun Study. Journals of American Medical Association 275 (7), 528-532.

Soumaré, A., Tavernier, B., Alpérovitch, A., Tzourio, C. & Elbaz, A. 2009. A cross-sectional and longitudinal study of the relationship between walking speed and cognitive function in community-dwelling elderly people. Journals of Gerontology Series A: Biomedical Sciences and Medical Sciences 64 (10), 1058-1065.

Stalvey, B. T., Owsley, C., Sloane, M. E. & Ball, K. 1999. The Life Space Questionnaire: A measure of the extent of mobility of older adults. Journal of Applied Gerontology 18 (4), 460-478.

Starr, J. M., Deary, I. J., Lemmon, H. & Whalley, L. J. 2000. Mental ability age 11 years and health status age 77 years. Age and Ageing 29 (6), 523-528.

Stern, Y. 2012. Cognitive reserve in ageing and Alzheimer's disease. The Lancet Neurology 11 (11), 1006-1012.

Stern, Y. 2009. Cognitive reserve. Neuropsychologia 47 (10), 2015-2028.

Stern, Y. 2002. What is cognitive reserve? Theory and research application of the reserve concept. Journal of the International Neuropsychological Society 8 (3), 448-460.

Stijntjes, M., Aartsen, M. J., Taekema, D. G., Gussekloo, J., Huisman, M., et al. 2016. Temporal relationship between cognitive and physical performance in middle-aged to oldest old people. Journals of Gerontology Series A: Biomedical Sciences and Medical Sciences 72 (5), 662-668.

Strauss, E., Sherman, E. & Spreen O.A. 2006. Compendium of neuropsychological tests. Administration, norms, and commentary. 3rd ed. New York, NY: Oxford University Press, 655-677.

Stroop, J. R. 1935. Studies of interference in serial verbal reactions. Journal of experimental psychology 18 (6), 643.

Syddall, H. E., Westbury, L. D., Cooper, C. & Sayer, A. A. 2015. Self-reported walking speed: a useful marker of physical performance among community-

dwelling older people? Journal of the American Medical Directors Association 16 (4), 323-328.
Taanila, A., Murray, G. K., Jokelainen, J., Isohanni, M. & Rantakallio, P. 2005. Infant developmental milestones: a 31-year follow-up. Developmental medicine and child neurology 47 (9), 581-586.
Tabbarah, M., Crimmins, E. M. & Seeman, T. E. 2002. The relationship between cognitive and physical performance: MacArthur Studies of Successful Aging. The journals of gerontology.Series A, Biological sciences and medical sciences 57 (4), 228.
Taniguchi, Y., Yoshida, H., Fujiwara, Y., Motohashi, Y. & Shinkai, S. 2012. A prospective study of gait performance and subsequent cognitive decline in a general population of older Japanese. Journals of Gerontology Series A: Biomedical Sciences and Medical Sciences 67 (7), 796-803.
Thelen, E. 1995. Motor development. A new synthesis. The American Psychologist 50 (2), 79-95.
Thelen, E. 2000. Motor development as foundation and future of developmental psychology. International Journal of Behavioral Development 24 (4), 385-397.
Tian, Q., An, Y., Resnick, S. M. & Studenski, S. 2017. The relative temporal sequence of decline in mobility and cognition among initially unimpaired older adults: Results from the Baltimore Longitudinal Study of Aging. Age and Ageing 46 (3), 445-451.
Tiihonen, J., Haukka, J., Henriksson, M., Cannon, M., Kieseppä, T., et al. 2005. Premorbid intellectual functioning in bipolar disorder and schizophrenia: results from a cohort study of male conscripts. American Journal of Psychiatry 162 (10), 1904-1910.
Tinetti, M. E. & Ginter, S. F. 1990. The Nursing Home Life-Space Diameter. Journal of the American Geriatrics Society 38 (12), 1311-1315.
Tsai, L., Portegijs, E., Rantakokko, M., Viljanen, A., Saajanaho, M., et al. 2015. The association between objectively measured physical activity and life-space mobility among older people. Scandinavian Journal of Medicine & Science in Sports.
Tudor-Locke, C. E. & Myers, A. M. 2001. Challenges and opportunities for measuring physical activity in sedentary adults. Sports Medicine 31 (2), 91-100.
Van Der Bij, Akke K, Laurant, M. G. & Wensing, M. 2002. Effectiveness of physical activity interventions for older adults: a review1. American Journal of Preventive Medicine 22 (2), 120-133.
Van Gelder, B. M., Tijhuis, M., Kalmijn, S., Giampaoli, S., Nissinen, A., et al. 2004. Physical activity in relation to cognitive decline in elderly men The FINE Study. Neurology 63 (12), 2316-2321.
Van Iersel, M. B., Kessels, R. P., Bloem, B. R., Verbeek, A. L. & Olde Rikkert, M. G. 2008. Executive functions are associated with gait and balance in community-living elderly people. The journals of gerontology. Series A, Biological Sciences and Medical Sciences 63 (12), 1344-1349.

Vaughan, L. & Giovanello, K. 2010. Executive function in daily life: Age-related influences of executive processes on instrumental activities of daily living. Psychology and aging 25 (2), 343.

Vazzana, R., Bandinelli, S., Lauretani, F., Volpato, S., Lauretani, F., et al. 2010. Trail Making Test predicts physical impairment and mortality in older persons. Journal of the American Geriatrics Society 58 (4), 719-723.

Verbrugge, L. M. & Jette, A. M. 1994. The disablement process. Social science & medicine 38 (1), 1-14.

Verghese, J., Annweiler, C., Ayers, E., Barzilai, N., Beauchet, O., et al. 2014. Motoric cognitive risk syndrome Multicountry prevalence and dementia risk. Neurology 83 (8), 718-726.

Verghese, J., Lipton, R. B., Hall, C. B., Kuslansky, G., Katz, M. J., et al. 2002. Abnormality of gait as a predictor of non-Alzheimer's dementia. New England Journal of Medicine 347 (22), 1761-1768.

Verghese, J., Wang, C., Lipton, R. B. & Holtzer, R. 2012. Motoric cognitive risk syndrome and the risk of dementia. Journals of Gerontology Series A: Biomedical Sciences and Medical Sciences 68 (4), 412-418.

Wang, L., Van Belle, G., Kukull, W. B. & Larson, E. B. 2002. Predictors of functional change: a longitudinal study of nondemented people aged 65 and older. Journal of the American Geriatrics Society 50 (9), 1525-1534.

Watson, N. L., Rosano, C., Boudreau, R. M., Simonsick, E. M., Ferrucci, L., et al. 2010. Executive function, memory, and gait speed decline in well-functioning older adults. Journals of Gerontology Series A: Biomedical Sciences and Medical Sciences 65 (10), 1093-1100.

Webber, S. C., Porter, M. M. & Menec, V. H. 2010. Mobility in older adults: a comprehensive framework. The Gerontologist 50 (4), 443-450.

Welmer, A., Rizzuto, D., Qiu, C., Caracciolo, B. & Laukka, E. J. 2014. Walking speed, processing speed, and dementia: a population-based longitudinal study. Journals of Gerontology Series A: Biomedical Sciences and Medical Sciences 69 (12), 1503-1510.

West, R. L. 1996. An application of prefrontal cortex function theory to cognitive aging. Psychological bulletin 120 (2), 272.

Weuve, J., Kang, J. H., Manson, J. E., Breteler, M. M., Ware, J. H., et al. 2004. Physical activity, including walking, and cognitive function in older women. Journals of the American Medical Association 292 (12), 1454-1461.

Whalley, L. J., Deary, I. J., Appleton, C. L. & Starr, J. M. 2004. Cognitive reserve and the neurobiology of cognitive aging. Ageing Research Reviews 3 (4), 369-382.

WHO 2006. Motor Development Study: windows of achievement for six gross motor development milestones. Acta Paediatrica (Oslo, Norway: 1992) Supplement 450, 86-95.

Williams, K. N. & Kemper, S. 2010. Interventions to reduce cognitive decline in aging. Journal of psychosocial nursing and mental health services 48 (5), 42-51.

Wilson, R. S., Beckett, L. A., Barnes, L. L., Schneider, J. A., Bach, J., et al. 2002. Individual differences in rates of change in cognitive abilities of older persons. Psychology and Aging 17 (2), 179-193.

Wood, K. M., Edwards, J. D., Clay, O. J., Wadley, V. G., Roenker, D. L., et al. 2005. Sensory and cognitive factors influencing functional ability in older adults. Gerontology 51 (2), 131-141.

World Health Organization 2001. International Classification of Functioning, Disability and Health: ICF. World Health Organization.

Wright, R. O. & Christiani, D. 2010. Gene-environment interaction and children's health and development. Current opinion in pediatrics 22 (2), 197.

Xue, Q., Fried, L. P., Glass, T. A., Laffan, A. & Chaves, P. H. 2007. Life-space constriction, development of frailty, and the competing risk of mortality: the Women's Health and Aging Study I. American Journal of Epidemiology 167 (2), 240-248.

Yaffe, K., Barnes, D., Nevitt, M., Lui, L. & Covinsky, K. 2001. A prospective study of physical activity and cognitive decline in elderly women: women who walk. Archives of Internal Medicine 161 (14), 1703-1708.

Ylihärsilä, H., Kajantie, E., Osmond, C., Forsen, T., Barker, D., et al. 2007. Birth size, adult body composition and muscle strength in later life. International journal of obesity 31 (9), 1392.

Yogev-Seligmann, G., Hausdorff, J. M. & Giladi, N. 2008. The role of executive function and attention in gait. Movement disorders 23 (3), 329-342.

Zelazo, P. D., Craik, F. I. & Booth, L. 2004. Executive function across the life span. Acta Psychologica 115 (2), 167-183.

Zelazo, P. D. & Müller, U. 2002. Executive function in typical and atypical development.

Zimmerman, M. E., Brickman, A. M., Paul, R. H., Grieve, S. M., Tate, D. F., et al. 2006. The relationship between frontal gray matter volume and cognition varies across the healthy adult lifespan. The American Journal of Geriatric Psychiatry 14 (10), 823-833.

ORIGINAL PUBLICATIONS

I

EXECUTIVE FUNCTION AND LIFE-SPACE MOBILITY IN OLD AGE

by

Poranen-Clark, T., von Bonsdorff MB., Rantakokko M., Portegijs E., Eronen J., Kauppinen M., Eriksson JG., Rantanen T., Viljanen A.

Aging Clinical and Experimental Research 2018; 30: 145–151.

Aging Clin Exp Res (2018) 30:145–151
DOI 10.1007/s40520-017-0762-3

ORIGINAL ARTICLE

Executive function and life-space mobility in old age

Taina Poranen-Clark[1] · Mikaela B. von Bonsdorff[1,2] · Merja Rantakokko[1] · Erja Portegijs[1] · Johanna Eronen[1] · Markku Kauppinen[1] · Johan G. Eriksson[2,3,4] · Taina Rantanen[1] · Anne Viljanen[1]

Received: 8 February 2017 / Accepted: 11 April 2017 / Published online: 21 April 2017

Abstract
Background Life-space assessment incorporates all movements in terms of the distance from home, the frequency of movement and the need of assistance for movement. Executive function (EF) is an important higher order cognitive ability that controls and guides people's goal-directed actions. We examined the cross-sectional and longitudinal associations between EF and life-space mobility, and investigated if perceived walking difficulties, lower extremity performance, and transportation difficulties explain the association.
Methods 157 community-dwelling persons aged 76–91 years participated in the study at the baseline, and 103 of them in 2-year follow-up study. Based on the distribution on the Trail Making Test participants were categorized into tertiles of EF. Life-space mobility was assessed using the Life-Space Assessment (range 0–120). Perceived walking difficulties and transportation difficulties were self-reported, and lower extremity performance was assessed with the short physical performance battery (SPPB). Adjustments were made for gender, age, number of chronic conditions, and years of education.
Results Average age of participants at the baseline was 82.6 (SD 4.2) years and 61% were women. Individuals with poor EF had lower life-space mobility compared to those with good EF. SPPB and transportation difficulties explained the association. Over the 2-year follow-up, those with poor EF at the baseline showed steeper decline but the difference did not quite reach statistical significance ($p = 0.068$).
Conclusions People with better executive function had higher life-space mobility. This was explained by better lower extremity performance and absence of transportation difficulties. Cognitive decline may hinder access to community amenities, which in turn may further accelerate cognitive decline.

Keywords Cognition · Functional capability · Participation

✉ Taina Poranen-Clark
taina.poranen-clark@jyu.fi

1 Gerontology Research Center, Faculty of Sport and Health Sciences, University of Jyväskylä, PO Box 35, Viveca 40014, Finland

2 Folkhälsan Research Center, Helsinki, Finland

3 Department of Chronic Disease Prevention, National Institute for Health and Welfare, Helsinki, Finland

4 Department of General Practice and Primary Health Care, University of Helsinki and Helsinki University Hospital, Helsinki, Finland

Introduction

The ability to go where and when one wants to go and how one wants to get there is a key component of active aging [1]. Limitations in mobility reduce access to community amenities and threaten possibilities for social contacts [1], and predict further disability [2]. Life-space mobility, an indicator of community mobility, incorporates an individual's internal physiologic and psychological capability relative to the environmental requirements of the place where the travel takes place [3]. Life-space mobility assessment includes estimates of the distance, the frequency and the need of assistance for moving [4]. Highly coordinated voluntary bodily movements caused by contracting muscles such as walking, as well as cognitively more complex but physically less demanding tasks such as using public transportation or driving a car [5] constitute important building blocks of life-space mobility. The association of life-space mobility with cognitive capacity in old age has been less studied. There are, though, some studies, that show that memory decline assessed with Mini-Mental State Examination correlates with lower life-space mobility [3, 6].

Mobility requires cognitive processing in addition to physiological functioning [7]. Holding information in mind, switching between tasks, inhibiting action and resisting distraction [8] are examples of cognitive processes needed for mobility control [9] and supervised by executive functioning (EF). EF refers to the higher order cognitive abilities, which are required when planning and carrying out complex, goal-oriented behavior [8]. Executive function plays an important role in supervising and managing many different cognitive domains [5]. These cognitive processes and mobility are supported primarily by the same prefrontal areas of the brain, which have been identified as the most vulnerable areas of the brain in the normal aging process [9–12]. The deterioration of the prefrontal area in aging does not only affect cognition but may contribute to motor performance and mobility as well, since the prefrontal areas regulate the speed of information processing, working memory and attention which have a crucial role in capability to complete motor tasks rapidly and efficiently [9, 13, 14]. Walking performance for example utilizes executive function and other complex cognitive processes such as estimation, planning and adjustments [15].

Life-space mobility correlates with lower extremity performance [16] and use of transportation [17], both of which also correlate with EF [18–20]. In this study, we investigated the association between EF and life-space mobility among community-dwelling older people, and assessed if perceived walking difficulties, lower extremity performance, and transportation difficulties, underlie this association.

Materials and methods

Study population

Altogether 169 community-dwelling people aged 76 to 91 years participated in the Hearing, Cognition and Wellbeing Study. Face-to-face interviews and sensory, physical and cognitive functioning measurements were conducted in the participants' homes. Valid data on executive function (EF) and life-space mobility were available for 157 participants who form the analytic sample of the current cross-sectional study (eight refused and four were unable to perform the TMT test due to poor vision or upper extremity impairment). Of the initial 169 persons, 108 participated in the follow-up study 2 years later (32 were not interested to participate, 19 had deceased, one moved outside study area and nine were not reached). Of them, 103 participants had complete data available, and form the analytic sample of the current follow-up study (four refused and one was unable to perform the TMT test due to poor vision).

The participants of the current study were part of the Life-Space Mobility in Old Age (LISPE) study, described in detail previously [21]. LISPE is a population-based study among community living older people including 848 participants. Using random number tables a subset of 230 individuals was selected for the Hearing, Cognition and Wellbeing sub-study in year 2014 [22]. Those willing to participate and who did not experience severe problems in communicating, underwent the examinations and interviews during spring 2014 ($n = 169$).

The Hearing, Cognition and Wellbeing substudy sample ($n = 169$) did not differ from the initial LISPE study sample ($n = 848$) in terms of sex, age, years of education, number of chronic conditions, lower extremity performance measured with the Short Physical Performance Battery (SPPB), or cognitive functioning measured with Mini-Mental State Examination (MMSE) (all p values > 0.127).

The LISPE study and the Hearing, Cognition and Wellbeing sub-study both comply with the principles of good scientific conduct and good clinical practice in all aspects of the Declaration of Helsinki, and were approved by the Ethical Committee of the University of Jyväskylä. All participants gave a written informed consent.

Executive function

EF was measured with the Trail Making Test (TMT). TMT is a paper-and-pencil task providing information on visual search, scanning, processing speed, mental flexibility, and executive function [23]. The TMT consists of two parts. In the TMT-A task participants were required to draw lines sequentially connecting randomly arranged encircled numbers (from 1 to 25) spread over a sheet of paper. In the TMT-B task participants were required to draw lines in numeric and alphabetical order (1-A-2-B-3-C, etc.) connecting randomly arranged encircles containing numbers (from 1 to 13) and letters (from A to L) spread over a sheet. The examiner pointed out errors as they occurred and the subject could continue to complete the task at the expense of additional time. Time to complete each task was measured in seconds [24, 25]. A maximum accepted time to complete each part of the test was 240 s and maximum accepted amount of errors was 4 [24]. Delta-TMT was calculated by subtracting time to perform TMT-A from time to perform TMT-B to control for the effects of motor function, visual scanning and processing speed. Delta-TMT has been used in previous studies to indicate executive functioning [19, 26]. EF was categorized into three approximately equal distribution-based groups as follows. Poor EF included those who did not perform TMT-A or TMT-B tasks within accepted time, or made more than 4 errors, or who failed to complete the task so that Delta-TMT could not have been calculated. Intermediate EF included those whose Delta-TMT was between 95 and 179 s and good EF included those whose Delta-TMT was 94 s or less. The cut-off between intermediate and good EF was defined according to the median value of Delta-TMT among those who completed the tests.

Life-space mobility

Life-space mobility was measured with the 15-item University of Alabama at Birmingham Study of Aging Life-Space Assessment (LSA) [3], which was translated into Finnish [27]. Participants were asked how many times during the past four weeks they had attained each life-space level (bedroom, other rooms, outside home, neighborhood, town, beyond town), and whether they needed help from another person or used assistive device. A composite score (range 0–120) that reflects distance, frequency, and independence of movement was calculated and used as an indicator of life-space mobility. Higher scores indicated higher life-space mobility [5, 21].

Mobility indicators

Lower extremity performance was assessed with the Short Physical Performance Battery (SPPB) [28]. The test battery comprises three tests assessing standing balance, walking speed over a distance of 2.44 m and time taken to complete five chair rises. Each test is rated from 0 to 4 points according to established age- and gender-specific cut-off points [28, 29]. A SPPB sum score was calculated (range 0–12) when at least two of the tests were completed [16]. If one of the tests was missing, the sum score of the two tests was transformed using proportion equation formula to reflect the maximum possible test score, i.e., the sum score was first multiplied by the maximum possible test score (12) and then divided by maximum possible performed test score (8). Higher scores indicate better physical performance.

Perceived difficulties walking 500 meters were self-reported. Participant was asked; “Are you able to walk about 500 m?” with response options “able without difficulty”, “able with minor difficulty”, “able with a great deal of difficulty”, “unable without the help of another person”, and “unable to manage even with help”.

Transportation difficulties were assessed based on perceived difficulties in use of public transportation, and frequency of driving. Participants were asked how they manage to use public transportation with response options; “able without difficulty”, “able with minor difficulty”, “able with a great deal of difficulty”, “unable without the help of another person”, and “unable to manage even with help”. This question was drawn from an 11-item self-report questionnaire for instrumental activities of daily living (IADL) [37]. Driving was assessed by asking “How often do you drive a car?” with response options; “Daily or nearly daily”, “Once or twice a week”, “Once or twice a month”, “Once or twice a year”, “Less than once a year”, “Never, I have never driven a car” and “Never, I have stopped driving a car”. People who did not drive regularly (at least once or twice a month) and had difficulties in using public transportation were categorized as having transportation difficulties while those, who did not have difficulties in using transportation or who drove a car at least once or twice a month were categorized as not having transportation difficulties.

Covariates

Number of self-reported chronic conditions was calculated from a list of 22 physician-diagnosed diseases and an additional open-ended question about any other physician-diagnosed chronic diseases [16, 21]. Participants were asked to report their total number of years of education.

Other variables

Cognitive functioning was measured using Mini Mental State Examination (MMSE) [30].

Statistical analyses

The descriptive measures were computed using means and standard deviations (SD) for continuous variables and percentages for categorical variables. Comparison between the three different EF groups was performed with one-way analysis of variance (ANOVA) for continuous variables and with cross-tabulation followed by Pearson’s Chi-square test for proportions in categorical variables.

The cross-sectional association between EF and life-space mobility was investigated with general linear regression model (GLM). The base model was adjusted for age and gender. To examine if the association between EF and life-space mobility was explained by the covariates, perceived walking difficulties, lower extremity performance and transportation difficulties were included into the model one at a time, and finally all the factors were included in the model simultaneously. Additionally, in the fully adjusted model we included the number of chronic conditions and years of education as covariates. The longitudinal association between EF and life-space mobility was investigated by constructing a general estimation equation (GEE) model

[31] by specifying an unstructured outcome covariance matrix. We estimated the main effects of EF on life-space mobility and time interaction effects (group by time) for the 2-year follow-up. Models were adjusted for age and gender. The interaction between gender and EF on life-space mobility was not statistically significant ($p > 0.290$), thus all analyses were pooled by gender. For all tests two-tailed p values are reported and the level of significance was set at $p < 0.05$. The analyses were carried out with SPSS IBM version 24.0 (SPSS, Armonk, NY, IBM Corp).

Results

Baseline characteristics of the study participants according to the approximate tertiles of EF are presented in Table 1. The average age of the participants at the baseline was 82.6 years (SD 4.2) and 61% of them were women. Mean MMSE score at the baseline was 26.2 (SD 2.6) and 7.6% of the participants had MMSE < 23. Compared to individuals with good EF those with poor or intermediate EF were less educated, had significantly lower SPPB scores and lower life-space mobility. Eighty-three per cent of participants with good EF had no transportation difficulties while 56% of those with poor EF had no difficulties. Number of chronic conditions or difficulties in walking 500 meters did not differ between EF groups (Table 1).

Marginal means and regression coefficients of life-space mobility by EF are shown in Table 2. Persons with poor or intermediate EF had lower life-space mobility compared to those with good EF ($p = 0.006$: marginal means 53.0, SE 2.7 for poor, 63.5, SE 2.7 for intermediate, and 64.0, SE 2.7 for good EF). Perceived difficulties in walking 500 meters did not attenuate the association between EF and life-space mobility ($p = 0.005$). Lower extremity performance and transportation difficulties attenuated the associations between EF and life-space mobility and rendered the differences statistically non-significant.

Compared to those who did not participate in the follow-up study ($n = 61$), those who participated ($n = 108$) were younger (82.2 years, SD 4.1 vs. 83.6 years, SD 4.3, $p = 0.038$), their mean SPPB (9.3, SD 2.0, vs. 7.2, SD 3.4, $p < 0.001$), MMSE (26.3, SD 2.7 vs. 25.4, SD 2.5, $p = 0.033$), and life-space mobility scores (63.1, SD 19.7 vs. 51.2, SD 20.4, $p < 0.001$) were higher at the baseline. The attrition was highest among those with poor

Table 1 Characteristics of the study participants according to executive function

Characteristics	$n = 157$	Executive function			p value
		Poor	Intermediate	Good	
		$n = 54$	$n = 50$	$n = 53$	
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	
Age (years)	82.6 (4.2)	84.1 (4.0)	82.2 (4.1)	81.5 (4.2)	0.003[a]
Education (years)	9.6 (4.3)	7.9 (3.4)	9.8 (4.8)	11.3 (4.0)	<0.001[a]
Number of chronic conditions	3.3 (1.6)	3.4 (1.6)	3.4 (1.5)	3.1 (1.8)	0.493[a]
Life-space mobility (total score)	59.0 (21.0)	50.3 (20.6)	62.9 (18.2)	64.2 (21.2)	0.001[a]
SPPB (total score)	8.5 (2.8)	7.5 (2.8)	8.6 (2.6)	9.5 (2.6)	0.001[a]
MMSE (total score)	26.1 (2.6)	24.4 (2.6)	26.5 (2.3)	27.6 (1.6)	0.001[a]
	%	%	%	%	
Women	61.1	64.8	60.0	58.5	0.782[b]
Walking difficulties for 500 m					0.667[b]
No difficulties	74.5	66.7	80.0	77.4	
Minor difficulties	11.5	14.8	10.0	9.4	
A great deal of difficulties	6.4	9.3	6.0	3.8	
Unable even with help	7.6	3.2	9.4	7.1	
Transportation difficulties					0.002[b]
No difficulties	72.6	55.6	80.0	83.0	
Difficulties	27.4	44.4	20.0	17.0	

SPPB, $n = 156$

Poor not able to complete either TMT A or $B < 240$ s, or made more than 4 mistakes or did not complete the task, *Intermediate* delta-TMT 95–179 s, *Good* delta-TMT ≤ 94 s, *SD* std. deviation, *SPPB* short physical performance battery, *MMSE* mini mental state examination

[a]Analysis of variance (*ANOVA*)

[b]Chi-square test

Table 2 Marginal means (MM) and standard errors (SE) of life-space mobility scores and regression coefficients (β) With 95% confidence intervals (CI) by executive function (EF). The covariates were included to the gender and age adjusted model one at the time

	Executive function								p value[#]
	Good		Intermediate			Poor			
	MM (SE)		MM (SE)	β	CI	MM (SE)	β	CI	
Unadjusted	64.2 (2.8)	Ref.	62.9 (2.8)	−1.30	−9.12, 6.42	50.2 (2.7)	−13.94	−21,61, −6.27	0.001
Gender and age	64.0 (2.7)	Ref.	63.5 (2.7)	−0.56	−8.03, 6.91	53.0 (2.7)	−11.03	−18.60, −3.46	0.006
+Walking difficulties for 500 m	51.4 (2.8)	Ref.	49.5 (2.9)	−1.92	−8.26, 4.42	41.2 (2.8)	−10.20	−16.62, −3.78	0.005
+SPPB	61.2 (2.3)	Ref.	63.1 (2.3)	1.90	−4.40, 8.20	56.4 (2.8)	−4.80	−11.35, 1.76	0.109
+Transportation difficulties	57.0 (2.6)	Ref.	56.8 (2.7)	−0.25	−6.91, 6.41	50.5 (2.4)	−6.50	−13.39, 0.40	0.116
Fully adjusted*	53.5 (2.7)	Ref.	53.9 (2.9)	0.39	−5.57, 6.35	49.0 (2.9)	−4.57	−11.03, 1.89	0.230

Good delta-TMT ≤94 s, *Intermediate* delta-TMT 95–179 s, *Poor* not able to complete either TMT A or B part test <240 s, or made more than 4 mistakes or did not complete the task. *SPPB* Short Physical Performance Battery

[#] *p* value for the significance of the differences between life-space mobility marginal means

*Fully adjusted = gender and age + walking difficulties for 500 m, SPPB, transportation difficulties, number of chronic conditions, and years of education

EF at the baseline (53.7%), followed by those with intermediate (30.0%) or good (18.9%) EF at the baseline. Those with poor EF were five times (OR = 4.99, 95% CI 2.09–11.92), and those with intermediate EF almost two times (OR = 1.84, 95% CI 0.74–4.61) more likely to drop out from the follow-up compared to those with good EF.

Table 3 shows the mean values for life-space mobility at baseline and 2-year follow-up according to EF. Life-space mobility decreased most among those who had poor EF at baseline compared to those with intermediate or good EF, but the difference did not quite reach statistical significance (group by time interaction effect $\beta = -6.198$, $p = 0.068$).

Discussion

Our results showed that people with poor EF had lower life-space mobility than those with intermediate or good EF. The differences were largely explained by their poorer lower extremity performance and higher prevalence of transportation difficulties, both of which also underlie life-space mobility. The results of the 2-year follow-up study suggest that poor EF predicts a steeper decline in life-space mobility among older community-dwelling people; however, the interaction term did not quite reach statistical significance.

This is to our knowledge the first study examining the cross-sectional and longitudinal association between EF and life-space mobility among older community-dwelling individuals. Our findings add novel knowledge to emerging literature relative to association between cognitive functioning and mobility. In relation to EF and mobility, previous studies have examined only one aspect of mobility at a time whereas we were able to use life-space mobility as an outcome, which takes into account all mobility in its' different forms including both physically active movement and movement using a vehicle. Life-space mobility assessment provides us information about "real life" mobility

Table 3 Means, standard deviations (SD), and general estimation equations (GEE) model parameters for group-by-time interactions for life-space mobility scores according to executive function tertiles at baseline and in the 2-year follow-up

Executive function	Baseline		2-year follow-up		Group × time interaction[2]		
	Mean	SD	Mean	SD	β	s.e	p value[2]
Good ($n = 43$)	68.3	19.3	67.5	18.5	Ref.		
Intermediate ($n = 35$)	64.3	16.8	65.7	16.5	2.188	3.110	0.482
Poor ($n = 25$)	53.8	20.1	46.8	20.4	−6.198	3.396	0.068

Good delta-TMT ≤94 s, *Intermediate* delta-TMT 95–179 s, *Poor* not able to complete either TMT A or B part test <240 s, or made more than 4 mistakes or did not complete the task

s.e. standard error

[2] GEE model group × time interaction adjusted for age and gender, good EF as a reference group. β sample estimate for GEE regression coefficient

that may take place closer or further away from home. As a person moves further away from one's home, the cognitive effort needed for the mobility may increase, e.g., in terms of finding directions, orienting oneself and recognizing the less familiar environmental features when approaching a far-away destination. Consequently, life-space mobility may be sensitive to early cognitive changes that may reduce the willingness to travel to more distant destinations [6, 32].

Motor control relies in prefrontal brain areas, which are most vulnerable to age-related losses [33], and cognitive and motor functions share the same neural network [13], which potentially explain why lower extremity performance and transportation difficulties coexist with cognitive decline. Adequate motor control, reaction speed, attention and working memory are important for lower extremity performance but they also are prerequisites for competent driving, and contribute to cognitive processes where EF is involved. Low EF decreases the likeliness that an individual could independently use public transportation or drive safely due to decreased ability to integrate information and plan a response [18, 34]. It is also possible that restricted life-space mobility due to physical disability or disease, may diminish brain stimulation needed for maintaining cognitive skills and thus have a negative influence to cognitive functioning over time.

One of the strengths of the study was that we analyzed the association between EF and life-space mobility which has not been addressed before. Additionally, using different mobility measures, we were able to investigate which mobility indicators may explain this association. Our study included persons who were community-dwelling and from all social stratum, who did not have severe cognitive decline (Mean MMSE score: 26.2, SD 2.6). We used computer-assisted face-to-face interviews by trained interviewers at participants' homes allowing cognitive and physical performance tests in a setting familiar to the participants.

There are also some limitations in this study that need to be acknowledged. First of all, the participants with poorer EF, or lower SPPB and MMSE scores and lower life-space mobility were more likely to drop out from the follow-up study than those with higher values. Therefore, the strength of the longitudinal association between EF and life-space mobility may have been underestimated. Second, the attrition reduced the statistical power in the longitudinal analyses. Nevertheless, the results suggest that life-space mobility may show steeper decline over time among those with lower EF. However, this needs to be confirmed in future studies. Third, self-reported walking difficulties as a measurement may under- or over-estimate true participants' difficulties. However, self-reported walking difficulties is a widely used measure in aging research, and thus, is an established method for assessing perceived mobility difficulties that participants experience in their daily life surroundings [28]. Fourth, we were using a single test to measure executive function instead of multiple tests due to time constraints in the study protocol considering that the participants were very old. Although TMT is a widely used test and simple and easy to perform, further studies should use more detailed test batteries for a more comprehensive evaluation of executive function.

Conclusion

Better EF is associated with higher life-space mobility and poorer lower extremity performance and transportation difficulties explained the association. Poor EF may predict steeper decline in life-space mobility. Our finding lays ground to future studies on the topic.

Acknowledgements This study was supported by the Academy of Finland: the Future of Living and Housing Program ASU-LIVE; Grant number 255403 to [TR], number 263729 to [AV]; number 285747 to [MR]; numbers 129369, 129907, 135072, 129255 and 126775 to [JGE] and number 257239 to [MBvB]; Finnish Ministry of Education and Culture to [TR], [MR] and [EP]. TP-C was supported by Yrjö Jahnsson Foundation and Juho Vainio Foundation.

Compliance with ethical standards

Conflict of interest The authors declare that there are no conflicts of interest.

Ethical approval The LISPE study and the Hearing, Cognition and Wellbeing sub-study both comply with the principles of good scientific conduct and good clinical practice in all aspects of the Declaration of Helsinki, and were approved by the Ethical Committee of the University of Jyväskylä

Informed consent Informed consent All participants gave a written informed consent.

References

1. Satariano WA, Guralnik JM, Jackson RJ et al (2012) Mobility and aging: new directions for public health action. Am J Public Health 102:1508–1515
2. Hirvensalo M, Rantanen T, Heikkinen E (2000) Mobility difficulties and physical activity as predictors of mortality and loss of independence in the community-living older population. J Am Geriatr Soc 48:493–498
3. Barnes LL, Wilson RS, Bienias JL et al (2007) Correlates of life space in a volunteer cohort of older adults. Exp Aging Res 33:77–93
4. Baker PS, Bodner EV, Allman RM (2003) Measuring life-space mobility in community-dwelling older adults. J Am Geriatr Soc 51:1610–1614
5. Webber SC, Porter MM, Menec VH (2010) Mobility in older adults: a comprehensive framework. Gerontologist 50:443–450
6. Crowe M, Andel R, Wadley VG et al (2008) Life-space and cognitive decline in a community-based sample of african american

and caucasian older adults. J Gerontol A Biol Sci Med Sci 63:1241–1245
7. Wood KM, Edwards JD, Clay OJ et al (2005) Sensory and cognitive factors influencing functional ability in older adults. Gerontology 51:131–141
8. Banich MT (2009) Executive function the search for an integrated account. Curr Dir Psychol Sci 18:89–94
9. Diamond A (2000) Close interrelation of motor development and cognitive development and of the cerebellum and prefrontal cortex. Child Dev 71:44–56
10. Kramer AF, Hahn S, Cohen NJ et al (1999) Ageing, fitness and neurocognitive function. Nature 400:418–419
11. Salthouse TA, Atkinson TM, Berish DE (2003) Executive functioning as a potential mediator of age-related cognitive decline in normal adults. J Exp Psychol: Gen 132:566
12. Rosso AL, Studenski SA, Chen WG et al (2013) Aging, the central nervous system, and mobility. J Gerontol A Biol Sci Med Sci 68:1379–1386
13. Rosano C, Studenski SA, Aizenstein HJ et al (2012) Slower gait, slower information processing and smaller prefrontal area in older adults. Age Ageing 41:58–64
14. Killane I, Donoghue OA, Savva GM et al (2014) Relative association of processing speed, short-term memory and sustained attention with task on gait speed: a study of community-dwelling people 50 years and older. J Gerontol A Biol Sci Med Sci 69:1407–1414
15. Hausdorff JM, Yogev G, Springer S et al (2005) Walking is more like catching than tapping: gait in the elderly as a complex cognitive task. Exp Brain Res 164:541–548
16. Portegijs E, Rantakokko M, Mikkola TM et al (2014) Association between physical performance and sense of autonomy in outdoor activities and life-space mobility in community-dwelling older people. J Am Geriatr Soc 62:615–621
17. Viljanen A, Mikkola TM, Rantakokko M et al (2016) The association between transportation and life-space mobility in community-dwelling older people with or without walking difficulties. J Aging Health 28:1038–1054
18. Anstey KJ, Wood J, Lord S et al (2005) Cognitive, sensory and physical factors enabling driving safety in older adults. Clin Psychol Rev 25:45–65
19. Ble A, Volpato S, Zuliani G et al (2005) Executive function correlates with walking speed in older persons: the InCHIANTI study. J Am Geriatr Soc 53:410–415
20. Vaughan L, Giovanello K (2010) Executive function in daily life: age-related influences of executive processes on instrumental activities of daily living. Psychol Aging 25:343
21. Rantanen T, Portegijs E, Viljanen A et al (2012) Individual and environmental factors underlying life space of older people—study protocol and design of a cohort study on life-space mobility in old age (LISPE). BMC Public Health 12:1018-2458-12-1018
22. Polku H, Mikkola TM, Rantakokko M et al (2016) Hearing and quality of life among community-dwelling older adults. J Gerontol B Psychol Sci Soc Sci. doi:10.1093/geronb/gbw045
23. Reitan R (1993) Wolfson D, ed. The halstead-reitan neutopsychologic test battery: theory and clinical interpretation. Neuropsychology Press, Tucson
24. Lezak M (ed) (1995) Neuropsychological assessment. 3rd edition ed. Oxford University Press, Oxford
25. Bowie CR, Harvey PD (2006) Administration and interpretation of the trail making test. Nature protocols 1:2277–2281
26. Drane DL, Yuspeh RL, Huthwaite JS et al (2002) Demographic characteristics and normative observations for derived-trail making test indices. Neuropsychiatry Neuropsychol Behav Neurol 15:39–43
27. Portegijs E, Iwarsson S, Rantakokko M et al (2014) Life-space mobility assessment in older people in finland; measurement properties in winter and spring. BMC Res Notes 7:323-0500-7-323
28. Guralnik JM, Simonsick EM, Ferrucci L et al (1994) A short physical performance battery assessing lower extremity function: association with self-reported disability and prediction of mortality and nursing home admission. J Gerontol 49:M85-94
29. Mänty M (2007) Iäkkäiden henkilöiden kaatumistapaturmat: Opas kaatumisten ja murtumien ehkäisyyn. National Public Health Institute
30. Folstein MF, Folstein SE, McHugh PR (1975) "Mini-mental state": a practical method for grading the cognitive state of patients for the clinician. J Psychiatr Res 12:189–198
31. Liang K, Zeger SL (1986) Longitudinal data analysis using generalized linear models. Biometrika 73:13–22
32. James BD, Boyle PA, Buchman AS et al (2011) Life space and risk of alzheimer disease, mild cognitive impairment, and cognitive decline in old age. Am J Geriatric Psychiatry 19:961–969
33. Seidler RD, Bernard JA, Burutolu TB et al (2010) Motor control and aging: Links to age-related brain structural, functional, and biochemical effects. Neurosci Biobeh Rev 34:721–733
34. Anstey KJ, Horswill MS, Wood JM et al (2012) The role of cognitive and visual abilities as predictors in the multifactorial model of driving safety. Accid Anal Prev 45:766–774

II

THE TEMPORAL ASSOCIATION BETWEEN EXECUTIVE FUNCTION AND LIFE-SPACE MOBILITY IN OLD AGE

by

Poranen-Clark T., von Bonsdorff MB., Rantakokko M., Portegijs E., Eronen, J., Pynnönen K., Eriksson JG., Viljanen A., Rantanen T.

The Journals of Gerontology, Series A: Medical Sciences 2018; 73 (6): 835-839.

The Temporal Association between Executive Function and Life-Space Mobility in Old Age

Taina Poranen-Clark, MSc, M.A.(Ed)[1], Mikaela B. von Bonsdorff, PhD[1,2], Merja Rantakokko, PhD[1], Erja Portegijs, PhD[1], Johanna Eronen[1], Katja Pynnönen[1], Johan G. Eriksson, MD, DM Sc[2-4], Anne Viljanen, PhD[1], Taina Rantanen, PhD[1]

[1]Gerontology Research Center, Faculty of Sport and Health Sciences, University of Jyväskylä, Finland

[2]Folkhälsan Research Center, Helsinki, Finland

[3]Department of Chronic Disease Prevention, National Institute for Health and Welfare, Helsinki, Finland

[4]Department of General Practice and Primary Health Care, University of Helsinki and Helsinki University Hospital, Helsinki, Finland

Corresponding author and reprint requests:

Taina Poranen-Clark, MSc, M.A.(Ed)

Gerontology Research Center

Faculty of Sport and Health Sciences

University of Jyväskylä

PO Box 35 (Viveca)

FI-40014 University of Jyväskylä

Tel. +358 50 566 3719, E-mail taina.poranen-clark@jyu.fi

The Temporal Association between Executive Function and Life-Space Mobility in Old Age

ABSTRACT

Background: Life-space mobility, an indicator of community mobility, describes person's movements in terms of the distance from home, the frequency of movement and the need of assistance for movement. Executive function (EF) is a higher order cognitive function that supervises motor control, and plays a key role in a person's ability to function independently. Cognitive impairment often co-occurs with restricted life-space mobility, however, the direction of the longitudinal associations between EF and life-space mobility is unclear. The aim of this study was to investigate the temporal associations between EF and life-space mobility among community-dwelling older people.

Methods: 108 community-dwelling persons aged 76 to 91 years participated in the two-year follow-up study. Executive function was measured with the Trail Making Test (TMT). The Life-Space Assessment (range 0-120, higher scores indicate more mobility) was used to assess life-space mobility. Cross-lagged model design was used to examine longitudinal relationship between EF and life-space mobility. The model was adjusted for age and gender.

Results: Average age of participants at baseline was 82.2 (SD 4.1) years and 59% were women. Better EF at baseline predicted higher life-space mobility at follow-up (path coefficient = 3.81, 95% Confidential Interval; 0.84, 6.78, *p* = 0.012), while baseline life-space mobility did not predict EF at follow-up.

Conclusion: Executive function was a determinant of life-space mobility. Supporting EF may enhance maintaining independence and active participation in old age.

Keywords: Cognitive aging, motor control, successful aging

INTRODUCTION

Life-space mobility reflects a person's physical ability as well as psychosocial capability relative to the environmental requirements [1]. Life-space mobility assessment includes estimates of the distance, the frequency and the need of assistance for mobility[1]. Moving outside more often and travelling further away from home on a regular basis may be viewed as higher environmental complexity of mobility among older people[2,3]. The further away from one's home an individual moves the more complex the environment and the greater cognitive investments might be required[2]. There is evidence that older people with better cognitive function have larger life-space mobility[4]. Executive function (EF) has an important role in performance of control processes, which are required when planning and carrying out complex, goal-oriented tasks [5]. Therefore, EF might be an important higher order cognitive domain for older people enabling them to maintain their life-space mobility[6].

Coexisting mobility limitations and cognitive impairments are prevalent among community-dwelling older people [7] interfering with their independency and active participation in society. However, according to previous studies the direction of the association between cognition and mobility are inconsistent [8]. There are some evidence from longitudinal studies which used Mini Mental State Examination as a measure of cognitive functioning, that having greater life-space mobility may be a protective factor for cognitive decline [3,9]. Furthermore, constricted life-space mobility has been found to be associated with increased risk of Alzheimer diseases and mild cognitive impairment [10]. Impaired EF is prevalent even among community-dwelling older people without a formal diagnosis of cognitive impairment, and has been found to be associated with longitudinal declines in functional status [11-13]. Further, one previous study suggests that poor EF measured with the Trail Making Test (TMT) is a strong predictor of decline in lower extremity function[14], which is known to be associated with constricted life-space mobility[15]. The results of a recent study reported TMT performance being associated with gait adaptation indicating that EF is important for planning and adjusting stepping in situations where rapid gait adjustment may be needed[16]. Thus, importance of EF may increase as task complexity increases in unfamiliar environments farther away from home. The TMT performance requires amongst other things attention, cognitive flexibility and task switching[5] that are cognitive processes needed for everyday challenges for older people when moving around in environment[16]. Consequently, using EF as a measure of cognitive functioning when investigating temporal association between cognition and life-space mobility could add useful information to current literature. The aim of this study was to assess the temporal association between EF and life-space mobility. Establishing the direction of the association between EF and life-space mobility might help to target interventions more accurately to the factor in which declines seem to appear first.

METHODS

Study population

At baseline, altogether 169 community-dwelling people aged 76 to 91 years participated in the Hearing, Cognition and Wellbeing Study. Face-to-face interviews and sensory, physical and cognitive functioning measurements were conducted in the participants' homes. Of the initial 169 persons, 108 participated in the follow-up study two years later (32 were not interested to participate, 19 had deceased, one moved outside study area, and nine were not reached), and formed the analytic sample of this study.

The participants of the current study were part of the Life-Space Mobility in Old Age (LISPE) study, described in detail previously [17]. LISPE is a population-based study among community living older people including 848 participants. Using random number tables a subset of 230 individuals was selected for the Hearing, Cognition and Wellbeing sub-study in year 2014 [18]. Those willing to participate and who did not experience severe problems in communicating, underwent the examinations and interviews during spring 2014 (n= 169). The Hearing, Cognition and Wellbeing substudy sample (n=169) did not differ from the initial LISPE study sample (n=848) in terms of sex, age, years of education, number of chronic conditions, lower extremity performance measured with the Short Physical Performance Battery (SPPB), or cognitive functioning measured with Mini Mental State Examination (MMSE) (all p-values >0.127).

The LISPE study and the Hearing, Cognition and Wellbeing sub-study both comply with the principles of good scientific conduct and good clinical practice in all aspects of the Declaration of Helsinki, and were approved by the Ethical Committee of the University of Jyväskylä. All participants gave a written informed consent.

Executive function

EF was measured with the Trail Making Test (TMT). TMT is a paper-and-pencil task providing information on visual search, attention, processing speed, cognitive flexibility, and executive function [19,20]. The TMT consists of two parts. In the TMT-A task participants were asked to make a trail with a pencil, sequentially drawing lines to connect randomly arranged encircled numbers (from 1 to 25) spread over a sheet of paper. In the TMT-B task participants were asked to make a trail in numeric and alphabetical order (1-A-2-B-3-C, etc.) by drawing lines to connect randomly arranged encircles containing numbers (from 1 to 13) and letters (from A to L) spread over a sheet. The participants were asked to perform the task as quickly as possible without lifting the pencil from the paper. If an error occurred the examiner pointed it out immediately. Then the participants were asked to revert to last correct number or letter and continue there to complete the task at the expense of additional time. Time to complete each task was measured in seconds [21,22]. A maximum accepted time to complete each part of the test was 240 seconds and maximum accepted amount of errors was 4[6,21,23]. Delta-TMT was calculated by subtracting time to perform TMT-A from time to perform TMT-B to control for the effects of motor function, visual scanning and processing speed. Delta-TMT has been used in previous studies to indicate executive functioning [24,25].

EF was categorized into three approximately equal distribution-based groups as follows. At baseline and follow-up, poor EF included those who started to do the TMT test but who could not complete the test an acceptable way; they did not perform TMT-A or TMT-B tasks within the given time (max 240 seconds), or made more than 4 errors, or who did not complete the task so that Delta-TMT could not have been calculated[6]. Intermediate EF included those whose Delta-TMT was between 95 and 179 seconds at the baseline and between 97 and 180 seconds at the follow-up. Good EF included those whose Delta-TMT was 94 seconds or less at the baseline and 97 seconds or less at the follow-up. The cut-off between intermediate and good EF was defined according to the median value of Delta-TMT among those who completed the tests.

Life-space mobility

Life- space mobility was measured with the 15-item University of Alabama at Birmingham Study of Aging Life-Space Assessment (LSA)[1], which was translated into Finnish [26]. The reliability of the Finnish translation of life-space assessment has been found to be acceptable [26]. Life-space mobility assessment measures person's actual mobility during the four weeks preceding the assessment on the following life-space levels (=level score): bedroom (score 0), other rooms (1), outside home (2), neighborhood (3), town (4), beyond town (5). Participants were also asked how many times they attained each life-space level (=frequency score); daily (score 4), 4-6 times/ week (3), 1-3 times/ week (2), less than once a week(1), and whether they needed help from another person or used assistive device (=assistance score): no assistance (2), use of device only (1.5), personal assistance (1). A composite score was calculated as follows; level score * frequency score * assistance score at respective level, and then summed for all levels. Thus, a composite score reflects distance, frequency, and independence of movement, and was used as an indicator of life-space mobility[26]. The score ranges between 0 and 120, and higher scores indicated higher life-space mobility[17,26].

Covariates and descriptive variables

Participants' age and gender derived from the national population register were used as covariates in the analysis. Number of self-reported chronic conditions, global cognitive functioning, and lower extremity functioning were used to describe the characteristics of the participants. Number of self-reported chronic conditions was calculated from a list of 22 physician-diagnosed diseases and an additional open-ended question about any other physician-diagnosed chronic diseases. [15,17]. Global cognitive functioning was assessed with Mini Mental State Examination (MMSE, range 0-30) [27]. Lower extremity functioning was assessed with Short Physical Performance Battery (SPPB). The test battery comprises three tests assessing standing balance, walking speed over a distance of 2.44 meters and time taken to complete five chair rises. Each test is rated from 0 to 4 points according to established age- and gender-specific cut-off points [28,29]. A sum score (range 1-12) was calculated if at least two of the tests were completed. Higher scores indicate better lower extremity function[6,15].

Statistical analyses

The longitudinal cross-lagged associations between EF and life-space mobility were estimated using cross-lagged model design. Cross-lagged analysis enables to study whether EF at baseline is associated with life-space mobility at follow-up after controlling for life-space mobility at baseline, or vice versa. The unstandardized values were used in the analyses. Weighted least square estimator (WLSMV) was used to obtain parameter estimates. The model was adjusted for age and gender. The analysis were performed with MPLUS version 5.21 (Muthén and Muthén, 1998-2009) which uses the Full Information Maximum Likelihood procedure for handling missing values. The proportion of missing data in individual variables varied between 2.7 to 4.6 %. The interaction between gender and EF on life-space mobility was not statistically significant ($p > 0.185$), thus all analyses were pooled by gender. For all tests two-tailed p-values are reported and the level of significance was set at $p < 0.05$. The descriptive data analyses were carried out with SPSS IBM version 24.0 (SPSS, Armonk, NY, IBM Corp).

RESULTS

Characteristics of the study participants at baseline and follow-up are presented in Table 1. The average age of the participants at baseline was 82.2 years (SD 4.1) and 59.3 % of them were women. The proportion of those with poor EF increased during the two year follow-up from 24.3 % to 29.5 %. However, the global cognition measured with Mini Mental State Examination remained nearly stable during the two-year follow-up period. The average composite score of life-space mobility declined during the two-year follow-up from 63.1 (SD 19.7) to 61.5 (SD 21.2) (Table1).

Figure 1 shows the unstandardized coefficients of cross-lagged model with two-year follow-up for EF and life-space mobility. At baseline, better EF was associated with higher life-space mobility. Both EF and life-space mobility showed relatively strong stability between baseline and follow-up assessments. After controlling for age, gender, and taking into account previous measurements of EF and life-space mobility, the analysis revealed that better EF at baseline predicted higher life-space mobility at follow-up (path coefficient = 3.81, 95% confidential interval; 0.84, 6.78, *p*= 0.012) while baseline life-space mobility was not associated with EF at follow-up (Figure 1). The cross-lagged model fitted the data well Comparative Fit Index (CFI) was 1.000, Tucker Lewis Index (TLI) was 1.000, and Root Mean Square Error Approximation (RMSEA) less than 0.0005.

Compared to those who did not participate in the follow-up study (n=61), those who participated (n=108) were younger (82.2 years, SD 4.1 vs. 83.6 years, SD 4.3, p = 0.038), and they had higher SPPB (9.3, SD 2.0, vs. 7.2, SD 3.4, p <0.001), MMSE (26.3, SD 2.7 vs. 25.4, SD 2.5 p=0.033), and life-space mobility scores (63.1, SD 19.7 vs. 51.2, SD 20.4, p<0.001) at baseline. The proportion of those who dropped out was highest among those with poor EF (53.7%), followed by those with intermediate (30.0%) or good (18.9%) EF. Those with poor EF at baseline were five times (OR= 4.99, 95% CI 2.09, 11.92), and those with intermediate EF almost two times (OR =1.84, 95% CI 0.74, 4.61) more likely to drop out from the follow-up compared to those with good EF.

Finally, we conducted additional cross-lagged modelling; first, to examine a stricter cut-point for good TMT, second, to analyze MMSE as an indicator of global cognition, and third, using Delta-TMT as a continuous variable. Using more strict cut-points suggested by an earlier study (good Delta-TMT performance <60s)[30] to define good EF (at baseline cut-point for good EF was 60s or less and at follow-up 72s or less) did not change the results. The analysis for MMSE and life-space mobility revealed similar associations as with using EF; coefficients and 95% confidential intervals for baseline MMSE predicting follow-up life-space was 1.22 (0.29, 2.15) and baseline life-space mobility predicting follow-up MMSE 0.01(-0.01, 0.03). The associations for EF as continuous variable and life-space mobility among those who completed both parts of the TMT test (n= 78) were no statistically significant in either of the directions.

DISCUSSION

To our knowledge, we were the first to examine the temporal association between executive function and life-space mobility among community-dwelling older people. Better EF at baseline predicted higher life-space mobility at follow-up, while baseline life-space mobility did not predict EF at follow-up. Thus, our findings suggest that impaired executive function is a precedent for restricted life-space mobility rather than restriction of life-space would further influence cognitive decline.

It is obvious in the light of previous studies that cognition is interrelated with mobility[7]. In addition to emerging literature on the associations between cognitive function and mobility, we were using specific higher order cognitive domain, EF, and a multidimensional mobility measure, life-space mobility, as measurements. Life-space mobility reflects person's actual mobility through a given area over a specific time period, and incorporates not only physical aspects of mobility but also psychosocial capability for participation in society[1]. Further, we examined which one of these measurements, EF or life-space mobility, is a stronger predictor for one another whereas previous studies have predicted associations only for one of the possible directions[9,10]. This was done by using analysis that enable simultaneous examination of longitudinal influences of one factor on the other and vice versa, while controlling for contemporary associations between factors, and the stability of each factor over time. The association between EF and mobility has been reported being bidirectional [8,31]. However, our results are in line with some of the previous studies suggesting that EF is a predictor for mobility decline[12-14] and conflicting the previous results that suggest that life-space mobility predicts changes in cognitive functioning[3,9,10]. The latter might be explained by the fact that neither of the studies had EF as a measure of cognitive functioning. After all, a person might have some deficit of EF despite evident cognitive impairment [12].

According to the environmental complexity theory, a more demanding environment requires more cognitive investment leading to increase in cognitive activity consequently resulting in better cognitive functioning.[2] However, our results suggest that higher order cognitive functioning such as executive functioning is a prerequisite for the capability to move further away from home and enabling to widen one's life-space. Life-space mobility is a mobility measure that takes into account all movement in its' different forms through one's environment. The life-space mobility reaching only to one's close neighborhood may require less cognitive investment than if an individual would be orienteering oneself further away from a familiar environment, and perhaps using a vehicle for transportation. Reduction in life- space mobility may reflect early changes in cognitive functioning. Impairment in EF may affect an individual's willingness to travel further away from home even before any other markers of cognitive decline have appeared. Restricted life-space mobility may be seen as an early sign of cognitive decline resulting from EF impairment.

In recent years, the understanding of the role of the brain in age-related declines in mobility has increased [32,33]. Furthermore, EF has been identified as one of the potential mediators between age-related cognitive decline and functional ability [34]. Cognitive processes such as attention, action-inhibition and task-switching are dependent on EF and needed for motor control [35]. These control processes are primarily supported by frontal areas of the brain that are most vulnerable in the aging process[35], which might potentially explain the causal relationship between EF and life-space mobility. Decline in life-space mobility has been found to be associated with decline in quality of life[36] and development of ADL disability[37]. Our earlier study suggested that poor EF may predict steeper decline in life-space mobility but the results did not quite reach statistical significant, hence, the causal association between EF and life-space mobility stayed unclear[6]. However, the result of this study confirm our earlier suggestions of EF being a predictor of life-space mobility. Further, poorer lower extremity functioning and difficulties in use of transportation partly explained the association between poor EF and lower life-space mobility [6]. Thus, we did not adjust for SPPB as it being potential mediator between EF and life-space mobility[6]. Future studies should examine if promoting EF by means of cognitive training interventions could possibly delay mobility limitations that further diminish life-space mobility.

Our study had several strengths. By using life-space mobility and EF as measurements in this study, we were able to further existing literature relative to association between cognitive functioning and mobility. Further, we were able to include considerable old people (range 78-93 years at follow-up) from all social strata into this study, and the participant did not have severe cognitive decline at baseline (mean MMSE 26.3, SD 2.7, and 12% < 23). In addition, we used computer-assisted face-to-face interviews by trained interviewers at participants' homes, which likely improve the quality of data. Further, we conducted several further modelling to test our results. Using more strict cut-points for good EF showed that the results were not dependent on the intermediate-good cut-point.

The results of cross-lagged model using MMSE instead of EF as the cognitive measure revealed similar associations. We found no statistically significant associations in either of directions when using EF measure as a continuous variable in cross-lagged modelling. This suggests that the cross-lagged association between baseline EF and follow-up life-space mobility observed in the larger sample where all the participants were included, was driven by the poor values. This also supports our finding that the null life space mobility - EF association was not due to the scale properties of the categorized EF variable but rather due to the absence of a causal relationship. We are aware that the limited sample size in these sensitivity analyses decrease power even further, however, the coefficient is so low that it may not be considered material.

Our study had some limitations. First of all, due to the fact that the participants with poorer functioning were more likely to drop out from the follow-up study, the results can be generalized only to somewhat better functioning community-dwelling older adults, and it is likely that the strength of the associations over time may be underestimated. Second, we had only a two-year follow-up. Although, this is a significant time period among older people to experience noticeable changes in functional capability, a longer follow-up period might reveal stronger effects. Third, we were using a single test to measure executive function instead of multiple tests due to time constraints in the study protocol considering that the participants were very old. Although TMT is a widely used test and simple and easy to perform, further studies should use several test batteries for a more comprehensive evaluation of executive function.

Conclusions

According to our knowledge, we were the first to explore the temporal association between EF and life-space mobility among community-dwelling older people. The results of the study suggest that better EF is a precedent for higher life-space mobility laying ground to future studies on the topic using larger sample sizes and longer follow-up periods with multiple follow-up points. Supporting EF may help maintain higher life-space mobility enhancing independency and quality of life in old age.

ACKNOWLEDGEMENTS

Funding

This study was supported by the Academy of Finland (the Future of Living and Housing Program ASU-LIVE; grant number 255403 to [TR], number 263729 to [AV]; number 285747 to [MR]; number 129369, 129907, 135072, 129255 and 126775 to [JGE] and number 257239 to [MBvB]; Finnish Ministry of Education and Culture to [TR], [MR] and [EP]. TP-C was supported by Yrjö Jahnsson Foundation and Juho Vainio Foundation.

The authors declare that there are no conflicts of interest.

Legend for the Figure 1 Unstandardized coefficients (95% confidence intervals) of cross-lagged model with two-year follow-up for executive function (EF) and life-space mobility adjusted for age and gender (n=108). Path coefficients are statistically significant if zero is not included in the confidential intervals.

REFERENCES

1. Baker PS, Bodner EV, Allman RM. Measuring life- space mobility in community- dwelling older adults. *J Am Geriatr Soc*. 2003;51(11):1610-1614. doi: 10.1046/j.1532-5415.2003.51512.x.

2. Schooler C. Psychological effects of complex environments during the life span: A review and theory. *Intelligence*. 1984;8(4):259-281.

3. Crowe M, Andel R, Wadley VG, Okonkwo OC, Sawyer P, Allman RM. Life-space and cognitive decline in a community-based sample of african american and caucasian older adults. *J Gerontol A Biol Sci Med Sci*. 2008;63(11):1241-1245. doi: 10.1093/gerona/63.11.1241.

4. Sartori AC, Wadley VG, Clay OJ, Parisi JM, Rebok GW, Crowe M. The relationship between cognitive function and life space: The potential role of personal control beliefs. *Psychol Aging*. 2012;27(2):364.

5. Banich MT. Executive function the search for an integrated account. *Current Directions in Psychological Science*. 2009;18(2):89-94.

6. Poranen-Clark T, von Bonsdorff MB, Rantakokko M, et al. Executive function and life-space mobility in old age. *Aging Clinical and Experimental Research*. 2017:1-7.

7. Demnitz N, Esser P, Dawes H, et al. A systematic review and meta-analysis of cross-sectional studies examining the relationship between mobility and cognition in healthy older adults. *Gait Posture*. 2016;50:164-174.

8. Stijntjes M, Aartsen MJ, Taekema DG, et al. Temporal relationship between cognitive and physical performance in middle-aged to oldest old people. *Journals of Gerontology Series A: Biomedical Sciences and Medical Sciences*. 2016;72(5):662-668.

9. Silberschmidt S, Kumar A, Raji MM, Markides K, Ottenbacher KJ, Al Snih S. Life‐ Space mobility and cognitive decline among mexican americans aged 75 years and older. *J Am Geriatr Soc*. 2017.

10. James BD, Boyle PA, Buchman AS, Barnes LL, Bennett DA. Life space and risk of alzheimer disease, mild cognitive impairment, and cognitive decline in old age. *The American Journal of Geriatric Psychiatry*. 2011;19(11):961-969.

11. Royall DR, Palmer R, Chiodo LK, Polk MJ. Declining executive control in normal aging predicts change in functional status: The freedom house study. *J Am Geriatr Soc*. 2004;52(3):346-352.

12. Johnson JK, Lui LY, Yaffe K. Executive function, more than global cognition, predicts functional decline and mortality in elderly women. *J Gerontol A Biol Sci Med Sci*. 2007;62(10):1134-1141. doi: 62/10/1134 [pii].

13. Gross AL, Xue QL, Bandeen-Roche K, et al. Declines and impairment in executive function predict onset of physical frailty. *J Gerontol A Biol Sci Med Sci*. 2016;71(12):1624-1630. doi: glw067 [pii].

14. Vazzana R, Bandinelli S, Lauretani F, et al. Trail making test predicts physical impairment and mortality in older persons. *J Am Geriatr Soc*. 2010;58(4):719-723.

15. Portegijs E, Rantakokko M, Mikkola TM, Viljanen A, Rantanen T. Association between physical performance and sense of autonomy in outdoor activities and Life‐ Space mobility in Community‐Dwelling older people. *J Am Geriatr Soc*. 2014;62(4):615-621.

16. Caetano MJD, Menant JC, Schoene D, Pelicioni PH, Sturnieks DL, Lord SR. Sensorimotor and cognitive predictors of impaired gait adaptability in older people. *Journals of Gerontology Series A: Biomedical Sciences and Medical Sciences*. 2016:glw171.

17. Rantanen T, Portegijs E, Viljanen A, et al. Individual and environmental factors underlying life space of older people - study protocol and design of a cohort study on life-space mobility in old age (LISPE). *BMC Public Health*. 2012;12:1018-2458-12-1018. doi: 10.1186/1471-2458-12-1018 [doi].

18. Polku H, Mikkola TM, Rantakokko M, et al. Hearing and quality of life among community-dwelling older adults. *J Gerontol B Psychol Sci Soc Sci*. 2016. doi: gbw045 [pii].

19. Reitan,R., Wolfson,D., ed. *The halstead-reitan neutopsychologic test battery: Theory and clinical interpretation.* Tucson, AZ: Neuropsychology Press; 1993.

20. Strauss E, Sherman E, Spreen O. Trail making test. *A Compendium of Neuropsychological Tests.Administration, Norms, and Commentary*. 2006:655-677.

21. Lezak M, ed. *Neuropsychological assessment.* 3rd edition ed. Oxford: Oxford University Press; 1995.

22. Bowie CR, Harvey PD. Administration and interpretation of the trail making test. *Nature protocols*. 2006;1(5):2277-2281.

23. Lezak MD. *Neuropsychological assessment.* Oxford University Press, USA; 2004.

24. Ble A, Volpato S, Zuliani G, et al. Executive function correlates with walking speed in older persons: The InCHIANTI study. *J Am Geriatr Soc*. 2005;53(3):410-415.

25. Drane DL, Yuspeh RL, Huthwaite JS, Klingler LK. Demographic characteristics and normative observations for derived-trail making test indices. *Neuropsychiatry Neuropsychol Behav Neurol*. 2002;15(1):39-43.

26. Portegijs E, Iwarsson S, Rantakokko M, Viljanen A, Rantanen T. Life-space mobility assessment in older people in finland; measurement properties in winter and spring. *BMC Res Notes*. 2014;7:323-0500-7-323. doi: 10.1186/1756-0500-7-323 [doi].

27. Folstein MF, Folstein SE, McHugh PR. "Mini-mental state": A practical method for grading the cognitive state of patients for the clinician. *J Psychiatr Res*. 1975;12(3):189-198. doi: http://dx.doi.org/10.1016/0022-3956(75)90026-6.

28. Guralnik JM, Simonsick EM, Ferrucci L, et al. A short physical performance battery assessing lower extremity function: Association with self-reported disability and prediction of mortality and nursing home admission. *J Gerontol*. 1994;49(2):M85-94.

29. Guralnik JM, Ferrucci L, Simonsick EM, Salive ME, Wallace RB. Lower-extremity function in persons over the age of 70 years as a predictor of subsequent disability. *N Engl J Med*. 1995;332(9):556-562.

30. Papandonatos GD, Ott BR, Davis JD, Barco PP, Carr DB. Clinical utility of the Trail- Making test as a predictor of driving performance in older adults. *J Am Geriatr Soc*. 2015;63(11):2358-2364.

31. Tian Q, An Y, Resnick SM, Studenski S. The relative temporal sequence of decline in mobility and cognition among initially unimpaired older adults: Results from the baltimore longitudinal study of aging. *Age Ageing*. 2016. doi: afw185 [pii].

32. Holtzer R, Epstein N, Mahoney JR, Izzetoglu M, Blumen HM. Neuroimaging of mobility in aging: A targeted review. *J Gerontol A Biol Sci Med Sci*. 2014;69(11):1375-1388. doi: 10.1093/gerona/glu052 [doi].

33. Rosso AL, Studenski SA, Chen WG, et al. Aging, the central nervous system, and mobility. *J Gerontol A Biol Sci Med Sci*. 2013;68(11):1379-1386. doi: 10.1093/gerona/glt089 [doi].

34. Puente AN, Lindbergh CA, Miller LS. The relationship between cognitive reserve and functional ability is mediated by executive functioning in older adults. *Clin Neuropsychol*. 2015;29(1):67-81.

35. Ren J, Wu YD, Chan JS, Yan JH. Cognitive aging affects motor performance and learning. *Geriatr Gerontol Int*. 2013;13(1):19-27. doi: 10.1111/j.1447-0594.2012.00914.x [doi].

36. Rantakokko M, Portegijs E, Viljanen A, Iwarsson S, Kauppinen M, Rantanen T. Changes in life-space mobility and quality of life among community-dwelling older people: A 2-year follow-up study. *Quality of Life Research*. 2015:1-9.

37. Portegijs E, Rantakokko M, Viljanen A, Sipilä S, Rantanen T. Identification of older people at risk of ADL disability using the life-space assessment: A longitudinal cohort study. *Journal of the American Medical Directors Association*. 2016;17(5):410-414.

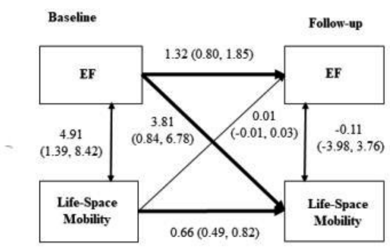
Table 1 Means, standard deviations (SD), and proportions of characteristics of participants at baseline and at two-year follow-up (n=108).

	Baseline	Follow-up
	%	**%**
Women	59.3	59.2
Executive function (n=103)		
Good	41.7	37.1
Intermediate	34.0	33.0
Poor	24.3	29.5
	Mean (SD)	**Mean (SD)**
Age	82.2 (4.1)	84.3 (4.1)
Life-space mobility	63.1 (19.7)	61.5 (21.2)
Number of chronic conditions	3.2 (1.6)	3.4 (1.7)
Cognitive functioning (MMSE)	26.3 (2.7)	26.2 (3.0)
Lower extremity function (SPPB)	9.21 (2.1)	9.10 (2.2)*

MMSE = Mini Mental State Examination, SPPB = Short Physical Performance Battery

*Note, n =106

Figure 1


Baseline
Follow-up
EF
EF
1.32 (0.80, 1.85)
4.91
(1.39, 8.42)
3.81
(0.84, 6.78)
0.01
(-0.01, 0.03)
-0.11
(-3.98, 3.76)
Life-Space
Mobility
Life-Space
Mobility
0.66 (0.49, 0.82)

III

INTELLECTUAL ABILITY IN YOUNG ADULTHOOD AS AN ANTECEDENT OF PHYSICAL FUNCTIONING IN OLDER AGE

by

Poranen-Clark, T., von Bonsdorff MB., Törmäkangas T., Lahti J., Wasenius N., Räikkönen K., Osmond C., Salonen MK., Rantanen T., Kajantie E., Eriksson JG.

Age and Ageing 2016; 45 (5): 727-731.

Request copy from author

IV

INFANT MOTOR DEVELOPMENT AND COGNITIVE PERFORMANCE IN EARLY OLD AGE: THE HELSINKI BIRTH COHORT STUDY

by

Poranen-Clark, T., von Bonsdorff MB., Törmäkangas T., Lahti J., Räikkönen K., Osmond C., Rantanen T., Kajantie E., Eriksson JG.

AGE 2015; 37 (3): 44

AGE (2015) 37: 44
DOI 10.1007/s11357-015-9785-x

Infant motor development and cognitive performance in early old age: the Helsinki Birth Cohort Study

Taina Poranen-Clark · Mikaela B. von Bonsdorff · Jari Lahti · Katri Räikkönen · Clive Osmond · Taina Rantanen · Eero Kajantie · Johan G. Eriksson

Received: 14 January 2015 / Accepted: 17 April 2015 / Published online: 1 May 2015

Abstract Motor development and cognitive development in childhood have been found to be fundamentally interrelated, but less is known about the association extending over the life course. The aim of this study was to examine the association between early motor development and cognitive performance in early old age. From men and women belonging to the Helsinki Birth Cohort Study, who were born between 1934 and 1944 and resided in Finland in 1971, 1279 participated in cognitive performance tests (CogState®, version 3.0.5) between 2001 and 2006 at an average age of 64.2 years (SD 3.0). Of these, age at first walking extracted from child welfare clinic records was available for 398 participants. Longer reaction times in cognitive tasks measuring simple reaction time (SRT), choice reaction time (CRT), working memory (WM), divided attention (DA), and associated learning (AL) indicated poorer cognitive performance. Adjustment was made for sex, age at testing, father's occupational status and own highest attained education, and occupation in adulthood. Average age of learning to walk was 12.2 months (SD 2.1). After adjusting for covariates, earlier attainment of learning to walk was associated with shorter reaction times in cognitive performance tasks (SRT 10.32 % per month, 95 % CI 0.48–21.12, p=0.039; CRT 14.17 % per month, 95 % CI 3.75–25.63, p= 0.007; WM 15.14 % per month, 95 % CI 4.95–26.32, p=0.003). People who learned to walk earlier had better cognitive performance in early old age. The earlier attainment of motor skills may track over to early old

T. Poranen-Clark (✉) · M. B. von Bonsdorff · T. Rantanen
Gerontology Research Center and Department of Health Sciences, University of Jyväskylä, PO Box 35, FI-40014 Jyväskylä, Finland
e-mail: taina.poranen-clark@jyu.fi

T. Poranen-Clark · J. Lahti · J. G. Eriksson
Folkhälsan Research Centre, Biomedicum, University of Helsinki, PL 20, FI-00014 Helsinki, Finland

J. Lahti · K. Räikkönen
Institute of Behavioural Sciences, University of Helsinki, PO Box 9, FI-00014 Helsinki, Finland

C. Osmond
MRC Life course Epidemiology Unit, University of Southampton, Southampton, United Kingdom

E. Kajantie · J. G. Eriksson
Department of Chronic Disease Prevention, National Institute for Health and Welfare, PL 30, 00271 Helsinki, Finland

E. Kajantie
Hospital for Children and Adolescents, Helsinki University Central Hospital and University of Helsinki, Helsinki, Finland

E. Kajantie
Department of Obstetrics and Gynecology, MRC Oulu, Oulu University Central Hospital and University of Oulu, Oulu, Finland

J. G. Eriksson
Unit of General Practice, Helsinki University Central Hospital, Helsinki, Finland

J. G. Eriksson
Department of General Practice and Primary Health Care, University of Helsinki, Helsinki, Finland

age and possibly reflect greater cognitive reserve in older age.

Keywords Infant motor development · Age at first walking · Cognitive performance · Cognitive reserve · Older age

Introduction

It has been suggested that motor development and cognitive development in childhood are fundamentally interrelated (Diamond 2000). Motor development in infancy is a continuous process through which a child achieves new movement patterns and learns new motor skill (Gallahue et al. 2012). Maturation of neural circuits and rapid brain growth is associated with motor development in infancy (Malina 2004; Shenkin et al. 2009; Thelen 1995). Infancy has been suggested to be one of the critical periods of development for intellectual abilities in subsequent life (Gale et al. 2004; Räikkonen et al. 2009).

A life course approach to cognitive ageing provides a concept of cognitive reserve, which indicates that certain aspects of the brain structure such as brain size, neural density, and synaptic connectivity, and the function of brain such as efficiency of neural network, can buffer the effects of cognitive ageing (Richards and Deary 2005). Executive functioning, i.e., the cognitive abilities that control and guide goal-directed performance (Banich 2009), include processing speed, visual attention, and working memory. These cognitive domains are supported by prefrontal and frontal areas of brain and have been shown to be most vulnerable in the ageing process (Kramer et al. 1999, Ren et al. 2013). They are also significantly and independently correlated with functional status in older ages (Royall et al. 2004).

So far, there are only a few studies that have investigated the association between infant motor development and cognitive functioning in adulthood. In the 1946 British Birth Cohort study, earlier age of learning to stand was found to be associated with better executive functioning in adulthood (Murray et al. 2006). In the Northern Finland, 1966 Birth Cohort study earlier infant motor development was found to be associated with better educational outcomes (Taanila et al. 2005) and level of intelligence (Murray et al. 2007) in adolescence and adulthood. Further, earlier motor development was found to be associated with increased gray and white matter densities and better executive function in adulthood (Ridler et al. 2006). However, little is still known about the relationship between early motor development and cognitive functioning in older age. Studying this relationship will further the understanding of early determinants of cognition in older age. The aim of this study was to investigate the association between age at first walking and cognitive performance in early old age at an average age of 64 years.

Materials and methods

Study population

Of 8760 persons belonging to the Helsinki Birth Cohort Study (HBCS) who were born during 1934–1944 in Helsinki and who had attended child welfare clinics and resided in Finland in 1971 (Barker et al. 2005; Eriksson et al. 2001), random number tables were used to select a subset of 2902 persons for a clinical study. Of the 2003 persons who participated in the clinical study during 2001–2006, 1586 participants who were living in the greater Helsinki area were invited to participate in cognitive performance tests. Of them, 1279 persons participated (Paile-Hyvarinen et al. 2009). Among them, 398 individuals had valid data on age at first walking. These participants form the analytic sample in this study. Among the participants of cognitive tests, we compared those with and without data on age at first walking. There were no differences between them in birth weight ($p=0.847$), but slightly more men ($p=0.040$) had missing data on age at first walking. Participants with missing data on age at first walking were also younger at the time of cognitive testing ($p=0.002$), and their fathers had more likely higher occupational status ($p<0.001$) compared with those who had data available. The groups did not differ in adult occupational status ($p=0.641$) or cognitive performance ($p>0.280$). The study complies with the guidelines of the Declaration of Helsinki. The study was approved by the Ethics Committee of Epidemiology and Public Health of the Hospital District of Helsinki and Uusimaa and that of the National Public Health Institute, Helsinki. All participants gave a written informed consent.

Age at learning to walk

The age when the child learned to walk without support was asked from the mothers during their visits to the child welfare clinics and was recorded in months. The children visited the welfare clinics on average 11 times between birth and 2 years.

Cognitive performance

Cognitive performance was measured using the CogState (CogState®, version 3.0.5) computerized cognitive test battery. The tasks included in the battery are based on playing cards presented on a computer screen. The level of performance in the test battery does not depend on the language or socioeconomic background of the participant. CogState cognitive test battery has been validated (Maruff et al. 2009) and designed to be efficient and sensitive in identifying major cognitive domains such as psychomotor speed, visual attention, working memory, divided attention, and associated learning (Darby et al. 2002). CogState test battery has shown good reliability with minimal practice effects (Falleti et al. 2006). Each of the five tasks of the test battery consists of 30 to 50 repeated stimuli, and it takes approximately 15 min to complete the whole test battery. Reaction times were measured in milliseconds, and mean reaction times were calculated for each task. Accuracy of responses was recorded as the number of correct answers divided by the number of all answers given. The five tasks were as follows:

1. In simple reaction time task (SRT) measuring psychomotor speed, participants had to react by pressing the spacebar as quickly as possible whenever a card faced down on the screen was turned face up. This task was repeated 35 times with random time intervals. The SRT task was done twice, first, and last in the test, and the mean reaction time of the two performances was calculated.
2. In choice reaction time task (CRT), measuring visual attention and psychomotor speed participants had to react as quickly as possible by pressing K ("yes") or D ("no") if the turning card on the screen was red. This task was repeated 30 times.
3. In the working memory task (WM) that measured working memory, psychomotor speed and visual attention participants had to react as quickly as possible by pressing K ("yes") or D ("no") if the card showing on the screen was identical to the previous card. This task was repeated 30 times.
4. In divided attention task (DA) that measured divided attention, participants had to monitor five cards on the screen moving randomly between two horizontal lines above and below the cards. Participants were asked to press the spacebar quickly as possible if one of the cards touched the lines. This test was repeated 30 times.
5. In associated learning task (AL) that measured visual learning and memory, participants had to match pairs of cards on the screen. Five pairs of cards were shown on the top half of the screen and one random pair faced down on the bottom half of the screen. When the card pair below these five pairs turned face up, the participants had to press K ("yes") or D ("no") if the pair was identical with one of the pairs above. After matching the pair, the random pair on the bottom half of the screen turned face down, and after this, the participants had to use their memory to be able to produce the right matching. After every match, the pair of cards turned face up, allowing learning during the task. This task was repeated 50 times.

The tasks were performed by 409 participants with data on age at first walking. Of these, 11 participants had invalid result in one, two, or three tests, respectively. These test results were excluded from the analyses.

Covariates

Based on earlier literature, we selected father's occupational status, highest educational attainment, and occupational status in adulthood as covariates (Murray et al. 2007; Taanila et al. 2005). Father's occupational status indicated by the highest occupational class was extracted from the child welfare and school healthcare records and was coded as upper middle class, lower middle class, manual workers, or unknown occupation (Central Statistics Office of Finland 1989). Own highest attained education in adulthood was recorded at 5-year intervals between 1970 and 2000 by Statistics of Finland and was categorized into basic or less or unknown, upper secondary, lower tertiary, and upper tertiary. Data on adult occupational status was extracted from the Finnish Population Register Center and was categorized into upper middle class, lower middle class, self-employed, and manual workers according to highest occupational class at 5-year intervals between 1970 and 2000.

Statistical analyses

Student's t test was used for comparing means for normally distributed and Mann-Whitney U test for non-normally distributed continuous variables, and Pearson's chi-squared test was used for comparing proportions for categorical variables. Linear regression analysis was used to investigate the association between age at first walking and cognitive performance in early older age. The reaction times of the cognitive performance tasks were $\log_{10}$ transformed in order to normalize the distribution, and standardized values were used in the regression models. The regression coefficients were expressed as percent changes per monthly change in the age of learning to walk with 95 % confidence intervals (CI). Multi-nominal regression analysis was used to investigate the associations between age at first walking and errors made in cognitive tasks.

We tested for the interaction between gender by age at first walking on cognitive performance tasks. A statistically significant association was observed for associated learning task (p=0.042) but not for other cognitive tasks (p>0.172). Based on these findings, we did gender-stratified analyses which revealed that associations between age at first walking and cognitive tasks were parallel except with associated learning task. Thus, we did analyses separately for men and women for associated learning task and pooled by gender for other cognitive tasks. Models were first adjusted for gender and age at cognitive testing, then for father's occupational status and own highest attained education, and finally for adult occupational status. All tests were performed two-tailed, the level of significance was set at $p<0.05$, and analyses were carried out with SPSS IBM version 22.0 (SPSS, Armonk, NY, IBM Corp).

Table 1 Characteristics of the participants (n=398)

Characteristics	Mean (SD)
Age at first walking (months)	12.1 (2.1)
Age at cognitive tests (years)	64.2 (3.0)
	%
Men	43.2
Father's occupational status	
Upper middle	8.8
Lower middle	23.5
Manual worker	67.7
Attained education	
Upper tertiary	11.8
Lower tertiary	23.4
Upper secondary	26.4
Basic	38.4
Adult occupational status	
Higher official	12.6
Lower official	45.5
Self employed	8.3
Manual worker	33.7

Results

Characteristics of the study participants (172 men, 226 women) are presented in Table 1. Average age at learning to walk was 12.1 months (SD 2.1, range 6 to 24 months). Average age at the time of performing cognitive tests was 64.2 years (SD 3.0).

Median reaction times and accuracy of performance in cognitive tasks are shown in Table 2. We investigated the associations between age at first walking and errors made in cognitive tasks using multi-nominal regression analysis and found no statistically significant associations (data not shown).

The association between age at first walking and each cognitive performance task and regression lines and their 95 % confidence intervals are displayed in Fig. 1. In the age- and gender-adjusted models, later attainment of learning to walk lengthened the reaction times in all cognitive performance tasks, associations being statistically significant in simple reaction time task (11.0 % per month, 95 % CI 1.14–21.89, p=0.028), choice reaction task (14.8 % per month, 95 % CI 4.43–26.18, p=.004), and working memory task (14.8 % per month, 95 % CI 4.77–25.84, p=.003). Further adjustment for father's occupational status and own maximum attained education (model 2), and for adult occupational status (model 3) did not attenuate the associations (Table 3). In the gender-stratified analyses, after adjustments, later attainment of learning to walk lengthened the reaction times in associated learning task for women (18.35 % per month, 95 % CI 3.94–34.77, p=0.011). For men, the association between age at first walking and associated learning task was not statistically significant (data not shown). Further adjustment for gestational age did not change the results.

Table 2 Median reaction times and accuracy of completing the cognitive performance tasks and their interquartile ranges

	Median (%)	25th percentile	75th percentile
Simple reaction time (ms)	332	295	373
Hit rate (%)	98.1		
Errors (%)			
None	47.7		
One	25.4		
Two or more	26.9		
Choice reaction time (ms)	564	508	631
Hit rate (%)	96.8		
Errors (%)			
None	51.3		
One	25.1		
Two or more	23.6		
Working memory (ms)	848	761	1031
Hit rate (%)	95.5		
Errors (%)			
None	36.4		
One	27.1		
Two or more	36.5		
Divided attention (ms)	482	418	569
Hit rate (%)	91.7		
Errors (%)			
None	14.3		
One	19.8		
Two or more	65.9		
Associated learning (ms)	1825	1552	2200
Hit rate (%)	72.0		
Errors (%)			
None	0		
One	0		
Two or more	100		

Discussion

The main result of the current study was that people who had learned to walk at an earlier age performed better in cognitive tests in early old age. The associations were linear associations and not explained by potential socio-economic or demographic confounders. Our study thus suggests that timing of motor development in infancy, which has been identified as a period of rapid brain growth, may track over to cognitive performance in early old age. We were, for the first time, able to study these associations from infancy to early old age. We were able to verify that the same trend in the associations between motor development and cognitive ability previous observed to extend to midlife can be found also in older age. Previously, based on data of the 1946 British Birth Cohort, it was observed that the earlier a child learned to stand, the better their subsequent intellectual function at ages 8, 26, and 53 years (Murray et al. 2007). In the Northern Finland 1966 birth cohort, those who reached key infant motor milestones earlier had better school performance at 16 years of age and educational attainment at 31 years of age (Taanila et al. 2005). Earlier motor development in infancy has been found to be linked with better executive functioning and greater gray matter density and white matter volume in the adult brain (Ridler et al. 2006). Another study from the Northern Finland 1966 birth cohort showed that earlier development in the cross motor domain, measured as the age of learning to stand, was associated with better executive functioning at ages 33–35 years. Furthermore, we have shown earlier in the HBCS data that lower weight, length, and head circumference at birth were associated with lower cognitive ability at age 68 years (Räikkönen et al. 2013). In all, infancy is a critical period of development of intellectual abilities in subsequent life (Gale et al. 2004; Räikkonen et al. 2009). Faster growth of the brain and central nervous system resulting in earlier motor development in infancy (Malina 2004) may have far-reaching effects on cognitive reserve capacity in older age (Murray et al. 2006), which might partly explain the finding of our study.

Although adjustment for educational attainment did not notably attenuate the associations in the present study, the results of the other studies might suggest that earlier motor development in infancy may increase opportunities to attain higher educational achievements in later life (Taanila et al. 2005) which are further associated with better cognitive performance (Deary et al. 2007). Earlier motor development together with faster maturation of basic neural circuits may lead to more favorable development of brain neural circuits which are involved in higher cognitive processes in later life (Murray et al. 2006).

As population ages, risks for decline in cognitive function threaten the independence and quality of life of older people and challenge the health care system (Dodge et al. 2005; Johansson et al. 2012). However, there is great variability among older persons in the rate

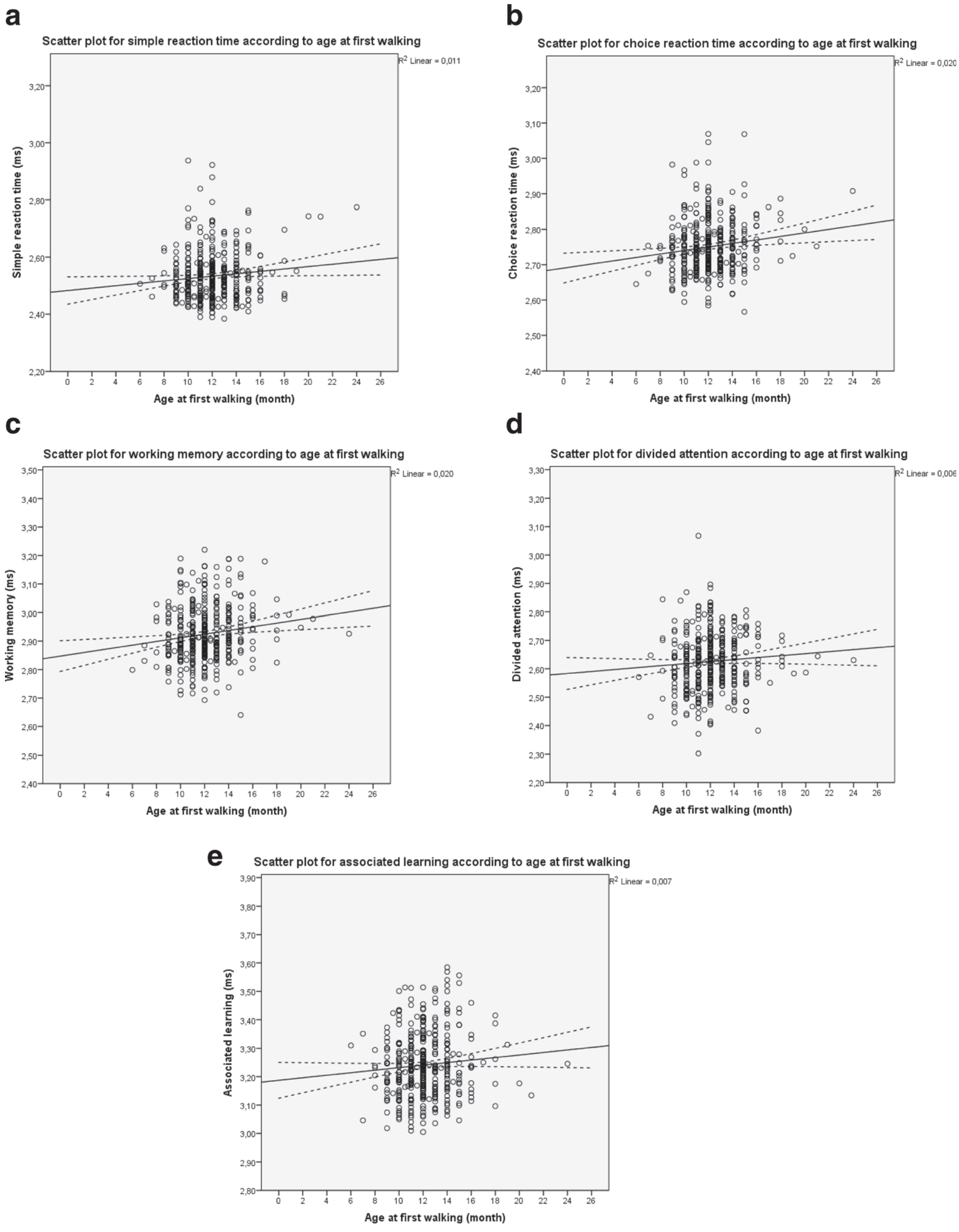


Fig. 1 Scatterplots with regression lines and their 95 % confidence intervals for $\log_{10}$ transformed cognitive performances (ms) according to age at first walking (month)

of decline across various domains of cognitive performance (Wilson et al. 2002). This can be explained partly by neurobiological factor such as the size and structure of the brain (Haier et al. 2004). The concept of reserve in neuroscience indicates that structure and functioning of the brain can protect from the effects of neuropathology. The greater the reserve, the less severe the decline in cognitive performance (Richards and Deary 2005; Stern 2009). Cognitive performance outcomes in this study, i.e., psychomotor speed, visual attention, working

Table 3 Increase (%) in reaction times on cognitive performance tasks (CogState) according to 1 month older age at first walking

	Model 1			Model 2			Model 3		
	%	95 % CI	*p* value	%	95 % CI	*p* value	%	95 % CI	*p* value
SRT	11.03	1.14, 21.89	0.028	10.68	0.88, 21.43	0.032	10.32	0.48, 21.12	0.039
CRT	14.79	4.43, 26.18	0.004	14.74	4.32, 26.17	0.005	14.17	3.75, 25.63	0.007
WM	14.82	4.77, 25.84	0.003	15.40	5.26, 26.53	0.002	15.14	4.95, 26.32	0.003
DA	7.51	−1.87, 17.77	0.120	7.07	−.2.28, 17.31	0.143	7.26	−2.17, 17.59	0.135

Longer reaction times indicate poorer performance on the task

SRT simple reaction time task, *CRT* choice reaction time task, *WM* working memory, *DA* divided attention task, *Model 1* adjusted for age and gender, *Model 2* adjusted for model 1 and father's occupational status and own highest attained education, *Model 3* adjusted for model 2 and adult occupational status

memory, divided attention, and associated learning, all of which are dimensions of executive functioning, are needed for successful performance in everyday life (Bell-McGinty et al. 2002; Wang et al. 2002).

One of the strengths of this study is the longitudinal study design. We were able to use register-based data on age at first walking gathered from child welfare clinic records which had been filled in by nurses at the close proximity to the age the child learned to walk. Cognitive performance was measured using a sensitive validated computerized testing battery. A computerized test is more instructor-independent resulting in fewer data entry errors compared to traditional paper-and-pencil neuropsychological tests (Collie and Maruff 2003). In addition, we were able to extend the study to a later age than ever before. There are also some limitations in our study. First, we cannot be completely sure that our results can be generalized to other cohorts. Even though the achievement of motor milestones in infancy is fairly universal, the age of attainment may be culturally influenced (WHO 2006). Second, our study population comprised people who were born in Helsinki and had attended child welfare clinics. It is likely that this does not bias the sample extensively, because the clinics were free. We cannot entirely rule out the people who were, deceased, declined to participate, or not willing to participate in the clinical examinations between the years 2004 and 2006 that were somehow different from those not interested. However, the participants consist of men and women from all social strata, so this is not likely to bias the results materially either. Unfortunately, we were not able to control for some potentially important early exposures such as parental characteristics because such data were not recorded in the clinics at the time the participants were growing up. Finally, there might have been other possible factors during the life course that may have affected the association between age at first walking and cognitive performance in early old age which we have not been able to control for in this study.

Conclusion

To conclude, our research has shown that persons who learned to walk earlier had better cognitive performance in early old age. Hence, the effects of earlier attainment of motor skills seem to track over to better cognitive functioning in early old age. The contribution of infant motor development should be further explored as an early predictor of cognitive decline.

Funding HBCS was supported by Emil Aaltonen Foundation, Finnish Foundation for Diabetes Research, Novo Nordisk Foundation, Signe and Ane Gyllenberg Foundation, Samfundet Folkhälsan, Finska Läkaresällskapet, Liv och Hälsa, and Finnish Foundation for Cardiovascular Research. TP-C was supported by Yrjö Jahnsson Foundation and Folkhälsan. The Academy of Finland supported MBvB (grant no. 257239), TR (grant no. 255403), EK (grant no. 127437, 129306, 130326, 134791, and 2639249), and JGE (grant no. 129369, 129907, 135072, 129255, and 126775). The research leading to these results has received funding from the European Commission within the 7th Framework Programme (DORIAN, grant agreement no 278603).

Conflict of interest No declared.

References

Banich MT (2009) Executive function the search for an integrated account. Curr Dir Psychol Sci 18:89–94

Barker DJ, Osmond C, Forsen TJ, Kajantie E, Eriksson JG (2005) Trajectories of growth among children Who have coronary events as adults. N Engl J Med 353:1802–1809

Bell-McGinty S, Podell K, Franzen M, Baird AD, Williams MJ (2002) Standard measures of executive function in predicting instrumental activities of daily living in older adults. Int J Geriatr Psychiatry 17:828–834

Collie A, Maruff P (2003) Computerised neuropsychological testing. Br J Sports Med 37:2–3

Darby D, Maruff P, Collie A, McStephen M (2002) Mild cognitive impairment can be detected by multiple assessments in a single Day. Neurology 59:1042–1046

Deary IJ, Strand S, Smith P, Fernandes C (2007) Intelligence and educational achievement. Intelligence 35:13–21

Diamond A (2000) Close interrelation of motor development and cognitive development and of the cerebellum and prefrontal cortex. Child Dev 71:44–56

Dodge HH, Kadowaki T, Hayakawa T, Yamakawa M, Sekikawa A, Ueshima H (2005) Cognitive impairment as a strong predictor of incident disability in specific ADL–IADL tasks among community-dwelling elders: the Azuchi study. Gerontologist 45:222–230

Eriksson JG, Forsen T, Tuomilehto J, Osmond C, Barker DJ (2001) Early growth and coronary heart disease in later life: longitudinal study. BMJ 322:949–953

Falleti MG, Maruff P, Collie A, Darby DG (2006) Practice effects associated with the repeated assessment of cognitive function using the CogState battery at 10-minute, One week and One month test-retest intervals. J Clin Exp Neuropsychol 28: 1095–1112

Gale CR, O'Callaghan FJ, Godfrey KM, Law CM, Martyn CN (2004) Critical periods of brain growth and cognitive function in children. Brain 127:321–329

Gallahue D, Ozmun J, Goodway J (2012) Understanding motor development: infants, children, adolescents, adults. McGraw-Hill International edition. 14 p

Haier RJ, Jung RE, Yeo RA, Head K, Alkire MT (2004) Structural brain variation and general intelligence. Neuroimage 23:425–433

Johansson MM, Marcusson J, Wressle E (2012) Cognition, daily living, and health-related quality of life in 85-year-olds in Sweden. Aging Neuropsychol Cognit 19:421–432

Kramer AF, Hahn S, Cohen NJ, Banich MT, McAuley E, Harrison CR, Chason J, Vakil E, Bardell L, Boileau RA (1999) Ageing, fitness and neurocognitive function. Nature 400: 418–419

Malina RM (2004) Motor development during infancy and early childhood: overview and suggested directions for research. Int J Sport Health Sci 2:50–66

Maruff P, Thomas E, Cysique L, Brew B, Collie A, Snyder P, Pietrzak RH (2009) Validity of the CogState brief battery: relationship to standardized tests and sensitivity to cognitive impairment in mild traumatic brain injury, schizophrenia, and AIDS dementia complex. Arch Clin Neuropsychol 24:165–178

Murray GK, Veijola J, Moilanen K, Miettunen J, Glahn DC, Cannon TD, Jones PB, Isohanni M (2006) Infant motor development is associated with adult cognitive categorisation in a longitudinal birth cohort study. J Child Psychol Psychiatry 47:25–29

Murray GK, Jones PB, Kuh D, Richards M (2007) Infant developmental milestones and subsequent cognitive function. Ann Neurol 62:128–136

Paile-Hyvarinen M, Raikkonen K, Kajantie E, Darby D, Yliharsila H, Salonen MK, Osmond C, Eriksson JG (2009) Impact of glucose metabolism and birth size on cognitive performance in elderly subjects. Diabetes Res Clin Pract 83:379–386

Räikkonen K, Forsen T, Henriksson M, Kajantie E, Heinonen K, Pesonen AK, Leskinen JT, Laaksonen I, Osmond C, Barker DJ, Eriksson JG (2009) Growth trajectories and intellectual abilities in young adulthood: the Helsinki birth cohort study. Am J Epidemiol 170:447–455

Räikkönen K, Kajantie E, Pesonen AK, Heinonen K, Alastalo H, Leskinen JT, Nyman K, Henriksson M, Lahti J, Lahti M, Pyhala R, Tuovinen S, Osmond C, Barker DJ, Eriksson JG (2013) Early life origins cognitive decline: findings in elderly Men in the Helsinki birth cohort study. PLoS One 8:e54707

Ren J, Wu YD, Chan JS, Yan JH (2013) Cognitive aging affects motor performance and learning. Geriatr Gerontol Int 13:19–27

Richards M, Deary IJ (2005) A life course approach to cognitive reserve: a model for cognitive aging and development? Ann Neurol 58:617–622

Ridler K, Veijola JM, Tanskanen P, Miettunen J, Chitnis X, Suckling J, Murray GK, Haapea M, Jones PB, Isohanni MK, Bullmore ET (2006) Fronto-cerebellar systems are associated with infant motor and adult executive functions in healthy adults but Not in schizophrenia. Proc Natl Acad Sci U S A 103:15651–15656

Royall DR, Palmer R, Chiodo LK, Polk MJ (2004) Declining executive control in normal aging predicts change in functional status: the freedom house study. J Am Geriatr Soc 52:346–352

Shenkin SD, Deary IJ, Starr JM (2009) Birth parameters and cognitive ability in older Age: a follow-Up study of people born 1921-1926. Gerontology 55:92–98

Stern Y (2009) Cognitive reserve. Neuropsychologia 47:2015–2028

Taanila A, Murray GK, Jokelainen J, Isohanni M, Rantakallio P (2005) Infant developmental milestones: a 31-year follow-Up. Dev Med Child Neurol 47:581–586

Thelen E (1995) Motor development. A New synthesis. Am Psychol 50:79–95

Wang L, van Belle G, Kukull WB, Larson EB (2002) Predictors of functional change: a longitudinal study of nondemented people aged 65 and older. J Am Geriatr Soc 50:1525–1534

WHO Motor Development Study (2006) Windows of achievement for Six gross motor development milestones. Acta Paediatr Suppl 450:86–95

Wilson RS, Beckett LA, Barnes LL, Schneider JA, Bach J, Evans DA, Wilson RS, Beckett LA, Barnes LL, Schneider JA, Bach J, Evans DA, Bennett DA (2002) Individual differences in rates of change in cognitive abilities of older persons. Psychol Aging 17(2):179–193