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The association between gait and cognitive function in relatively healthy elderly people

Master's thesis in Human Movement Science
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Abstract - English

Background: Age related changes in physical and cognitive function are well documented. A wide range of gait characteristics has shown associations with cognitive function in elderly people, but it is unclear which gait parameters are best suited when investigating the association. Furthermore the gait conditions in which the gait parameters are recorded may influence the association.

Aim: The aim of the study was to investigate the association between gait characteristics and cognitive function in a relatively healthy elderly population, and to determine which gait parameters show the closest association with cognition. Secondary aims were to investigate the association between gait and cognition in different walking conditions, and to evaluate possible gender differences in the association.

Design: This study used a population based cross sectional design.

Methods: Data was collected from 405 participants. Of these were 11 subjects excluded, resulting in a sample size of 394. Gait characteristics were measured using a 6.10 meter computerized walkway and cognitive function was measured using the Montreal Cognitive Assessment (MoCA). Pearson's correlation test (Pearson's r) and multiple linear regression models were used to investigate the associations between gait characteristics and cognition.

Results: Low to moderate significant bivariate correlations between several gait parameters and cognition, including both spatial and temporal measures was found. Gait speed was significantly correlated to cognitive function in all walking conditions, for both men and women. When adjusting for covariates gait speed remained significant in all conditions, except from fast gait speed condition in men. Of the variability measures only Stance Time SD in men in the preferred walking condition was significantly correlated with cognition. The most and strongest correlations were found when testing in the preferred walking speed condition. The associations were stronger in women.

Conclusion: Of the included gait parameters, gait speed showed the nearest correlation to cognition. Future studies on the relationship between gait and cognition may include several gait conditions in their protocol, and include gait parameters that cover the range of gait domains. Furthermore, future studies may determine early gait markers that works as predictors of future cognitive decline, in order to initiate appropriate interventions.

Key words: *Gait function, gait speed, variability, step length, step time, stride width, stance time, double support, cognition, mild cognitive impairment, MoCA and elderly*

Abstract - Norwegian

Bakgrunn: Aldersrelaterte endringer i fysisk og kognitiv funksjon er vel dokumentert. Mange ulike gangkarakteristikker er brukt for å vise assosiasjoner til kognitiv funksjon hos eldre, men det er uklart hvilke gangparameter som er mest passende å bruke når man undersøker sammenhengen med kognisjon. Videre kan valget av gangkondisjon påvirke assosiasjonen mellom gangkarakteristikker og kognisjon.

Mål: Hovedmålet med studien var å undersøke sammenhengen mellom ulike gangkarakteristikker og kognisjon i en relativ frisk eldre populasjon, og undersøke hvilke gangkarakteristikker som viser den nærmeste assosiasjonen med kognisjon. Sekundere mål var å undersøke forskjell i sammenhengen mellom gange og kondisjon når man tester i ulike gangkondisjoner, samt å evaluere eventuelle kjønnsforskjeller.

Studiedesign: Denne studien har brukt et populasjonsbasert tverrsnittsdesign

Metode: Data ble innhentet fra 405 deltagere. 11 subjekter ble ekskludert, som resulterte i at 394 subjekter ble inkludert for videre analyser. Gangkarakteristikker ble målt på en 6.10 meter lang elektronisk gangmatte. Kognitiv funksjon ble målt med Montreal Cognitive Assessment (MoCA). Pearson’s korrelasjons test og multiple lineære regresjonsmodeller ble brukt for å undersøke assosiasjonen mellom gange og kognitiv funksjon.

Resultat: Bivariate korrelasjonstester viste små til moderate sammenhenger mellom ulike gangkarakteristikker og kognisjon, inkludert både spatiale, temporale og variabilitetsmål. Ganghastighet var signifikant korrelert til kognitive funksjon i alle ganghastigheter for begge kjønn. Kontrollert for andre variabler var ganghastighet fortsatt signifikant korrelert til kognisjon i alle gangkondisjoner bortsett fra i rask ganghastighet for menn. Av målene på variabilitet var det bare Stance Time SD for menn i selvvalgt ganghastighet som var signifikant assosiert med kognitiv funksjon, etter å ha justert for kontrollerende variabler.

Konklusjon: Av de inkluderte gangparameterne viste ganghastighet nærmest sammenheng med kognitiv funksjon. Fremtidige studier som undersøker sammenhengen mellom gange og kognisjon bør inkludere flere gangkondisjoner og inkludere gangparameter som dekker bredden av de forskjellige domenene innen gange. Fremtidige studier kan også undersøke hvilke gangkarakteristikker som tidlig fungerer som predikatorer for fremtidig kognitiv svikt. Kunnskap om dette kan være til hjelp for å utvikle intervensjoner på et tidlig stadium**.**

Nøkkelord: *Gangfunksjon, ganghastighet, variabilitet, steglengde, stegtid, stegbredde, ståtid, dobbel support, kognisjon, mild kognitiv svikt, MoCA og eldre.*

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1.0 Introduction

The population of the world has experienced remarkable improvements in life expectancy over the past century, leading to an increasing older population. It has been estimated that the number of people aged 65 or older will increase from an estimated 524 million in 2010, to around 1.5 billion in 2050.[1] With a growing number of elderly new challenges arises, which will have great impact on both individual and a global level. Older adulthood is associated with functional and physiological changes, which may lead to illness, disability and dependency in daily life.[1] The demand of future health care may request substantial social costs, and it is therefore important to keep the aging population healthy and independent for as long as possible.

1.1 Age related changes in cognition

The human body changes through the lifespan, including both physical and biological alterations. Both structural and functional changes occur in the brain in old age, but there are large individual differences, which make it difficult to understand the path of normal cognitive aging [2,3]. Cognitive function persists of a variety of abilities, but they do not follow the same trajectory of decline in the adult development. While language, including verbal abilities, information and comprehension are stable until very old age, speed of processing, spatial ability, memory and reasoning are more likely to decline more with aging[4].

The level of cognitive function in older adult can generally be divided into three groups. The first group consists of those who experience normative cognitive function, where the decline does not affect the daily living. Secondly, Mild cognitive impairment (MCI) is a state between normal cognitive function and dementia, characterized by changes in cognitive function, proceeding what is normal for their age, but do not reach the level required to be diagnosed with dementia[5]. The global prevalence of MCI is estimated to be 15-20% and the risk of developing Alzheimer's disease (AD) is 10-15 times higher in people with MCI[6,7]. The third cognitive state is dementia, a chronic syndrome characterized by cognitive deficits in at least two cognitive domains, in such manner that it affects daily functioning [4]. There are many subtypes of dementia, with AD as the most common. High education, good vascular and cognitive health and a cognitive reserve work as protective factors for maintaining good cognitive function [8]. In opposite, several risk factors contribute in the development of cognitive decline, such as age, physical activity and vascular diseases. Also, female gender has been reported to be a risk factor for dementia [8].

Changes in cognition that leads to dementia may happen over a long time frame, making it important to identify persons at risk in an early state. Several screening tests, such as the Mini Mental Status Evaluation (MMSE) and the Montreal Cognitive Assessment (MoCA) are designed to identifying people with MCI. Identifying people at risk at an early stage makes it possible to start interventions. Several modifiable factors, such as cognitive activity and exercise may delay the potential onset of dementia [4].

1.2 Age related changes in gait

Walking is a motor skill that is smooth, efficient and automatic, but the underlying mechanisms are complex and multifactorial and involve several systems, such as musculoskeletal, pulmonary, neurological and the cardiovascular system[9,10]. To define normal walking in elderly adults is difficult, hence the great individual differences in what we characterize as normal. Normative population databases may indicate what to expect in certain population groups, such as elderly adults[11]. A decline in gait function may reduce the mobility of elderly and gait disturbances work as a risk factor for several health related outcomes, such as dependence, falls, hospitalization, death and cognitive decline[12,13]. The most common age related changes in gait are reduced gait speed and a shorter step length, but a variety of temporal and spatial measures may identify changes in gait. Men tend to walk faster, with longer steps, while women have higher cadence than men[11]. There is also great interest in the literature according the individual variance in gait, often reported as gait variability[14,15].

Gait speed has shown to be a good indicator of functional level and a predictor of several health related outcomes in clinical and epidemiological studies, including physical function, health status quality of life and mortality[10,13,16], and is widely reported in the literature. Gait speed assessment is low cost and easy to perform in both clinical and non-clinical settings[17]. The literature have presented several cut points for normative age-defined gait speed in order to identify persons at risk of future health problem[13,18]. These cut points vary from 0.6 m/s to 1.0 m/s in people aged 65 or more, while a walking pace of 1,3 m/s were identified as extremely fit[13]. Interestingly Peel et al,[19] found in a meta analyses that gait speed increased over time, with a mean of 0.013 m/s per publication year from 1988 to 2011, suggesting that gait speed has been influenced by improved health and survival rates. White et al,[20] found that the trajectory of how fast the decline in gait speed was, influenced the risk of death, indicating that a fast decline in gait speed increased the risk of death. In addition, Hardy and collegues[16] found that an improvement or maintaining gait speed over time increased survival in healthy elderly adults.

1.3 Association between gait and cognitive function

Gait speed is also associated with cognitive function in elderly and the association is well supported by cross sectional studies, but there is a lack of causal explanation, and unclear whether decline in gait function precedes a decline in cognitive function or vice versa. Atkinson et al reported in a prospective cohort study that cognitive function at baseline could predict decline in gait speed among well functioning elderly people. Gale et al.[21] found a bidirectional relationship between gait speed and cognitive function, they could not determine whether change in cognitive function lead to gait speed decline or the other way around. Mielke et al.[22] assessed the temporal relationship and found that gait speed at baseline was both cross sectional and longitudinally associated with cognitive decline, while baseline cognition not predicted any change in gait speed.

The association between cognitive function and gait variability has been a growing subject for researcher in the last decades. Verghese et al.[23] identified three domains that characterized gait performances in older adults, and the different cognitive domains they were associated with. Differences in pace, characterized by gait speed and stride length, were associated with a decline in executive function. A rhythm domain, characterized by differences in cadence, swing time and stance time were associated with memory decline, and third, differences in variability characterized by stride length was associated with subtype categorizing of mild cognitive impairment. This only explains some of the many gait parameters that may distinguish different gait characteristics.

Walking in preferred gait speed is the most common technique when assessing the associations between gait and health related outcomes[24]. When investigating cognition in associations with gait, the use of an attention divided task, called dual task is often used. In addition to walking, the participant is given a secondary task (i.e. numerical subtraction) demanding divided attention, which is considered a cognitive task. Dual task has shown to have an affect on destabilizing the gait in elderly, and especially elderly idiopathic fallers[25]. Fast walking speed has also been of interest when investigating associations between gait and cognition. One argument for testing in fast walking speed condition is that it might be considered a more conscious task, compared to walking at the preferred speed[26]. Furthermore, fast gait speed reportedly displayed more variability then preferred gait speed and was a more sensitive measure than preferred gait speed in differentiating levels of cognition in healthy elderly adults without dementia[27].

1.4 The present study

Several cross sectional studies have reported the association between different measures of cognition with different characteristics of gait. A wide range of gait characteristics have been used to establish association with cognition in the literature, but it is unclear which gait characteristics that are closest associated with cognition in relatively healthy elderly adults. There is no clear consensus regarding which walking conditions that are most suiting when investigating the association between gait and cognition, with preferred gait speed, fast gait speed and dual task walking being the most reported in the literature. Since female gender may work as a risk factor for dementia[8], and normative data indicating differences in gait between the genders[11] there might be differences in the association between the genders.

The main aim of this study is to investigate the association between gait characteristics and cognitive function in relatively healthy elderly people and determine which gait parameters show the closest association with cognitive function. Secondary aims are to investigate the association between different walking conditions (preferred gait speed, fast gait speed and dual task walking) and cognitive function, and to evaluate possible gender differences in the association between gait and cognition. In accordance with the literature, associations between several gait characteristics and cognitive function is expected. Furthermore, gait speed and measures of variability are expected to show the closest associations between gait and cognition. Fast gait speed and dual task walking are expected to be the most suiting walking condition, all the time fast walking and dual task walking are more cognitive demanding tasks than preferred walking[26,28]. Differences in gait and the risk of developing dementia differ between the genders, and the interrelationship between these factors may therefore be different in women compared to men.

2.0 Methods and materials

2.1 Study design

A population-based, cross sectional study design was used to examine whether there was a relationship between gait and cognitive function in older persons.

Data for this study was collected through the larger, *Generation 100* study. This is a prospective randomized controlled study with a main aim of investigating the long-term effects of exercise on mortality in elderly people. Baseline data was collected in 2012, before randomization, with one year follow up in 2013, three-year follow-up in 2015 and the final five-year follow up in 2017. The participants were randomized into either an exercise group or a control group. Furthermore, the participants of the exercise group were divided into either a high intensity exercise group (Weekly sessions of 10 min warm up followed by 4x4 min intervals at ≅90% of peak heart rate) or a moderate-intensity exercise group (50 min of continuous work at ≅70% of peak heart rate). The control group was instructed to follow the national accommodations regarding physical activity.

This study will solely use data from the three-year follow up.

2.2 Participants

Eligible participants of the Generation 100 study had to be born in the period from 1936 to 1942 (70-76 years at the time of inclusion) and be living in the municipal of Trondheim, Norway. Further, they had to be able to complete their allocated exercise program. Illness or disabilities that prevented participants from exercising or participating in Generation 100 were exclusion criteria, as were uncontrolled hypertension, hypertrophic cardiomyopathy, unstable angina, primary pulmonary hypertension, heart failure, severe arrhythmia, diagnosed dementia and cancer that makes participation impossible or exercise contraindicated. Also, chronic communicable infectious diseases were subject for exclusion, in line with test results indicating that further participation is unsafe, and if the participants were participating in other studies conflicting with Generation 100[29].

This current study has used data collected from the three-year follow up of the Generation 100 study. The three-year follow-up testing was conducted between August 2015 and June 2016. Due to the restricted time frame of this thesis, only data collected between the dates of August 31th and December 10th, 2015 was included. During this time period data has been collected from 405 participants.

Participation in the Generation 100 study was voluntary and all persons participating in the study signed an informed consent prior to testing. The Regional Committee for Medical Research Ethics, Southern Norway (REK), has approved this study (2015/2300/REK midt).

2.3 Equipment

Walking test

The ProtoKinetics® Zeno walkway was used to collect data on gait footfalls from pressure sensors in the three layered carpet, which the participants were walking on (Figure 1). The pressurized carpet had an active measurement area of 6.10x1.22 meters, which measured and recorded temporal and spatial parameters of gait. The Zeno walkway system is similar to the widely used GaitRite® walkway system, which have excellent reliability and concurrent validity for most temporal and spatial measures of gait[30,31].Egerton et al.[32] compared the two software's coming with each of the systems, and found that for the most of the spatial temporal variables the outcome measures from both programs could be used interchangeably. An acceleration/declaration zone of 1.16 meters from was set at each end of the walkway. Including the non-active area of the walkway this resulted in a total walking length of approximately 8.6 meters. The duration of the walking test was approximately 5 minutes.

The Zeno walkway was directly connected to a computer with PKMAS software, also a product of ProtoKinetics. It recorded and stored the gait output and presented the walks visually on the screen. Each walk was inspected, and each footprint was marked as either right or left. Footprints that were just partially inside the active measurement area were deleted (Figure 2). Noise or other false readings from the sensors were deleted, to ensure they did not affect the analysis. If a walk was interrupted, or a subject stopped during the walk, only the footprints before or after the interruption was included, depending on which had most acceptable steps. Four continuous steps were required for a walk to be accepted. The first example in Figure 2 shows an accepted trial, where all footprints are completely inside the active area. In the second example the first step (from left to right) was incomplete, and this footprint was therefor excluded.

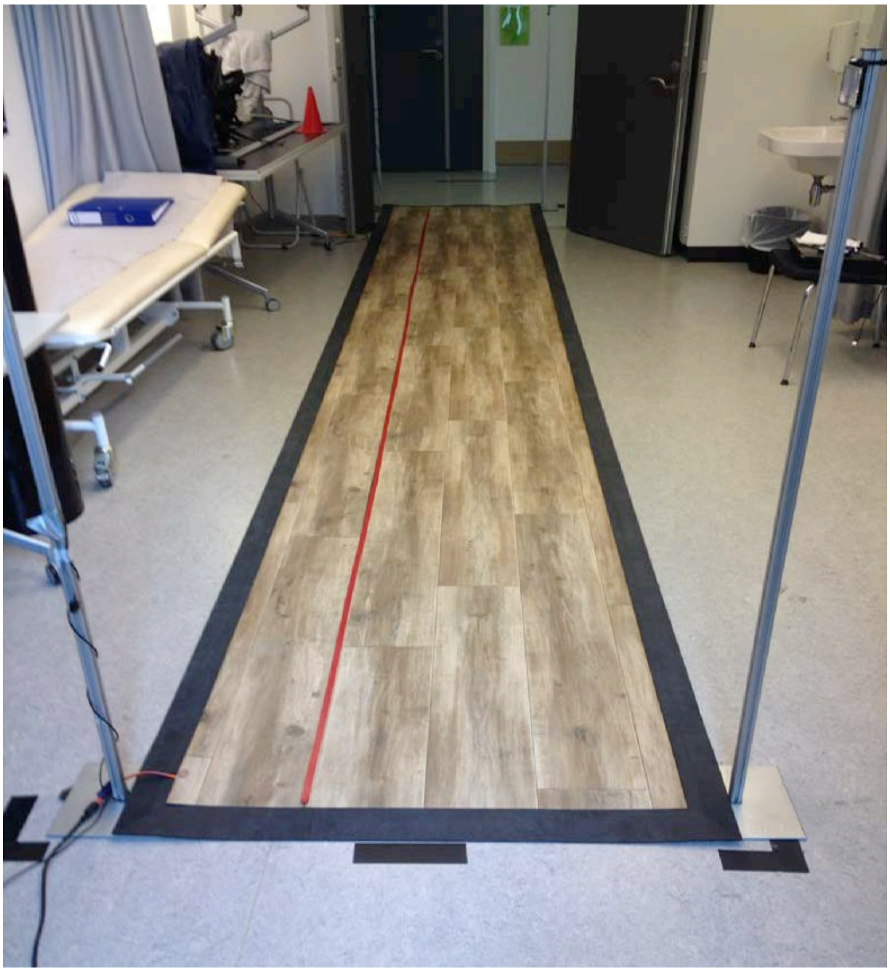


Figure 1: *The Zeno walkaway set up in the test facility. The participants were instructed to walk in the broad field and not cross the red line.*

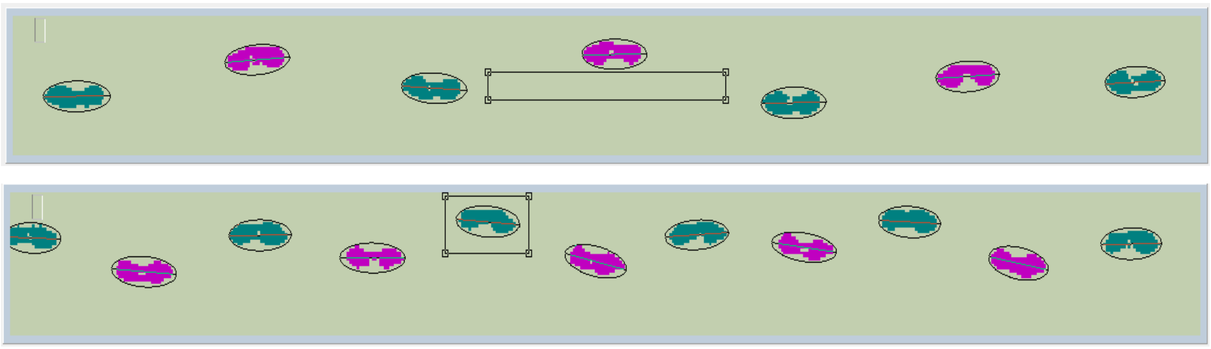


Figure 2: *Example of an approved trial (top) and not approved trial (lower).*

Cognitive test

For measuring cognitive function, the Montreal Cognitive assessment (MoCA), version 7.1 was used[33]. MoCA is a screening test developed to detect mild cognitive impairment (MCI), a clinical state that often is followed by dementia on a later state. The test assesses different cognitive domains, and scoring is made for separately for each of the domains, before they are summarized in sum score, henceforth called MoCA full score. The domains included are executive function/visuoconstructional function (0-5 points), naming (0-3 points), language (0-3 points), abstraction (0-3 points), attention (0- 6 points), memory, in form of delayed recall (0-5 points) and orientation (0-6 points). Adding the scores from all cognitive domains gave a maximum sum score of 30 and a minimum of 0 points. One point is added to the sum score if the subject has 12 years education or less. A score of 26 or above is considered normal[33]. In this study the Norwegian version of the MoCA test was used, translated by M.R. van Walsem and H. Tyvoll. The MoCa test had duration of 10-15 minutes per participant. For further details, see Appendix 1.

2.4 Procedure

The participants of the Generation 100 study underwent a variety of tests that were divided into two separate test days. The first day consisted of anthropometric measures, blood sampling and blood pressure and body composition. After test day one they were handed questionnaires that were to be returned at test day two. At the second day of testing, the participants underwent different physical tests, such measurement of grip strength, leg strength, walking, VO2max, and cognitive function. Only the tests used in this study will be further described.

Walking test

The participants were instructed to walk back and forth on the walkway, given four different instructions, resulting in a total of 8 walks. They were told to use an acceleration/deceleration zone marked by a piece of tape on the floor in both ends of the walkway. This was done in order to only include steady state walking and hence reduce the effect of acceleration and deceleration in the analysis. In this particular test the participants were asked to stop at the end and wait a few seconds before turning and returning.

The first task given was “to walk at your regular pace. A pace that feels natural for you”. If a participant still was unsure about the pace setting, an example was given. “Like if you are walking to the grocery store". The second task was "to walk in a slow pace. Like if you are taking a stroll, or as if you are waiting for someone". Third, they were instructed to "walk at a fast pace! As fast as you can, without running!" The fourth and last task was a dual task walk. The participants were asked to walk at their regular pace, and were given an extra cognitive task, in form of counting backwards from 80, subtracting three and three at the time. On the return they were given the same instructions, but were asked to start counting from 100 instead of 80. "This time you will walk at your regular pace, but we have made a small disturbance for you. While you are walking we want you to count backwards from 80, subtracting three and three at the time. 80 – 77, and so on. Understood?" If the participants showed reluctance or felt unsure about the additional task, they were informed that the test was not a mathematical test, rather just something that makes you think on something else, than just walking. The whole test procedure took approximately 5-7 minutes per participant.

Cognitive test

The MoCA test was performed in a separate and quiet room at the testing facilities at St. Olav's hospital. Since the test was new for the participants, a thorough introduction was given to each participant, explaining what a cognitive test is and giving some examples of areas that will be tested, such as attention, memory and language. After the initial introduction the test started.

First, executive function was assessed by an alternation task adapted from the trail making B task[34] (see appendix 1). Then visuospatial performance was assessed using a three-dimensional cube copy and using a clock-drawing test. The naming task consisted of a three-item task with animals of low familiarity (lion, camel and rhinoceros). Short-term memory was tested by two learning trials of five nouns, followed by delayed recall after approximately five minutes. Only the delayed recall was point giving. Attention was tested using a two-item verbal abstraction test, a sustained attention task, where the participants were instructed to tap one time each time they identified the letter A in a list of different letters, and a serial subtraction task. Language was assessed by a repetition task of two syntactically complex sentences and a fluency test, naming as many words starting with an F as possible in one minute. Lastly, an orientation task considering time and place completed the MoCA test. After checking the education status of the participants one point was added to those with 12 years of education or less. The tester did scoring continuously. The duration of the test varied between the participants, from approximately 10 to 20 minutes (See Appendix 1 for overview of the test form).

Demographics and covariates

Information on age, education, medication use and whether the participants were living alone or not, were retrieved trough a questionnaire. Medication use was reported as medication intake on the day of test day one (yes or no). Level of education was reported as the highest level of education the participant finished. Elementary school (1), secondary school (2), vocational school (3), trade school (4), high school (5), college/university less then three years (6) and college/university of three year or more (7) were the possible choices in the questionnaire. Height and weight, and thereof calculation of BMI was measured on the first day of testing. Grip strength works as an indicator and predictor of physical capacity; hence JAMAR hydraulic hand dynamometer (Patterson Medical Inc.) was used to measure isometric grip strength[35]. The participants were instructed to squeeze as hard as possible for a few seconds, while given motivation from the test person. This was repeated three times and the mean score of the three trials was reported. The force was measured in kilograms (kg).

2.6 Data Processing and analysis

All the measures on gait function were retrieved from the walking test performed on the Zeno walkway and processed using the PKMAS software. This resulted in several temporal and spatial gait footfall outcome measures. The parameters used in this study are presented in table 1. This study reported step measures instead of stride measures. This was done to secure enough data points to the analysis, in all walking conditions[36].

Data from the Zeno walkway was processed using the PKMAS software before it was stored as text files, one for each of the walking conditions. Furthermore, these text files were opened in excel, reorganized to make a data matrix for further analysis. The reorganization of the data was performed using a custom made Matlab (Mathworks Inc.) script. The reorganized data matrix was then converted to SPSS, for statistical analysis. The mean characteristics of the two walks in each condition were calculated and used in the analysis. The scores from each of the domains in the MoCA test were directly plotted in SPSS, where the MoCA full score was calculated, as the sum of all sub scores. Since there were signs of ceiling effect of the MoCA full score (8.4% - scored 30 points), a dichotomous variable was made to distinguish between good and impaired cognitive function. Scores from 0-25.999 was set defined as lower cognitive function, and the remaining score from 26 -30 was defined as normal cognitive function. 26 points and more are used as a cut-off point in the literature, marking normal cognitive function. This was done in order to investigate if the associations were stronger in those with low cognitive function. In this particular case 26 points were also the median score of all the subjects. Since one education point was given to those with 12 years of education or less, three subjects made a final score of 31.

Table 1: *Gait parameters and calculation*

Gait parameters	Calculation
Spatial parameters	
Step Length (cm)	The distance between corresponding successive points on the heel of opposite feet measured parallel to the direction of progression for the ipsilateral stride of which is the second part (cm).
Stride Width (cm)	The distance between a line connecting the two ipsilateral foot heel contacts (the stride) and the contralateral foot heel contact between those events and is measured perpendicular to the stride (cm).
Temporal parameters	
Step time (s)	The period of time taken for one step, measured from the first contact of one foot to the first contact of the following opposite foot (s).
Stance time (s)	The period of time when the foot is in contact with the ground. From the initial contact to the last contact of a single footfall (s).
Double support time %	The period of time when both feet are in contact with the ground at the end of the stance phase, presented as a percentage of the gait cycle.
Spatiotemporal parameter	
Gait speed (m/s)	Gait speed is obtained after dividing the sum of all Stride Length by the sum of all Stride Time (m/s).
Variability parameters	
Step length SD Stride width SD Step time SD Stance time SD Double support time % SD	Variability of the temporal and spatial parameters was measured by calculating the within-subject standard deviation (SD), dividing the individual mean by SD. Since variability in this case is unrelated to the size of the measured value, SD was used instead of the coefficient of variation (CV)[36].

Calculation as they are described by the developer, Protokinteics© (PKMAS) SD =Standard Deviation

All statistical analysis was conducted, using IBM SPSS statistics 21.0. Sample descriptive were presented as means and standard deviation (SD) of the variables. Visual inspections of QQ-plots were conducted to determine normality of variables. Not all of the variables, including the MoCA full score were normally distributed. Nonparametric variables were than visually inspected for possible outliers before further analysis. When assessing the association between gait variables and MoCA full score, both non-parametric (Spearman's rho) and parametric (Pearson's r) analysis was done. Due to the small differences in associations between the two tests and the relatively large sample size Pearson's correlation test (Pearson's r) was chosen to present the association between gait parameters and cognition. Pearson's r, measuring the strength of a linear association between two variables, is presented as an *r*-value. This value can range from -1 to +1, where a value of 0 means that there is no association between the variables. The association may be positive (0 to1) as long as the value of one variable increases so does the value of the second variable. The association is negative (0 to -1) if the value of one variable increases, while the second variable decreases. Table 2 presents a guideline to interpreting the strength of the associations of the Pearson's correlation coefficient[37].

Table 2: *Interpretation of strength of correlation by the Pearson's r.*

	Coefficient, r	
Strength of the association	Positive	Negative
Low	0.1 to 0.29	-0.1 to -0.29
Moderate	0.3 to 0.49	-0.3 to -0.49
Strong	0.5 to 1	-0.5 to 1

Differences between genders in descriptive, gait and cognition were investigated with independent samples t-test, and differences between gait parameters in different conditions were investigated by using paired sampled t-tests, in order to investigate if there were actual differences when testing in different gait conditions.

Gait parameters that were significantly correlated (significantly different from zero) with the MoCa full score in the Pearson's correlation analysis were further explored in multiple linear regression models, separately for each of the gait parameters. The multiple linear regression models were conducted separately for men and women. A linear regression with multiple predictor variables was used, with MoCA full score set as the dependent variable. The Gait parameter was the target predictor, with gait speed, education, living situation (living alone or in a relationship), grip strength, medication use and Body Max Index (BMI) as controlling predictors. Gait speed was included as a predictor since several of the gait parameters were highly correlated with gait speed (i.e. Step Length Mean in preferred walking condition, $r=.823$ $p<.005$). This was done to ensure that the correlation between the gait variables and MoCA were significant independently from gait speed. The MoCA test does take into account the level of education, but also after adjusting for education, education was significantly correlated with MoCA full score. Education is also a protective factor of cognitive decline and was therefore included in the model[8]. Living alone or being in a relationship in older is also a risk factor of cognitive and functional decline, while grip strength is a much-used measure of general physical function[35,38]. The intake of medications may also explain the general health, while BMI works as an indicator of lifestyle[39].

The correlation of the relative contribution of each independent variable was presented as B (standardized coefficient), being statistically significant with a p-value of $<.05$. The total variance explained by the model was reported as r^2 (0-1.0), with an r^2 score of 1.0 meaning that the model explains 100% of the variance.

3.0 Results

After checking for missing data and errors in the dataset 394 of the eligible 405 subjects were included in the statistical analysis, including 190 men and 206 women (Figure 3). Four participants either declined or were incapable of completing the MoCA test due to visual or language problems. Complete data from all of the sub scores were missing in three participants, which also led to exclusion. Missing gait data lead to exclusion of two subjects, while missing background data led to the exclusion of the remaining two subjects (Figure 3).

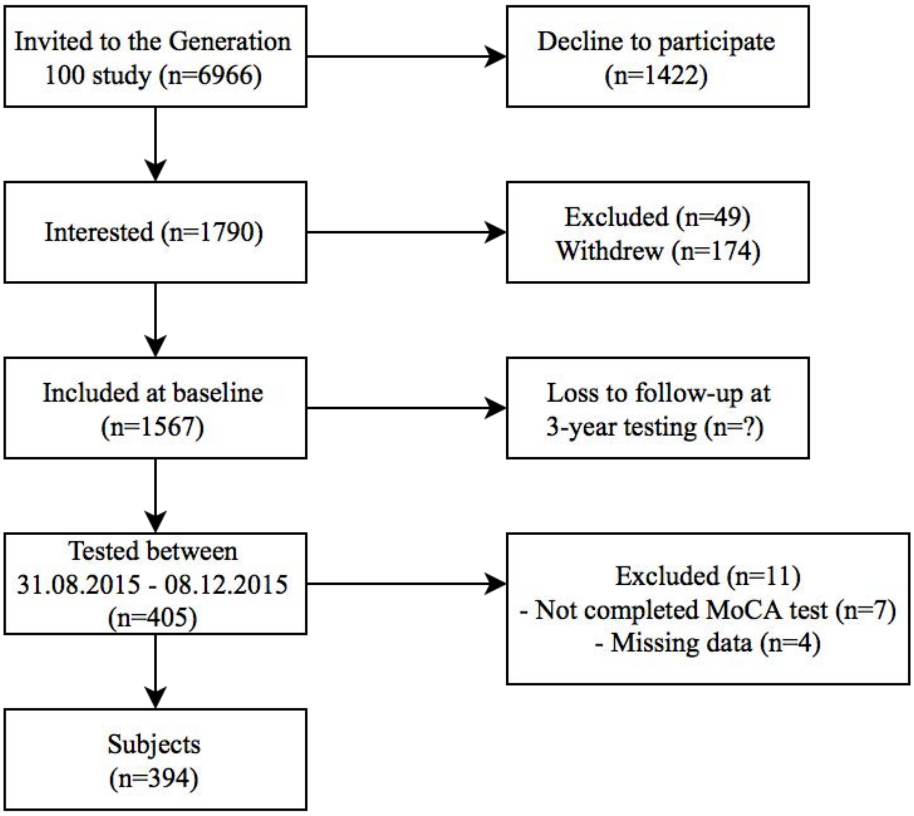


Figure 3: *Flow chart of participants*

3.1 Participants Characteristics

The included participants had a mean age of 74.86 (SD=1,36). Women and Men differed significantly in both height and weight, and men also had a significantly higher BMI than women (t=3.25, p<.05). There were slightly more female participants in the sample (table 3). In men, 85.8% were married or living with someone, in contrary to only 55.4% of all women. 40% of all participants had taken medication on the day of testing, with no significant difference between the genders. All of the participants completed the walking test without walking aids.

Table 3: *Participants characteristics, presented as mean (SD)*

	Total (n=394)		Men (n=191)		Women (n=203)		t-test	
Age (Years)	74.86	(1.36)	74.85	(1.37)	74.90	(1.37)	t=-.352	p=.725
Height (cm)	169.89	(8.45)	176.45	(5.64)	163.72	(5.26)	t=23.17	p<.001
Weight (kg)	73.86	(12.25)	81.10	(9.92)	67.04	(10.15)	t=13.90	p<.001
BMI (kg/m^2)	25.50	(3.31)	26.06	(3.01)	24.98	(3.51)	t= 2.02	p=.045
Pref. gait speed (m/s)	1.35	(0.20)	1.37	(0.20)	1.32	(0.20)	t=2.47	p=.014
Fast gait speed (m/s)	1.98	(0.30)	2.06	(0.29)	1.91	(0.29)	t=5.47	p<.001
Dual task speed (m/s)	1.10	(0.35)	1.18	(0.34)	1.03	(0.34)	t=4.36	p<.001
MoCa Full score (0-30)	25.87	(3.27)	25.57	(3.27)	26.15	(3.31)	t=-1.93	p=.054
Grip strength (kg)	28.94	(10.72)	37.71	(7.97)	20.68	(4.78)	t=25.45	p<.001
Level of education (1-7)	5.22	(1.94)	5.44	(1.94)	5.01	(1.89)	t=2.21	p=.028

BMI=Body Mass Index, Pref. = Preferred, cm=centimeter, kg= kilogram, m/s= meter/second. 0-30 is the scoring range of the MoCA test.

3.2 Gait parameters

Gait speed, Step Length Mean, Step Time Mean and Stance Time Mean was significantly different between genders in both preferred and fast gait speed. In the dual task setting gait speed and step length were significantly different between genders (p<.05). Of the variability measures only Step Length SD (t=2.621, p<0.01) in fast walking speed and Step Time SD (t=2.119, p<.05) in the dual task condition were significantly different between genders. The remaining gait parameters showed no significant differences between genders.

Mean gait speed in preferred gait was 1.35 m/s (SD=0.20). When asked to walk in a fast pace the participants had a mean gait speed of 1.98 m/s (SD=0.30), and when performing dual task gait the mean gait speed was 1.10 m/s (SD=0.35) (Table 3). Stride Width SD was only significantly different between preferred walking speed and fast gait speed. Stride Width Mean was not significantly different between in preferred gait speed and Dual task gait, while Step length SD did not significantly differ between fast walking speed and Dual task walking.

The remaining gait parameters were significantly different in the three different walking conditions.

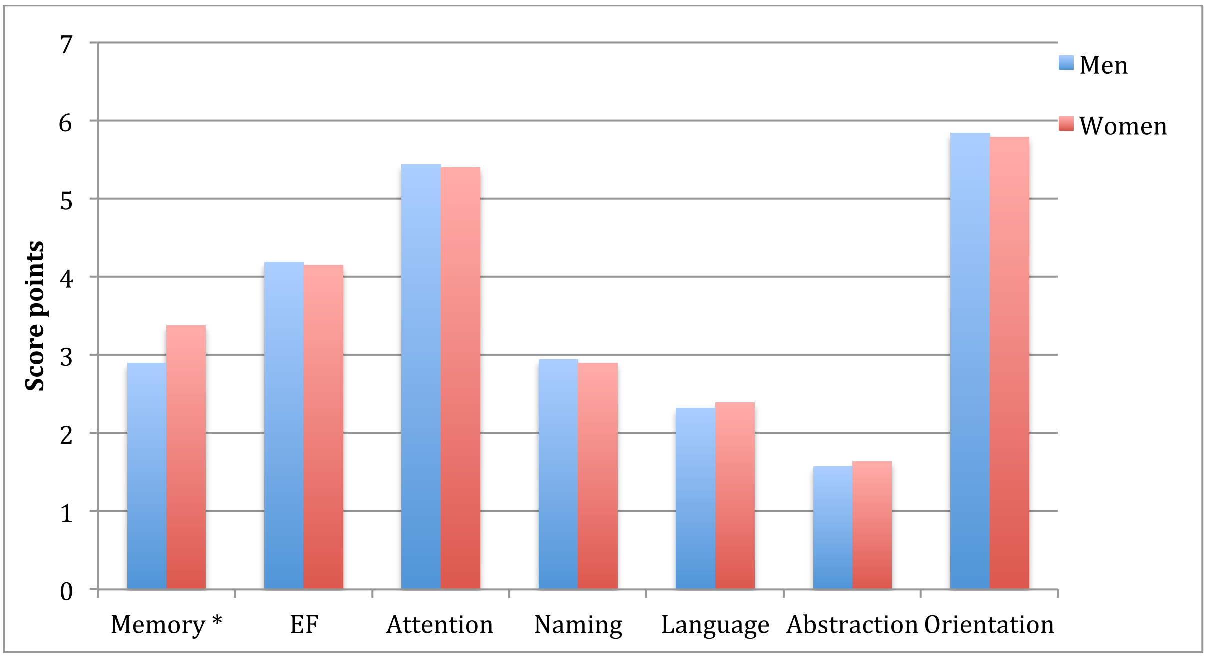
Table 4: *Gait parameters in each walking conditions*

	Preferred gait speed (SD)		**Fast gait speed (SD)**		**Dual task speed (SD)**	
	Men (SD)	**Women (SD)**	**Men (SD)**	**Women (SD)**	**Men (SD)**	**Women (SD)**
Number of steps	15.94 (1.74)	17.32 (2.13)	13.31 (1.58)	15.12 (2.07)	16.14 (2.59)	18.76 (3.53)
Step Length M (cm)	74.78 (7.48)	67.49 (7.17)	90.17 (9.51)	78.64 (9.26)	72.54 (10.37)	62.15 (8.80)
Stride Width M (cm)	7.72 (3.15)	6.38 (2.57)	8.52 (3.22)	6.15 (2.89)	7.48 (3.62)	6.38 (3.00)
Step time M (s)	0.55 (0.05)	0.52 (0.04)	0.44 (0.04)	0.42 (0.41)	0.67 (0.19)	0.68 (0.28)
Stance time M (s)	0.71 (0.07)	0.66 (0.07)	0.54 (0.06)	0.51 (0.06)	0.86 (0.26)	0.89 (0.38)
DSup_M (%)	13.16 (1.62)	13.18 (1.64)	10.12 (1.89)	10.29 (1.91)	13.68 (2.25)	14.66 (2.70)
Step length SD	2.98 (1.09)	2.91 (1.10)	3.56 (1.42)	3.19 (1.36)	3.56 (1.39)	3.41 (1.30)
Stride Width SD	2.01 (0.71)	1.95 (0.70)	2.20 (0.84)	1.99 (0.77)	2.04 (0.98)	2.03 (0.74)
Step time SD	0.02 (0.01)	0.02 (0.01)	0.01 (0.01)	0.01 (0.01)	0.02 (0.08)	0.08 (0.17)
Stance time SD	0.03 (0.02)	0.03 (0.02)	0.03 (0.01)	0.03 (0.01)	0.08 (0.10)	0.10 (0.18)
DSup % SD	1.01 (0.43)	1.03 (0.45)	1.19(0.51)	1.20 (0.48)	1.23 (1.03)	1.63 (1.95)
Gait speed (m/s)	1.37 (0.20)	1.32 (0.20)	2.07 (0.29)	1.91 (0.28)	1.18 (0.34)	1.03 (0.34)

M= Mean, SD= Standard Deviation, cm=Centimeter, s=seconds, m/s= Meter/Second. DSup= Double support.

3.3 Cognitive Function

The mean MoCA full score for the total sample was 25.87 (SD= 3.27), and the median score matched the cut point for mild cognitive impairment at 26. Men had slightly lower MoCA full score than women (t=-1.93, p=.54), but women scored significantly higher than men in the memory sub score (t=3.460, p<.01). No differences were found between genders in the other sub scores (figure 4). A maximum score of 30 (31) points were demonstrated in 8,5 % of the participants.

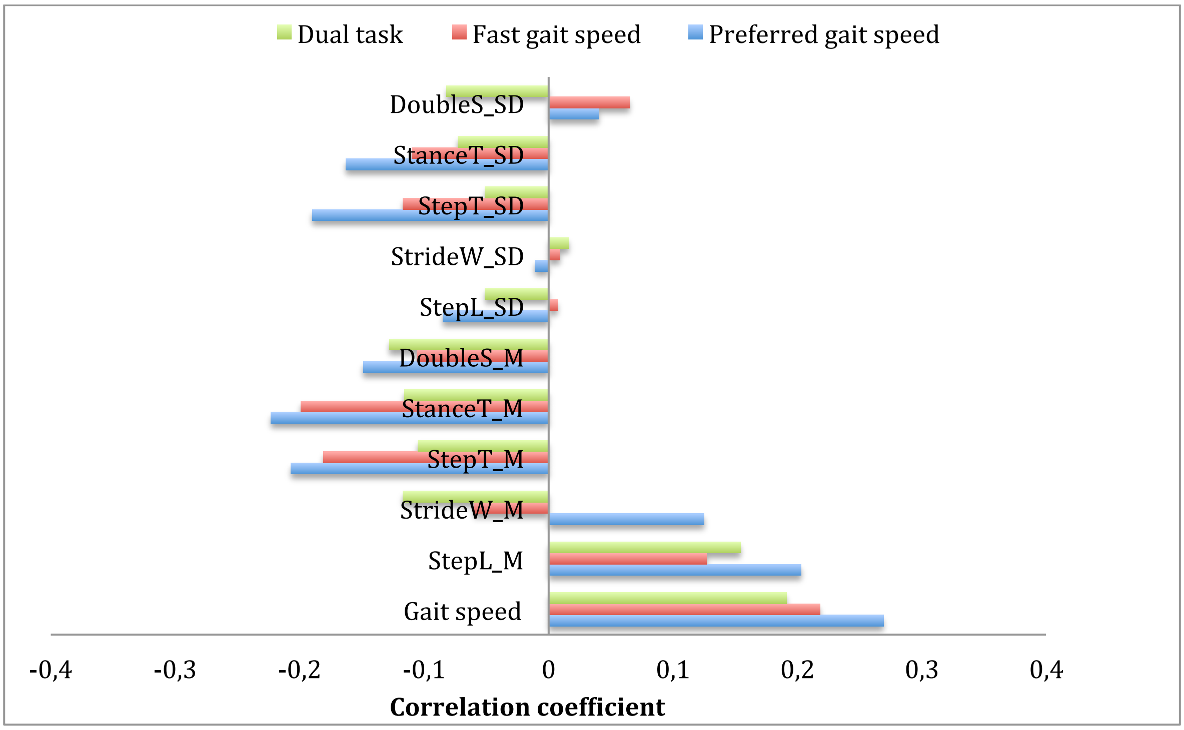


EF= Executive Function
* = The score in the memory domain was significantly lower in men, than in woman. t=-1.93 (p<.01)

Figure 4: *Mean MoCA sub scores for men and woman separately*

3.4 Associations between different gait parameters and cognitive function

Figure 5 shows the Pearson's correlation coefficient between each gait parameter and MoCA full score in all three walking conditions, for the whole sample. Increases in gait speed and Step Length Mean were correlated with an increase in MoCA full score in all gait conditions, while increases in Step Time Mean, Stance Time Mean and Double Support Time Mean (%) were correlated with a decrease in MoCA full score. The remaining gait variables were both negatively and positively correlated to MoCA full score, depending on the gait condition. All correlations were low (r<.03) and only correlations with Gait speed, Step Time Mean, Stance Time Mean and Stance Time SD were statistically significant for all gait conditions (p<0.01).



DSup= Double support time (%), T= Time, L= Length, W= Width, SD=Standard deviation, M= Mean

Figure 5*: Correlation between MoCA full score and gait parameters in each walking condition for the entire study population.*

When analysis bivariate correlations between cognition and gait function separately for men and women, the correlations were stronger in women, and more gait parameters were significantly associated with cognition then in men (table 5). In preferred gait speed condition; Gait speed, Step Time Mean, Step Length Mean, Stance Time Mean, Stride Width Mean, Double Support time (%), Step Time SD ($p<.01$) and Stance Time SD ($p<.05$) showed low to moderate correlations with MoCA full score. In men, Gait speed, Step Length Mean ($p<.01$), Step Time SD and Stance Time SD ($p<.05$) showed significant correlations. In the fast gait speed condition the same variables, except from stride width mean were significantly correlated with MoCA in women. In men, only gait speed correlated significantly with cognition. ($p<.05$) In the dual task condition the correlations between Gait speed, Step Time Mean, Step Length Mean and Stance Time were significant in men, while Gait speed, Step Length Mean, Stride Width Mean showed significant correlations with the MoCA full score. All correlations were low, except Gait speed ($r=.376$ $p<.01$) and Step Length ($r=.364$ $p<.01$) in preferred walking condition in women. Gait speed ($r=.355$ $p<.01$) in fast walking condition in women and Step Length Mean ($r=.306$ $p<.01$) in dual task condition in women also showed moderate associations to MoCA full score. Step Length SD, Stride Width SD and Double support time (%) SD showed no significant correlation to MoCA full score in any of the gait conditions.

***Table 5**: Pearson´s correlation coefficient (r) between MoCA full score and gait characteristics*

	Preferred gait		Fast gait		Dual task	
	Men	Women	Men	Women	Men	Women
Gait speed (m/s)	.191	.376	**.150**	.355	.217	**.171**
Step Time_M (s)	-.118	-.253	-.054	-.248	**-.178**	-.066
Step Length M(cm)	.191	.364	.138	.282	**.163**	.306
Stance Time M (s)	-.122	-.286	-.077	-.288	**-.170**	-.093
Stride Width M (cm)	-.042	-.182	.025	-.082	-.035	-.183
DSup % M	-.077	-.221	-.034	-.184	-.079	-.210
Step Time SD	**-.148**	-.243	-.028	-.248	-.127	-.038
Step Length SD	-.067	.096	.089	-.078	-.004	-.097
Stance Time SD	**-.182**	**-.162**	-.033	-.**178**	-.165	-.040
Stride Width SD	.026	-.040	.038	.005	.049	-.026
DSup% SD	.042	-.121	.098	.028	-.028	-.137

Red = p<.01, Bold = p<.05. M= Mean, SD= Standard Deviation, m/s = meter/second, s= second, cm = centimeter. DSup= Double support time in %,

Figure 5 illustrates the differences in bivariate association between gait parameters and cognition in those with normal cognitive function (MoCA score: 26-30) and those with lower cognitive function (MoCA score: 0-25). The two upper boxplots illustrates the difference between gait speed and MoCA full score in those with normal cognitive function to the left (r^2=.004), and those with low cognitive function to the right (r^2=.080) The two lower boxplots illustrates the difference between Stance Time Mean in those with normal cognitive function to the left (r2=.011), and those with low cognitive function to the right (r2=.278). These differences in association were present for most of the gait variables, in all walking conditions.

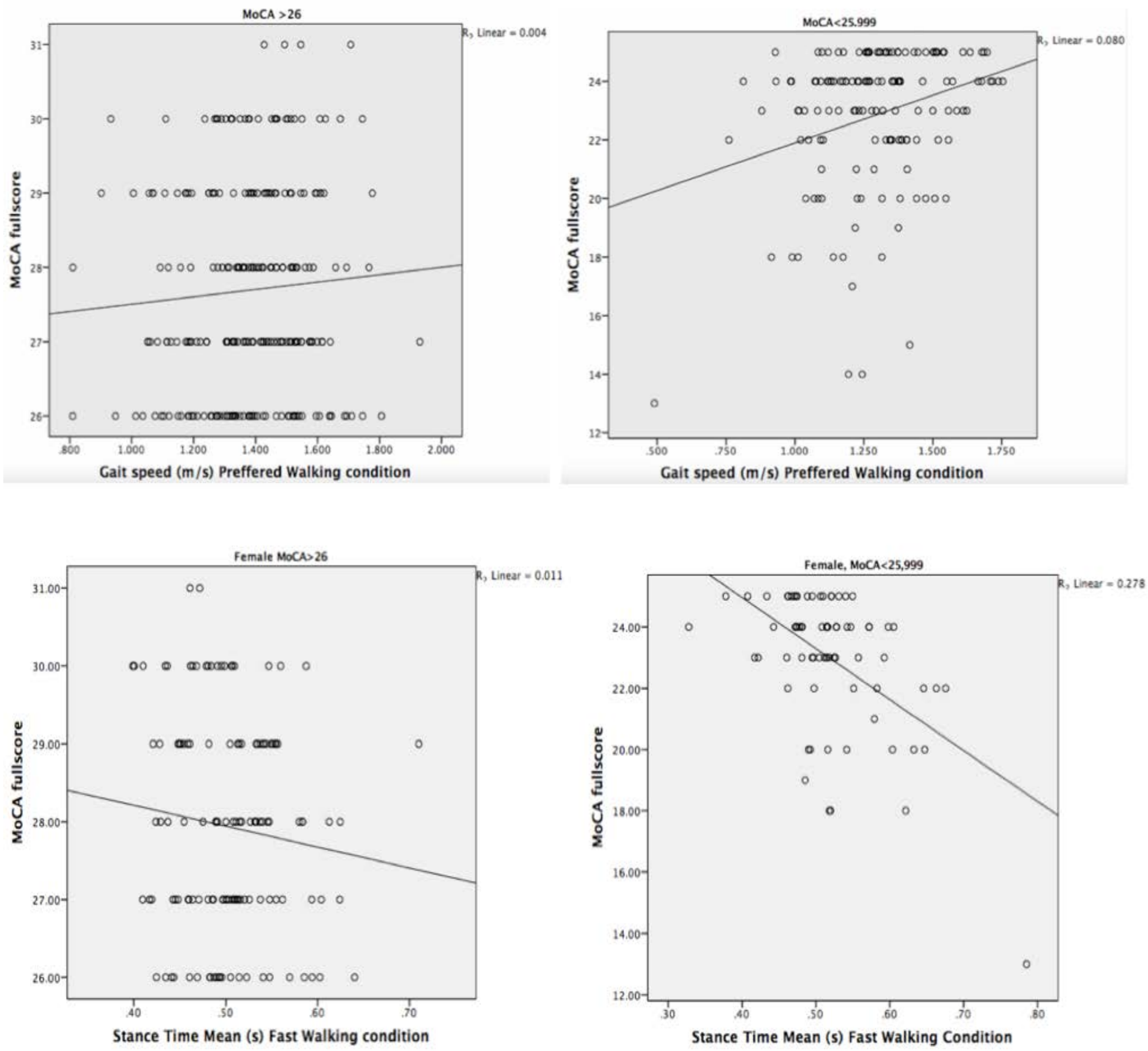


Figure 6*: Examples of scatterplots showing the differences in correlation between MoCA scores and gait parameters in subjects with MoCA full score +- 26.*

Table 5 shows the multiple linear regression models for the significantly correlated gait parameters in women. In the preferred gait speed condition stride width mean had a predictive value of -.152 (p=.020). The model explained 21.5 % of the overall variance. Gait speed had a predictive value of .368 (p<.001) and the overall variance explained was 19.2%. The remaining gait variables did not significantly contribute to the model. In the fast speed condition Double Support Time (%) B=.257 (p=.020) were positively predictive of the overall explained variance of 20%. Gait speed had a predictive value of .355 (p<.001) and the overall explained variance was 17.7%. The remaining gait parameters did not significantly contribute to the model. In the dual task condition step length had a predictive value of .313 (p<.001) and the overall explained variance was 14.3%. Gait speed had a predictive contribution of .184 (p=.01) with an overall explained variation of 10%. Gait speed and medication use were overall the most influential controlling variables to the model.

Table 6: *Multiple linear regression models between each gait parameter in each walking condition and the MoCA full score (women), using gait speed, level of education, living situation, grip strength, medication and BMI as controlling variables*

	Gait Variable		*Gait speed*		*Education level*		*Living alone*		*Grip Strength*		*Medication*		*BMI*		**R2**
	B	p	B	p	B	p	B	p	B	p	B	p	B	p	
Preferred gait speed condition															
StepT M	.091	.382	.438	<.01	.110	.095	-.08	.25	-.06	.397	-.17	.009	.09	.17	**.196**
StepL M	.162	.216	.232	.073	.111	.092	-.08	.25	-.06	.348	-.17	.009	.09	.17	**.199**
StanceT M	.101	.399	.452	<.01	.111	.093	-.08	.26	-.06	.406	-.18	.008	.09	.20	**.195**
StrideW M	-.152	.020	.360	<.01	.123	.058	-.07	.30	-.05	.470	-.17	.010	.10	.13	**.215**
DSup% M	.107	.285	.440	<.01	.117	.075	-.08	.26	-.04	.504	-.18	.007	.06	.39	**.197**
StepT SD	-.043	.583	.345	<.01	.114	.084	-.09	.25	-.04	.520	-.17	.009	.08	.24	**.194**
StanceT SD	.017	.818	.374	<.01	.117	.076	-.07	.27	-.04	.505	-.17	.009	.09	.18	**.193**
Gait speed	.368	<.01	-	-	.102	.076	-.07	.27	-.04	.503	-.17	.009	.09	.19	**.192**
Fast gait speed condition															
StepT M	-.042	.635	.326	<.01	.109	.103	-.07	.29	-.08	.270	-.16	.017	.08	.22	**.178**
StanceT M	-.003	.977	.352	<.01	.111	.097	-.07	.29	-.08	.243	-.16	.017	.08	.22	**.177**
StepL M	.034	.743	.328	<.01	.112	.094	-.07	.29	-.09	.218	-.16	.018	.08	.22	**.177**
DSup% M	.257	.020	.550	<.01	.100	.131	-.07	.27	-.08	.217	-.17	.011	.04	.55	**.200**
StepT SD	-.115	.109	.316	<.01	.122	.068	-.07	.32	-.07	.298	-.15	.033	.07	.30	**.188**
StanceT SD	-.095	.165	.348	<.01	.106	.110	-.06	.37	-.09	.205	-.15	.033	.07	.30	**.185**
Gait speed	.355	<.01	-	-	.111	.096	-.07	.29	-.08	.233	-.16	.017	.08	.22	**.177**
Dual task condition															
StepL M	.313	<.01	-.039	.700	.081	.233	-.11	.10	-.05	.466	-.17	.014	.07	.30	**.143**
DSup% M	-.113	.238	.110	.246	.085	.224	-.12	.09	-.08	.936	-.18	.012	.08	.29	**.107**
StrideW M	-.149	.036	.154	.032	.095	.167	-.12	.09	.01	.959	-.18	.009	.08	.28	**.121**
Gait speed	.184	.01	-	-	.092	.183	-.13	.07	-.01	.898	-.18	.011	.07	.30	**.100**

Gait Variable indicates the contribution of each gait parameter on the model. Gait speed is measured in meters per second. Living alone, or in a relationship. Grip strength is a measure of physical function. Medication= yes or no on day of testing. BMI= Body Mass Index. B = The correlation of the relative contribution of each independent variable. p = p-value. R^2=The overall explained variance. T= time, L=length, W= width, DSup=Double support time, M= Mean, SD = Standard deviation.
Red numbers = p<.05

In preferred gait speed condition in men Stance Time SD had a predictive value of -.159 (p=0,27) with an overall explained variance of 16% (table 6). Gait speed had a predictive value of .158 with an overall explained variance of 13.7%. Gait speed was not a significant predictor in the fast walking condition, but contributed significantly in the dual task condition; B=.144 (p=.046), and the total variance explained by the model was 13.4%. Of the controlling variables in men education was the most influential predictor to the models (B=.301 to.330, p<.01).

Table 7: *Multiple linear regression models between each gait parameter in each walking condition and the MoCA full score (men), using gait speed, level of education, living situation, grip strength, medication and BMI as controlling variables.*

	Gait Variable		*Gait speed*		*Educati-on level*		*Living alone*		*Grip Strength*		*Medic-ation*		*BMI*		**R2**
	B	p	B	p	B	p	B	p	B	p	B	p	B	p	
Preferred gait speed condition															
StepT SD	-.104	.207	.109	.188	.326	<.01	.08	.25	-.02	.759	.04	.64	.055	.47	**.145**
StepL M	.082	.600	.092	.530	.316	<.01	.08	.26	-.04	.626	.05	.51	.051	.55	**.139**
StanceT SD	-.159	.027	.114	.130	.330	<.01	.08	.28	-.02	.780	.04	.53	.046	.54	**.160**
Gait speed	.158	.032	-	-	.318	<.01	.08	.25	-.03	.636	.04	.54	.035	.63	**.137**
Fast gait speed condition															
Gait speed	.117	.117	-	-	.323	<.01	.08	.28	-.04	.628	.04	.60	.022	.29	**.127**
Dual task condition															
StepT M	-.007	.951	.138	.229	.300	<.01	.08	.26	-.10	.923	.04	.56	.008	.91	**.134**
StepL M	-.035	.753	.170	.122	.301	<.01	.08	.26	-.01	.965	.04	.56	.006	.94	**.135**
StanceT M	.043	.729	.178	.150	.302	<.01	.08	.25	-.02	.877	.04	.57	.009	.90	**.135**
Gait speed	.144	.046	-	-	.301	<.01	.08	.25	-.01	.914	.04	.59	.009	.91	**.134**

Gait Variable indicates the contribution of each gait parameter on the model. Gait speed is measured in meters per second. Living alone, or in a relationship. Grip strength is a measure of physical function. Medication= yes or no on day of testing. BMI= Body Mass Index. B = The correlation of the relative contribution of each independent variable. p = p-value. R^2=The overall explained variance. T= time, L=length, W= width, DSup=Double support time, M= Mean, SD = Standard deviation
Red numbers = p<.05

4.0 Discussion

The main aim of this study was to investigate the association between gait characteristics and cognitive function, and determine which gait parameters showed the closest association with cognitive function. Secondary aims were to investigate differences in the association between gait and cognitive function when gait was assessed in different walking conditions. Furthermore, as men tend to walk faster, and female gender being reported as a risk factor for dementia, differences in the associations between the genders were investigated.

4.1 Main findings

The main results showed that there were low to moderate significant bivariate correlations between several gait parameters and cognition, including both spatial and temporal measures. Gait speed was significantly correlated to cognitive function in all walking conditions, for both men and women. When adjusting for covariates gait speed remained significant in all conditions, except from fast gait speed condition in men. Of the variability measures only Stance Time SD in men in preferred walking condition were significantly correlated with cognition. The most and strongest correlations were found when testing in preferred walking speed condition. More gait parameters showed correlation to cognition in women than men, and the r-values were stronger for women. The total variance explained by the multiple linear regression models in women was highest in preferred gait speed condition, and lowest in dual task condition. The total explained variance was low in all walking conditions (r^2<.215).

4.2 Association between different gait parameters and cognition

Gait speed was significantly correlated with cognition in all gait conditions, in both men and women. After adjusting for covariates in the multiple linear regression models, only gait speed in fast walking condition in men, failed to remain statistically significant. The association was stronger in preferred gait speed condition, than in dual task condition. These findings are in line with cross sectional and prospective studies that have found association between gait speed and different outcomes of cognitive function[22,26,27]. Step Length Mean was significantly associated with cognition in all three conditions for both genders, except from fast gait speed condition in men. After checking for covariates in the linear regression model, only Step Length Mean in women in preferred gait speed condition was significantly contributing to the model. Stride Width Mean was significantly associated with cognition in preferred and dual task condition in women, also after adjusting for controlling variables in the multiple linear regression models. No correlations between gait parameters were found in men. Step Length Mean and Step Width Mean represent spatial parameters of gait. Three temporal gait parameters were investigated. Step Time Mean showed a low association with cognition in men, but was not longer significant after adjusting for covariates. In women, Step Time Mean, Stance Time Mean and Double Support Time Mean (%) were significantly associated with cognition in both preferred and fast speed condition, while only Double Support Time Mean (%) significantly associated with MoCA full score in the dual task condition. Of these only Double Support Time Mean (%) in fast gait speed was significant in after adjusting for covariates. The present study included variability measures of all spatiotemporal gait measures used in this study. Only variability measures of temporal gait parameters (Step Time SD, Stance Time SD) were associated with cognition, and no associations were found in the dual task condition, respecting both genders. In the multiple linear regression models an increase in Stance Time SD in men, was significantly associated with a decrease in the MoCA full score in the preferred gait speed condition.

The findings of this study support the hypothesis of an association between gait function and cognition. This association is however, not explained by all gait parameters, in all walking conditions, differences between genders are present and the strength of the associations are low to moderate. The underlying mechanisms of why certain gait characteristics are associated with cognitive decline needs further research. The findings of this study showed that the associations of gait characteristics and cognition varied largely between the different walking conditions, and between genders.

4.3 Gender differences

In this study women had slightly higher MoCa full score, while men walked faster then women in the gait assessment. When assessing bivariate correlations in the present study, more gait characteristics were significantly associated with gait in all walking conditions in women compared with men. The associations were also slightly higher in women (table 4). Gait speed was significantly correlated with MoCA full score after adjusting for covariates in all walking conditions for both genders except for fast gait speed condition in men. Stride

Width Mean in both preferred speed (B=-.152 p=.020) and dual task condition (B=-.149 p=.036), Double Support Time % Mean (B=.257 p=.020) in the fast walking condition and Step length Mean (B=.313 p<.01) in the dual task condition was significantly correlated with MoCA full score in the multiple linear regression model. In men, apart from gait speed only Stance Time SD (B=.-159 p=.027) was significantly correlated with MoCA full score in the multiple linear regression models. When the controlling variables are taken in to account, gait speed is the only gait characteristic that are significantly correlated to both genders.

To the authors' knowledge, few studies have investigated gender related differences in the association between gait and cognition. Female gender is reported as a risk factor of cognitive decline, while higher education reportedly lowers the risk of cognitive decline[8]. The women in the present study had significantly lower education but scored higher on the cognitive test than men. Of the sub domains of cognition only memory showed significant differences between men and women (t=-1.93, p<.01).

Hollman et al.[11] showed that there were significantly differences in gait characteristics between men and women. Much of this may be explained by difference in height, and body composition[40], but the differences in association between genders may be an interesting subject for future studies. One explanation may be that more steps were registered in women than men (i.e.13.31 vs. 15.12 in fast speed condition), giving more precise calculation of the different gait characteristics, due to more data points[36]. Lord et al.[15] suggested that at least 12 steps should be collected while investigating gait variability. Since only gait speed showed significant bivariate correlation in fast gait speed condition in men, the numbers of steps might have been insufficient, even do the guidelines of Lord et al[15] were followed.

4.3 Different walking conditions

Walking speed and several gait parameters were significantly different in each of the three walking conditions. Also, the associations between gait parameters and cognition differed between the conditions, and gait speed was the only gait variable significantly correlated with cognition in all walking conditions in both women and men. Bivariate correlation between gait characteristics and cognition were most present in the preferred walking condition (table 5). Interestingly, when adjusting for controlling variables in Stride

Width Mean for women, the correlation is quite similar in preferred walking condition (B=-.152, p<.020) and the dual task condition (B=-.149, p<.036). However, while the model in the preferred walking condition (r^2) explains 21,5% of the total variance, the dual task model only explains 12,1 % of the variance. This may indicate that when preforming a dual task walk, other underlying mechanisms are more involved than when walking in preferred walking speed, which is a more automatic task. Dual task is a method of investigating the effect of cognition on gait, and forces the participants to divide their attention[41]. The low correlations in the dual task condition, and small total explained variance in the multiple linear regressions were unexpected. One possible explanation may be that differences in gait during dual task involve several mechanisms, which are not accounted for in the model. Springer et al.[25] reported that dual task did not affect gait variability in healthy elderly, but that dual task destabilized idiopathic elderly fallers. The lack of associations between gait characteristics and cognitive function may be explained by the relatively good health of the present study sample.

The results from the present study indicate that preferred gait speed seems to be most suitable in detecting relationships between gait and cognitive function. However, even though few gait measures from the dual task walking condition were significantly correlated with MoCA full score, and the total variance explained were lower, than in preferred gait speed, the value of testing in dual task condition should not be underestimated. Several studies have reported that gait characteristics, when tested in fast gait speed have shown association with measures of cognitive function[27,28]. As mentioned earlier, the fast gait speed condition in man, may have been affected by the number of steps. However, the associations were not stronger in the fast gait condition compared to the preferred gait speed condition in women, indicating that in a relatively healthy population, the preferred gait speed condition is as good as the fast gait speed condition.

The age and health of the population may explain the relatively low associations between gait characteristics and cognitive function found in this study. Other studies have often reported a larger range in age[42,43],investigated the association in more frail populations[44] or investigated the association on people already diagnosed with MCI[45]. Figure 5 illustrates the differences in associations between those with normal and lower cognitive function. The stronger correlations found in those with lower cognitive function indicates that gait characteristics better differentiate cognitive function in those with lower cognitive function, than those with normal cognitive function.

4.4 Methodical considerations

Participants

Studenski et al.[13] found in their data that gait speed over 1.0 m/s suggested better than average life expectancy, while gait speed over 1.2 m/s suggested exceptional life expectancy. In the present study the participants had a mean preferred gait speed of 1.35 m/s, thus indicating a very healthy population of elderly people. Those who were included in the Generation 100 study also reported better health, more physical activity and higher education, in comparison to non-participants[29]. This may affect the generalization of results from the present study, since this study population may represent a healthier population than the general elderly population. Much of the previous research on the subject is done on groups who already are diagnosed with cognitive deficiencies or are frailer than the present study sample. Investigating the association between gait and cognition in a healthy elderly population may add more knowledge to the research area. The sample size of 394 is fairly good.

Walking test

The walking test in the present study was conducted in a lab setting, at St. Olav's Hospital, Trondheim. Walking tests on pressurized carpets have shown good validity and reliability[30,31], and are a much-used tool in gait research. Some may debate that the relative performance from walking tests over short distances not represent the independency required inside the community[24]. In clinical settings, disturbances from the outside environment like noises and obstacles are not present, and may influence the result. On the other hand, a great deal of walking consists of short bursts of walking, for instance inside the house, or in the grocery store. Cognitive dimensions including navigation, visuospatial perception and attention are all tools that are important for safe walking[46]. It is difficult to control for all aspects of walking while testing gait, but by including different walking condition one might identify more aspects of gait, especially while investigating complex association like cognition and gait.

The active area of the walkway used in this study was 6,10 meter. For each gait condition the mean of the two trials was used in the analysis. As earlier mentioned, the mean number of steps included in each walking condition ranged from 13.31 (1.58) in fast gait for men, to 18.76 (3.53) steps in dual task for woman. In the fast walking condition 8,4% of the male participants had less than 12 steps. Hollman et al[47], reported that data collected from fewer than 10-20 strides may reliably measure pace and rhythm parameters of gait, but found that reliability in variability measures may required data from several hundred steps. Brach et al.[48] found that test-retest reliability of gait variability recorded from 5-6 steps were poor to fair, while gait variability from 10-12 steps showed fair to good reliability. The present study reported step parameters instead of stride parameters. This has shown to have higher reliability, due to a higher number of data points[36]. The low association in fast gait speed condition found in this study, especially in men, may partially be explained by low number of steps, and should be interpreted with caution. One solution may be to add more walking trials, when testing in fast walking conditions in short-length walking tests, in order to get more data points.

Cognitive test

Cognitive function could be assessed in numerous ways. Brief cognitive screening assessment tools like MMSE and MoCA investigate several cognitive domains in a relative short time and are suitable in studies with large cohorts. MMSE have been used widely in the literature, as a brief cognitive assessment tool, but MoCA has high sensitivity of detecting MCI (90%), is considerably more sensitive than MMSE[33] and the superiority of MoCA over MMSE was also supported by Roalf and Colleagues[49]. The MoCA has a lower risk of ceiling effect, in comparison to MMSE[33], and the MoCA test also include executive function. The benefit of including executive function is that several studies have reported associations between gait executive function and different gait characteristics[50], including gait speed[51], swing time variability[25] and stride length variability[41] The cut off point for “normal” cognition in the MoCA test is set at 26 points.

The MoCA test is made up by several test constructed to investigate different domains of cognition. Investigating the correlation between each domain and different gait parameters is interesting, but regarding the fact that MoCA is a brief cognitive assessment, it is questionable if each domain get enough data, to differentiate scores in for example memory. Mild cognitive impairment is often divided into amnestic or non-amnestic, with amnestic MCI at higher risk of developing dementia[6]. This has not been investigated in this study, but regarding the differences between men and women in the memory domain in the MoCA test, this could be of interest in future studies of the Generation 100 population (Figure 2).

Covariates

Gait speed, education, living situation (living alone or in a relationship), grip strength, medication use and Body Max Index (BMI) were included as controlling predictors, in the multiple linear regression models. Age did not show significant association to MoCA full score and was therefor not included in the model. This may be due to the relative low range in age in the participants. Gait speed was closely related to several of the gait parameters, but the correlation differed between the different gait conditions. Gait speed was therefor included as a controlling variable, although some studies have suggested that this will cause and overadjustment[52].

4.5 Strengths and limitations

394 participants make out a relatively good sample size, minimizing the risk of random errors in the analysis. Further, this study provided a variety of gait variables, which reflects different aspects of gait, including those of pace, rhythm and variability. However, far from all aspects of gait were analyzed. This study also measured gait in three different conditions; preferred speed, normal speed and dual task conditions. Including different walking conditions may contribute to a broader understanding of the different demands of changing gait conditions, in relation to cognitive function. This study reported the length of the walkway, the number of steps acquired and a rationale for selection of gait parameters, according to the advice from Lord et al.[15] The present study also has several limitations. The cross sectional study design does not give a causal explanation of the relationship between gait function and cognition. Furthermore, the results from the study may not be representable for the entire population of elderly, due to the generally good fitness of the participants, in comparison to non-participants. This study did not investigate the association between different subtypes of cognitive function, and gait, measured in the MoCA test. Since different gait variables may be related to different cognitive function, this could have been of interest. History of falling was not reported in this study. Springer et al.[25] found that dual task does not affect gait variability in elderly non-fallers, but were destabilizing in idiopathic elderly fallers. The multiple linear regression models used in this study only explained some of the total variance. Associations between gait and cognition is complex and multifactorial, but there may be potential residual confounders.

4.6 Future studies

In general, future studies on gait and cognition should focus on determining causal explanations of the associations. Salthouse[53] reported that cognitive decline may already start in people aged 20-30 years old. Understanding the associations between different gait characteristics and cognition in relatively young adults may give a better explanation of the age related changes occurring through the life span, and give knowledge to how and when interventions should take place. Spatial and temporal gait characteristics have also shown to be associated with alterations in certain brain networks in elderly[52]. The use of neuroimaging in addition to a cognitive test battery when assessing the association between gait and cognition may add more knowledge in order to understand the causal explanations.

More specific, regarding the Generation 100 study, the relationship between change in gait over 1-3 years, 1-5 years and/or 3-5 years and cognitive function (change in cognitive function (3-5)) would be interesting to investigate. Given the large sample size and the length of the study, this will add important knowledge to the field. In form of being a randomized controlled trial (RCT), Generation 100 may also give insight in the role of physical activity and exercise in the association between cognitive function and gait.

5.0 Conclusion

This study has investigated the association between cognition and different characteristics of gait in a relatively healthy elderly population. Significant but low correlation between several gait parameters and cognition were found. Of the included gait parameters gait speed showed the highest association with cognition. There were more and stronger correlation for women than men, and preferred gait speed was best suited in detecting associations between gait and cognition. The lack of association between gait variability and cognition, especially in the dual task condition was surprising and in conflict with the literature. Future studies on the relationship between gait and cognition should include several gait conditions in their protocol, and include gait parameters that cover the range of gait domains. Furthermore, future studies may determine early gait markers that works as predictors of future cognitive decline, in order to initiating appropriate intervention.

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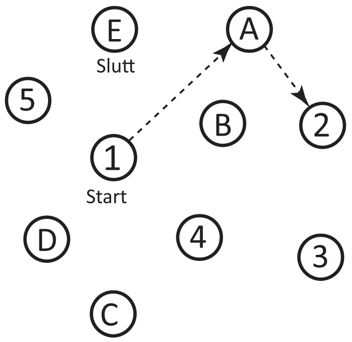
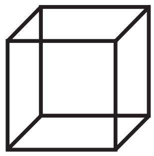
Appendix 1 - The Norwegian version of the MoCA test.

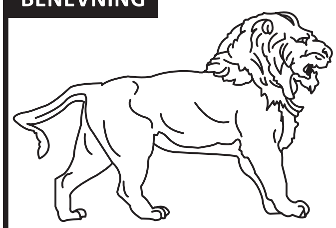
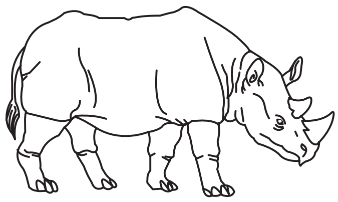
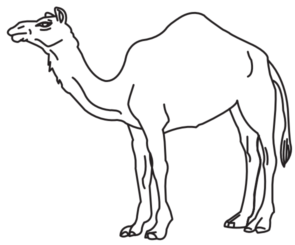
Norsk Versjon 7.1

MONTREAL COGNITIVE ASSESSMENT (MOCA)

NAVN:
Utdanning (i år): Fødselsdato:
Kjønn: DATO:

			POENG
VISUOKONSTRUKTIV/EKSEKUTIV  [ ]	 Kopier kube (1 poeng) [ ]	Tegn en klokke (ti over elleve) (3 poeng) [ ] Kontur [ ] Tall [ ] Visere	___/5

BENEVNING

 [ ]
 [ ]
 [ ]

___/3

HUKOMMELSE Les ordene, forsøksperson må gjenta dem. Gjør to forsøk, selv om første forsøk gjennomføres helt riktig. Gjør gjenkalling etter 5 minutter.

	ANSIKT	FLØYEL	KIRKE	TUSENFRYD	RØD
1e forsøk					
2e forsøk					

ingen poeng

OPPMERKSOMHET Les rekken med tall (1 tall/sekund).
Forsøksperson skal gjenta i samme rekkefølge. [ ] 2 1 8 5 4
Forsøksperson skal gjenta i baklengs rekkefølge. [ ] 7 4 2 ___/2

Les listen med bokstaver. På hver bokstav A skal forsøkspersonen banke på bordet med hånden sin.
Ingen poeng ved 2 feil. [ ] F B A C M N A A J K L B A F A K D E A A A J A M O F A A B ___/1

Seriell subtraksjon med 7, begynnende med 100 [ ] 93 [ ] 86 [ ] 79 [ ] 72 [ ] 65
4 eller 5 riktig: 3 png 2 eller 3 riktig: 2 png 1 riktig: 1 png 0 riktig: 0 png ___/3

SPRÅK Gjenta etter meg: Jeg vet kun at det er Jon som skal hjelpe i dag. [ ]
Katten gjemte seg alltid under sofaen når det var hunder i rommet. [ ] ___/2

Ordflytt: Si så mange ord du kan komme på som begynner med F innenfor ett minutt. [ ] _____ (N ≥ 11 ord) ___/1

ABSTRAKSJON Likhet mellom for eksempel en banan og en appelsin = frukt [ ] tog – sykkel [ ] klokke – linjal ___/2

UTSATT GJENKALLING

	ANSIKT	FLØYEL	KIRKE	TUSENFRYD	RØD
Ord skal gjenkalles uten stikkord	[ ]	[ ]	[ ]	[ ]	[ ]
Frivillig: Kategori-stikkord					
Frivillig: Multiple-choice stikkord					

Kun poeng for gjen-kalling uten stikkord. ___/5

ORIENTERING [ ] Dato [ ] Måned [ ] År [ ] Ukedag [ ] Sted [ ] By ___/6

Normal ≥26 / 30

TOTAL SKÅRE ___/30
Legg til 1 poeng dersom ≤12 år utdanning

Administrert av: ______________________________ **www.mocatest.org**