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Computer-based Cognitive Training with people at risk for Mild Cognitive Impairment

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Väestöllisen huoltosuhteen kasvaessa myös erilaiset muistisairaudet yleistyvät. Tämän vuoksi on tärkeää kehittää preventiivisiä työkaluja, jotta elinvuodet olisivat mahdollisimman elinvoimaisia. Tämän pro gradu -tutkielman tarkoituksena oli tutkia kognitiivisen heikentymisen riskissä olevien henkilöiden (*N* = 631) tietokonepohjaista kognitiivista harjoittelua, sekä erilaisten taustatekijöiden vaikutusta suoriutumisen parantumiseen ja sen lähtötasoon.

Kognitiivinen interventio koostui tietokonepohjaisesta harjoittelusta ja ryhmätapaamisista. Itsenäinen tietokonepohjainen harjoittelu koostui kahdesta puoli vuotta kestäneestä harjoittelujaksosta. Tietokoneharjoittelu suoritettiin kolme kertaa viikossa ja jokainen harjoittelukerta kesti 10–15 minuuttia. Henkilöille, joilla ei ollut tietokonetta kotona, annettiin mahdollisuus tietokoneella harjoitteluun. Tutkimus keskittyy ensimmäisen puolen vuoden harjoitteluun.

Tutkimusten tulosten mukaan tutkimukseen osallistujien ikä, koulutusvuodet, masennuspisteet sekä muistitesti MMSE:n tulokset olivat yhteydessä henkilön lähtötasoon tietokonepohjaisissa kognitiivisissa harjoitteissa. Nämä taustatekijät eivät kuitenkaan olleet yhteydessä henkilön suorituksen parantumiseen yksittäisiä tuloksia lukuun ottamatta. Lähtötaso oli vahvasti yhteydessä suorituksen parantumiseen muistitehtävissä sekä niissä käytettävän ajan kanssa.

Mitä huonompi lähtötaso oli, sitä enemmän henkilö paransi suoritustaan. Harjoittelun määrä oli positiivisesti yhteydessä yhteen muistitehtävistä. Päivittäinen toimintakyky ja toimintakyvyn muutos eivät olleet harjoittelun tulosten kanssa yhteydessä.

Tutkielman tuloksia voidaan hyödyntää erilaisten interventiotyökalujen suunnittelussa. Jatkotutkimuksien analyyseissä voitaisiin hyödyntää koko tehtäväsarjan kirjo täsmällisemmän tiedon saamiseksi. Alaryhmäanalyysit ja yksilölliset kehitysreitit täydentäisivät saatuja tuloksia. Tulevaisuudessa uusia interventioita suunnitellessa tulisi varmistaa, että tehtäviin ei voida palata enää tietyn aikajakson jälkeen, jotta voidaan olla varmoja siitä, että kehitys on tapahtunut tietyn ajanjakson aikana. Lisäksi harjoitustulosten vertaaminen esimerkiksi terveisiin tai jo kognitiivisen heikentymisen diagnoosin saaneisiin henkilöihin antaisi uutta tietoa intervention vaikuttavuudesta.

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The number of neurodegenerative disorders has increased as people are living longer. Preventive measures and the development of different interventions are increasingly important. This study aims to investigate the impact of computer-based cognitive training (CCT) on subjects with a risk of mild cognitive impairment (*N* = 631).

The cognitive intervention included six group meetings, an independent CCT phase, and assessment meetings. Two six-month practice phases comprised practice sessions that occurred three times a week and lasted for 10–15 minutes. The research at hand focuses on the first six month of the CCT. Participants who did not have access to a computer were allowed to train at the study center.

Significant associations were found between the subject’s background and health information with CCT task baselines. The background information included age, educational years, The Mini Mental State Examination (MMSE) results, activities of daily living and depression scores. The background characteristics, however, were not associated with the improvement of CCT tasks. The amount of training was positively associated to one memory task. The change in activities of daily living was not associated with the task improvement.

Further analyses could focus on utilizing the whole task battery to have more precise information. Subgroup and singular-trajectory analyses could be made to complement these results. Future studies should make sure that the participants cannot return to the exercises after certain amount of time so the timeline of the tasks progress would be precise. Moreover, a comparison group in CCT would give new information about the intervention's effectiveness.

Abbreviation

AD	Alzheimer’s disease.
ADL	Activities of Daily Living.
CAIDE	Cardiovascular Risk Factors, Aging and Incidence of Dementia.
CCT	Computer-based Cognitive Training.
CERAD	Consortium to Establish a Registry for Alzheimer´s Disease.
CVD	Cardiovascular Disease.
DLB	Dementia with Lewy bodies.
FINGER	The Finnish Geriatric Intervention Study to Prevent Cognitive Impairment and Disability.
FTD	Frontotemporal Dementia.
MCI	Mild Cognitive Impairment.
MMSE	Mini Mental State Examination.
PDD	Parkinson’s Disease Dementia.
VCI	Vascular Cognitive Impairment.
ZSDS	Zung Self-Rating Depression Scale.

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1 Introduction

As the number of elderly citizens has been increasing steadily over the past decade, so have a variety of memory disorders surged (Prince, Bryce & Ferri, 2018). A total of 46 million people suffer from memory disorders worldwide, and this number is expected to almost triple in the next 30 years (Prince et al., 2015). The dependency ratio is burdened, as people are living longer, and birth rates are declining. The dependency ratio is a ratio of the working-age population to the children and people aged 65 or over. (Prince et al., 2015.) The burdened dependency ratio and increasing number of memory disorders have created new challenges for the healthcare system, highlighting the importance of disease prevention and early diagnosis (Prince, Comas-Herrera, Knapp, Guerchet & Karagiannidou, 2016; Prince et al., 2018).

Memory disorders are neurodegenerative disorders that begin with a decline in memory and other cognitive symptoms. Neurodegenerative disorders with progressive brain changes lead, generally, to severe memory and cognitive processing decline. As the disease progresses, the patient's independence is reduced and the need for assistance increases. (Erkinjuntti, Remes, Rinne & Soininen, 2015.) In Finland, as many as 193 000 people display mild to moderate stages of dementia. Approximately 14 500 people get diagnosed with memory disorder every year. The most common memory disorders are Alzheimer's Disease (AD), Vascular Cognitive Impairment (VCI), dementia with Lewy bodies (DLB), frontotemporal dementia (FTD), and Parkinson's disease dementia (PDD). (Rosenvall et al., 2021.)

Mild cognitive impairment (MCI) is a collection of different symptoms in which an individual has mild but noticeable decline in some areas of cognitive function. MCI is considered as a risk factor for neurodegenerative disorders, such as AD. (Breton, Casey & Arnaoutoglou, 2019.) One of three people aged 65 or older suffer from memory-loss symptoms. Additionally, as many as 200 000 people display symptoms of MCI. MCI does not, however, influence a person's ability to function in daily tasks. One of the exclusion criteria for MCI is that the symptoms do not meet any memory disorder's diagnostic criteria. (Rosenvall et al., 2021.)

Cognitive testing has an important role in neurodegenerative diagnostics. The Consortium to Establish a Registry for Alzheimer's Disease (CERAD), and The Mini-Mental State Examination (MMSE), which is also included in the CERAD, are commonly used tools for detecting possible cognitive decline. (Rosenvall et al., 2021.) CERAD is a test battery that aims to identify patients with a decline in cognition (Hänninen et al., 2010). MMSE is a scale that provides a general overview of an individual's general cognitive ability and its possible decline (Folstein, Folstein & McHugh, 1975). However, one of the disadvantages of the scale is its poor sensitivity. (Hänninen et al., 2010.) For complex differential diagnostics or mild symptoms, broader neuropsychological assessment is necessary for clinical diagnosis (Rosenvall et al., 2021).

As mentioned above, neurodegenerative diseases decline patients' independence. The ability to perform everyday tasks is essential for individuals' autonomy, and activities of daily living (ADL) measure this ability to be independent. The current assessment tools focus mostly on questionnaires that are either self or professionally assessed by for example, a physiotherapist. The chosen tools are important for detecting a change in subject's performance. (Pashmdarfard & Azad, 2020.) Problems with ADLs are related to dementia (Lindbergh, Dishman & Miller, 2016).

To date, no cure exists for memory disorders and the treatment focuses on stabilizing and slowing the progression of symptoms and maintaining daily independence (Rosenvall et al., 2021). Current interventions for neurogenerative disorders, both medical and non-medical, focus either on prevention before diagnosis or reducing symptoms after diagnosis (see for example Lissek & Suchan, 202; Sheng et al., 2020; Shi-Hui, Su-Fee & Chiew-Jiat).

One example of non-medical intervention is cognitive training. It has shown promising results in improving and maintaining cognitive functioning on elderly (Butler et al., 2018; Chiu et al., 2017). Current literature provides few mechanisms in which cognitive training benefits the subjects. Firstly, cognitive training may provide supporting neural processes when new skills are learned (Reuter-Lorenz & Park, 2014). Secondly, it may activate cognitive reserves acquired earlier in life through active lifestyle habits (Stern, Barnes, Grady, Jones & Raz, 2019). Thirdly, it may help to activate existing networks to respond to task demands in the framework that genetic background, previous illnesses, education, and lifestyle habits provides (Sherman, Mauser, Nuno & Sherzai, 2017; see also Stern et al., 2019).

Computer-based cognitive training (CCT) is a cost-efficient way to carry out cognitive training. Computer-based technology and its possibilities to offer more insight regarding memory and cognitive functions has not yet been utilized to its potential. Due to the prevalence of technology, the stereotype of the elderly individuals struggling with computers and computer-based programs is no longer applicable. The aging population is adopting information technology at an increasing rate (Birkland, 2019; Ching-Ju & Chia-Wen, 2017). Furthermore, people with MCI and dementia use technology, and technology usage is expanding with each generation (Guzman-Parra et al., 2020).

Research on CCT is in its early stages, but the preliminary results are promising on people with MCI (Hill et al., 2017; Shao et al., 2015). However, scholars who have performed reviews and meta-analyses of CCT studies have indicated issues with these studies. First, the sample sizes are small (Sherman et al., 2017), and follow-up studies are lacking (Hill et al., 2017; Zhang et al., 2019). Second, the use of technology varies greatly between studies making the comparison between the results challenging. Commonly used technology in CCT have been virtual reality technology (Zhong et al., 2021), mobile applications (Bonnechère, Klass, Langley & Sahakian, 2021), video games (Ramnath, Rauch, Lambert & Kolbe-Alexander, 2021) and computers (Sherman, Durbin & Ross, 2020). Third, the experimental conditions differ, from the amount of supervised training to the active or inactive nature of the control groups and the randomization methods. Additionally, the exercises of different studies vary; some studies included scaled exercises while others did not. Furthermore, some studies utilized multidomain interventions while some focused only on memory training or far transfer activities, such as exercise, not on cognitive training per se (Sherman et al., 2020). The variance between experimental conditions makes comparing results from different studies difficult. While the results seem to show mild to large effects of CCT on people with MCI, the reported limitations prevent making more decisive conclusions (Hill et al., 2017; Zhang et al., 2019).

The previous results of the Finnish Geriatric Intervention Study to Prevent Cognitive Impairment and Disability (FINGER) indicated that the multidomain intervention that was implemented, was found to be effective in preventing cognitive decline or even improve cognitive function in all cognitive domains studied (Ngandu et al., 2015). Besides cognition, the results showed that the intervention benefitted physical performance (Kulmala et al., 2019) and participants' quality of life (Strandberg et al., 2017). To reach more definitive conclusions in the effectiveness of the CCT, more research with active control settings and standardized study protocols are needed.

The underlying hypothesis of the current study is that an improved cognitive performance during training reflects the brain's ability to learn. The ability to learn may also indicate a lack of significant aging changes or emerging memory disorders. Furthermore, learning ability may reflect the cognitive reserve acquired earlier in life, while the lack of learning ability may indicate changes caused by aging or a memory disorder. Additionally, the researcher hypothesizes that learning ability during the independent phase produces different information than the data collected in a single test situation.

The aim of this study is to determine factors associated with cognitive performance of people at risk for cognitive decline during computer-based cognitive training. The following research questions are formed to investigate:

1. How are demographic factors and health-related information associated with baseline performance in computer-based cognitive tasks?
2. Are demographic factors and health-related information associated with an improvement in computer-based cognitive task performance?
3. Is the baseline performance associated with the improvement of computer-based cognitive task performance?
4. Is the amount of training sessions associated with performance in computer-based cognitive tasks?
5. How is improvement in computer-based cognitive tasks associated with a change in activities of daily living?

This study may bring new insights into the fields of lifelong learning, memory, and cognition. The Information provided could be used to create new intervention tools in the field of dementia.

2 Data and methodology

This study is a part of the longitudinal FINGER study. FINGER began in 2009 and will continue until 2024. The CCT intervention lasted till 2014. FINGER study aims to investigate the impact of multi-domain lifestyle intervention and aims to prevent memory impairment among the elderly. (Turunen et al., 2019.) The main results of FINGER study have been previously published (see Ngandu et al., 2015; Turunen et al., 2019).

2.1 Participants

The participants were selected from previous studies (Saaristo et al., 2007; Vartiainen et al., 2010), were between the ages of 60 and 70 at the start of the study and were at risk of developing a memory disorder. The risk was measured with Cardiovascular Risk Factors, Aging and Incidence of Dementia (CAIDE) and CERAD (for more information about CAIDE, see Kivipelto et al., 2006).

All participants were at-risk for dementia and cardiovascular disease (CVD) (Rosenberg et al., 2018). Additionally, the participants had to meet one of the following criteria. For CAIDE, the requirement was at least 6 points. For CERAD, the participants had to complete either ≤ 19 words in the Word List Learning task, achieve ≤ 75% in the Word List Savings task, or receive 20–26 points in MMSE.

Participants were excluded if they had conditions that could interfere with results, such as major depression; dementia; scoring < 20 points in MMSE; major cognitive decline; CVD; revascularization within one year; severe vision problems; problems with communication or hearing; or difficulties disturbing cooperation. The interfering conditions to the study results was evaluated by the study physician. Participants were also excluded from the study if they were part of another intervention. The chosen participants (*N* = 1260) were randomized into test and control groups using double blinding (for more information about the study design, see Kivipelto et al., 2013).

All participants provided a written informed consent before participation in screening and baseline visits, and FINGER research has been reviewed and accepted by the Finland's Coordinating Ethics Committee, Hospital District of Helsinki and Uusimaa.

2.2 Background and health information

The background information in this study included gender, age, and the number of educational years. The health information included cognitive performance, daily physical performance, and depressive symptoms.

The Mini Mental State Examination (MMSE) was used to assess individual's cognitive performance. The MMSE includes 19 tasks that assess memory, attention, orientation, and verbal skills. The maximum score is 30 points. (Folstein, Folstein & McHugh, 1975.) Under 20 points was used as an exclusion criterion indicating that broader neuropsychological assessment was needed.

The daily physical performance, or the Activities of Daily Living was assessed with 17 question questionnaire where the ability to do everyday tasks, like light housework or dressing, was assessed. The questionnaire was constructed using guidelines formed by Katz and colleagues (1963), Lawton & Brody (1969) and Kingston and colleagues (2012). The maximum score was 85, where higher points meant poorer performance. (For more, see Kulmala et al., 2019.)

The Zung Self-Rating Depression Scale (ZSDS) was performed to evaluate depressive symptoms. ZSDS includes 20 items that assess affective, physiological, psychomotor, and psychological disturbances. The threshold indicating mild depression is 50 to 59 points, moderate depression from 60 to 69 points, and severe depression, if the score is 70 or above. The maximum score is 100 points. (Zung, 1965.)

2.3 Study design

The full intervention of FINGER research included cognitive training, physical exercises, health guidance, and health monitoring. The intervention phase lasted for two years. The control group did not do the exercises but received standard health counseling. Therefore, the research will focus on the data accumulated by the test group (N = 631) (for more see, Turunen et al., 2019.)

The present study focuses on the cognitive training performed by the intervention group. The cognitive training phase included ten visits, six of which included group discussions. The themes of these visits were memory and cognition changes through senescence, as well as reasoning strategies to implement into everyday life. Three meetings were held to assess the progression of the CCT tasks, and one additional visit was organized for the local Alzheimer's Association (for more information about the research, see Ngandu et al., 2015; Turunen et al., 2019).

The practice phase included 2x72 sessions. Both blocks lasted for six months, and they were 3–6 months apart. Both blocks included three sessions that monitored the participants' progression. Practice sessions were held three times a week and lasted 10–15 minutes each. The participants were given instructions on how to use CCT at home and how many times to use it. Those who did not own a computer were offered the opportunity to train at the study center. The participants' activity and performance were registered automatically. (Turunen et al., 2019.) This study focuses on the first block of CCT.

2.4 Measures

The baseline data of the CCT task included data from the participants who completed the test at the first CCT assessment visit or practiced at least once. The CCT tasks comprised exercises for executive function, processing speed, episodic memory, and working memory. Automatically scaled exercises were excluded to maintain comparability.

Executive function

Two tasks measured the executive function domain. The first assignment was to remember the last four letters, digits, or colors in a correct order. The first variable measured how many items the participant remembered correctly. The second variable measured how many lists of items the participant recalled precisely. These variables were measured during the CCT assessment visit. This task is referred as "items recall" in this study.

In the second task the participants were shown a square that was divided into four slots. The participants were shown numbers from one to nine that appeared in one of the four slots. If the number appeared on the two upper slots, the participant's task was to differentiate the number's parity. When a number appeared on the two lower slots, the task was to differentiate whether the number was less or greater than five. The first variable measured how fast the subject responded to the task change and measured the difference in response time, while the second variable collected the correct responses the subject had. This task is referred as the "two-tasks game" in this study.

Processing speed

One-back task was used to measure the participant's processing speed. The variable was measured during the practice phase. The participants' task was to differentiate abstract pictures from each other by determining whether each picture was similar to or different from the previous picture. The variable collected measured the subject's mean response time.

Episodic memory

Two tasks measured the participant’s episodic memory. The first assignment was word-connect game where the assignment was to recall the correct words and colors that were presented. The participants were shown word pairs written in different colors. One word was a place, while the other was something else. After twelve word pairs the place words were presented again, and the participants’ task was to combine the correct place and color. The first variable collected the correct colors, while the second collected the correct names. In this study, these two variables were combined into a sum variable. The variables collected were measured during the assessment visits.

The second task was a classic memory game in which the participants were shown sixteen cards. The participants’ task was to find eight matching figures. The first variable measured the number of seconds until the subject found all pairs and the second variable measured how many times the participant turned cards around. This task was measured during the practice phase.

Working memory

Working memory domain included four variables. The variables were measured during the same task, a spatial span task. In this task, the participant’s assignment was to remember presented squares and their order of presentation. The number of squares increased as the task progressed. Two of the variables were measured during the assessment visits and the other two were measured during the practice phase. From the first two assessment visit variables, the first measured the highest level the subject reached in one session, and the other variable measured how many lists (in which all the items were correct) the participant recalled correctly. During the practice phase, the first variable measured the highest level the subject achieved, and the second variable how many squares the subject recalled correctly.

2.5 Statistical analyses

This quantitative study focused on the data collected during the intervention group's CCT sessions and the health information collected by a survey at the beginning of the study. The chosen analytical tool was IBM SPSS, Statistics, version 27.

The CCT practice data from the first six months was included in this study. The participants' improvement in CCT task performance was determined by subtracting the final CCT session from the first CCT session.

The Pearson correlational coefficient was used to examine the relationships between variables if the variables followed normal distribution. If these assumptions were not met, Spearman's rank correlational coefficient were used. Association between variables were interpreted as small if the value was |.10|, medium if the value was |.30|, and large if the value were |.50| (Gignac, 2019).

Group differences were compared by using an independent samples t-test. The assumptions of the normality of the subgroup's distribution were tested by using Kolmogorov-Smirnov test. The t-test were used if the data met the following criteria: skewness < |2.0|, kurtosis < |9.0|, minimum subgroup size of 7, and the same skewness in each subgroup (positive or negative). If the skewness or kurtosis criteria were not met, the independent samples t-test with bootstrapping method was used (Gignac, 2019).

This study did not clean outliers and therefore outliers may disturb the results. However, the outliers were analyzed and are discussed in the discussion section. The results that included extreme values were left out as non-significant in the independent samples t-test to maintain the reliability (Gignac, 2019).

3 Results

The background information is shown in the Table 1.

Table 1. Background information of the study group.

Background information	Value
Baseline age *m*(*sd*)	69(4.67)
Male/Female *n*(%)	345(54.7) / 286 (45.3)
Educational years *m*(*sd*)	9.96(3.47)
Male/Female	10.23(3.66)/9.65(3.22)
Training sessions, two years total *(n)*	631
Training sessions *m*(*sd*)	45.69(54.95)
Dropped out *n*(%)	138(21.9)
Male/Female *n*(%)	71(24.8)/67(19.4)
MMSE *m*(*sd*)	26.69(2.06)
The activities of daily living *m(sd)*	18.20(2.87)
After 24 months *m(sd)*	18.62(3.73)
Zung depression scale *m*(*sd*)	33.93(9.80)

Note. m = mean, *sd* = standard deviation, MMSE = Mini Mental State Examination.

3.1 Baseline results in CCT

The first research question studied the association between baseline performance and CCT task improvement. A younger age and higher education were associated with greater performance in episodic and working memory domains, as well as in items recall task (see table 2.). The number of educational years correlated negatively with the time variable in the classic memory game, indicating that the participant's performance was slower when they had achieved a higher number of educational years.

Higher MMSE scores were associated with better performance for some of the executive function, episodic, and working memory variables. The lower depression scores were associated with better CCT baseline performance in the items recall task, classic memory game, and spatial span task. Neither age, education, MMSE or depression scores were associated with the one-back task or the two-task game.

Table 2. The CCT baseline measures and the association of demographic and health information

Variables	Age	Education	MMSE	Zung depression scale
Executive function				
Items recall-task				
Correct items, 1.	-.191***	.252***	.210***	-.149**
Correct lists of items, 1.	-.155***	.222***	.227***	-.122*
Two task-game				
Response time difference, 1.	-.020	.087	-.021	.106
Difference in proportion of correct responses, shifting to non-shifting items (sc_ns), 1.	-.061	-.070	.064	-.061
Processing speed				
1-back task				
Differentiation time (*m*), 1.	-.067	-.043	-.042	-.014
Episodic memory				
Word Connect -game				
Words and colors, 2.	-.151**	.341**	.207**	-.070
Classic memory game				
Pairs finding time, 1.	.270***	-.201***	-.090	.170**
Card turns, 1.	.205***	.141**	-.054	.125*
Working memory				
Spatial span task				
Highest level reached, 1.	-.253***	.173***	.183***	-.184***
Correct lists of squares, 1.	-.304***	.204***	.208***	-.171***
Highest level (min. two correct lists of squares), 2.	-.193**	.190**	-.024	-.163**
Correct squares, 1.	-.305*	.141**	.087	-.156**

Note. * p<0.05, ** p<0.01, ***p<0.001, 1= Pearson Correlation Coefficient, 2 = Spearman Correlational Coefficient.

Based on the independent samples t-test, the CCT baseline performances differed between genders in three working memory variables measured during the spatial span task (see Table 3). The results favored males.

Table 3. *CCT baseline performance differences regarding gender*

Variables	*n* Females	*n* Males	*m(sd)* Females	*m*(*sd*) Males	*t*
Executive function					
Items recall					
Correct items, 1.	190	254	16.76(6.20)	17.43(6.57)	ns
Correct lists of items, 2.	190	254	1.36(1.42)	1.58(1.55)	ns
Two task -game					
Response time difference 1.	142	177	295.03(478.88)	225.31(236.08)	ns
Difference in proportion of correct responses, shifting to non-shifting items (sc_ns) 2.	142	177	-.03(.04)	-.02(.04)	lo
Processing speed					
1-Back task					
differentiation response time, 2.	166	217	197.28(308.35)	315.41(342.2)	lo
Episodic memory					
Word-connect game					
Words and colors, 2.	190	254	12.44(4.05)	12.32(4.18)	ns
Classic memory game					
Pairs finding time, 2.	146	189	87.62(59.28)	92.46(74.25)	ns
Card turns, 2.	146	189	35.97(10.77)	36.66(12.22)	ns
Working memory					
Spatial span task					
Highest level reached (min. two correct lists of squares/session), 2.	142	178	4.21(.974)	4.48(.998)	lo
Highest level reached, 2.	190	254	3.91(1.11)	4.17(1.09)	2,48*
Number of correct lists of squares, 2.	190	254	8.37(3.21)	9.16(3.19)	2.58*
Correct squares, 1.	142	178	30.44(7.42)	32.28(6.99)	2,29 *

*Note. * p*<0.05, ** *p*<0.01, ****p*<0.001, 1. = Independent Samples T-test 2. = bootstrapped, lo = Left out due to extreme values, ns = not significant.

3.2 The association of background characteristics with improved performance

The second research question examined the association between the background and health information and the improvement of the CCT tasks. Small associations were found between the CCT performance improvement, participants' age, MMSE scores and depression scores. Younger age was associated with greater improvement in time performance in the classic memory game (*r*(207)=-.154, *p*<.01). Higher MMSE results at baseline were associated with more improved performance in card turns in the classic memory game (*r*(206)=-.192, *p*<.01). The depression scores were associated with two variables; negatively with the response time difference in two task -game (*r*(33)=-.464, *p*<.01) and positively with the one-back task (*r*(85)=.261, *p*<.05).

The improved MMSE score was associated to more improved performance in items recall task with both variables; the number of correct list of items (*r*(360)=.136, *p*<.05) and with the number of correct items (*r*(360)=.132, *p*<.05). The change in MMSE score was positively associated to the card turns in classic memory game (*r*(203)=.218, *p*<.001). Statistically significant associations between the gender and improved performance were not found (p>.05).

3.3 The association between the CCT baselines with improved performance

The third research question studied the association of CCT baseline performance and improvement in each task. Each CCT task baseline had weak to strong associations with its own improvement (see Table 4). A low performance at the CCT task baseline was associated with greater improvement of the CCT task performance.

Table 4. *The association between CCT baseline performance and CCT improvement*

Variables	Value
Executive function	
Items recall	
Correct items, 1.	-.349**
Correct lists of items, 2.	-.381***
Two task -game	
Response time difference, 1.	-.956***
Difference in proportion of correct responses, shifting to non-shifting items (sc_ns), 2.	-.644**
Processing speed	
1-Back task	
Differentiation time *(m)*, 2.	-.814**
Episodic memory	
Word connect-game	
Words and colors, 2.	-.434**
Classic memory game	
Pairs finding time, 2.	-.584***
Card turns, 2.	-.490**
Working memory	
Spatial span -task	
Highest level reached, 2.	-.495***
Correct lists of squares, 2.	-.445***
Highest level (min. two correct lists of squares), 2.	-.303**
Correct squares, 1.	-.288**

Note. * p<0.05, ** p<0.01, ***p<0.001, 1. = Pearson Correlation Coefficient, 2. = Spearman Rank Coefficient.

3.4 The impact of the amount of training sessions to the performance improvement

The number of training sessions was associated with two CCT assessment visit variables in the items recall task; the correctly memorized items ($r(346)=.137$, $p<.05$) and the lists of correctly memorized items ($r(371)=.114$, $p<.05$). The amount of training was positively associated to the recall task.

Various amounts of training were also studied. Participants that trained from 25–50% from the total training amount were included, and the associations were analyzed. However, statistically significant correlations were not found.

3.5 The association between the improved performance and ADL

The final research question examined the association between performance improvement and ADL. The association was studied with ADL baseline measure and with the change in ADL. There were no statistically significant findings between CCT task improvement and the change in ADL ($p>.05$).

4 Discussion

This research aimed to determine factors contributing the cognitive performance of people at risk for cognitive decline during the computer-based cognitive training. The results can be utilized to create new intervention methods in the field of dementia.

Correlational associations were found between the participants' CCT task baselines and background characteristic. Background and health information comprised of age, study years, MMSE and depression scores. With few exceptions, however, the background and health information were not associated with CCT task improvement. The lower baseline scores in each task were associated to the higher task improvement. The amount of training and the items recall task showed positive correlations. ADL and its change were not associated with task improvement.

4.1 CCT baseline and background

The first research question focused on the association between background and health information to the CCT baseline performance. A greater age was associated with lower CCT baseline performance in the episodic and working memory domain, as well as in the items recall task. The results supported the existing knowledge that aging is negatively associated with cognitive performance (see, Tucker-Drob et al., 2019; Vuoksimaa, 2019). However, typically, working memory decline start at the age of 60 to 70 and episodic memory changes are well maintained through senescence (Vuoksimaa, 2019). In AD, however, episodic memory is the first cognitive domain to decline (Erkinjuntti et al., 2015). Considering that the population of this study is at risk for mild cognitive impairment, the association between the age and episodic memory performance may indicate possible emerging memory disease.

In addition to episodic memory decline, working memory in AD is declined as well (Erkinjuntti et al., 2015). With MCI, however, the results in the current literature are mixed. Some studies have found working memory deficits in MCI (Pandey & Thapa, 2017), while others have not (Kessels, Overbeek & Bouman, 2015). The small sample sizes and overall lack of studies do not offer the possibility to make more definitive conclusions, but the results may suggest that working memory decline may associate with pathological decline in memory.

As hypothesized, education provided an advantage for the CCT baseline in the items recall task, word-connect game, and spatial span task. Seblova and colleagues (2020) proposed that the education may improve the baseline performance. These results support their findings. It seems, that the cognitive resources acquired earlier in life, may in fact, protect from cognitive decline and produce as a result greater baseline performance (see Stern et al., 2019).

Contrary to the hypothesized association, higher education was negatively correlated with the time performance in the classic memory game. The association may suggest that people with higher education may think more thoroughly before answering. The researcher did not find any supporting evidence from the current literature for this hypothesis. Additionally, the results were not significant with measures that computed participant's reaction time. One small negative correlation does not allow to make any decisive conclusions and the results should be considered tentative. To complement these results, in the future, studies should investigate the association between recall and time dimensions to determine whether the differences come from different acquired strategies or whether it is just a randomness of the data.

As mentioned previously, MMSE scores may indicate possible cognitive decline (Hänninen et al., 2010). In this study, better MMSE scores resulted in better performance at CCT baseline for the items recall task and word-connect game. However, the performance was significantly associated with the tasks that were measured during the assessment visits. This may indicate that the performance was influenced when the participants had to perform exercises for the first time by themselves or that some of the subjects may have had help. Research performed by Delphin-Combe and colleagues (2016) support this hypothesis that the anxiety level impacts memory performance negatively. Additionally, although the tasks were designed to measure the same cognitive function, they differed. Different tasks create different demands and load for cognition and therefore can create diversity to results. The study at hand did not include the whole task battery data from FINGER CCT intervention. The scaled exercises were left out for maintaining comparability. Further analyses should study if the data from the whole task battery would change the results.

Lower CCT baseline performance in the spatial span task, classic memory game, and items recall task was linked with higher scores in ZSDS. These results are in line with previous research that depression may influence cognitive performance in a negative manner (see for example Parkinson, Rehman, Rathbone & Upadhye, 2020). Later investigations, however, should examine whether these results are linked with future diagnoses, considering that dementia and depressive symptoms are linked (John et al., 2019; Mourao, Mansur, Malloy-Diniz, Castro Costa & Diniz, 2016; Parkinson et al., 2020).

Few differences were found between genders. The results suggested, with one exception, that the male's cognitive performance in the spatial span task was better at baseline than females. The only exception was the highest level reached where the minimum performance was two correct lists of squares per session. The result was left out due to the extreme values (Gignac, 2019). The results are in an agreement and supported by previous studies about the spatial differences between genders favoring males (see for example Voyer, Voyer & Saint-Aubin, 2017).

However, the study performed by Ahrenfeldt and colleagues (2018), suggested that gender differences may originate from differences in educational level or upbringing. In their study the gender differences were diminishing in countries where women had better access to education (Ahrenfeldt et al., 2018). The data from this study were collected from a group with more males, and the male group had, on average, a slightly higher level of educational years. The reason behind these results, however, is hard to determine. The possible factors could be located to education, parenting, or cognitive differences or simply all the above. These results encourage to pursue for further studies.

Overall, it seems, that education, greater MMSE performance, lower depression scores and younger age were linked with higher performance at baseline. The correlational associations, however, were all small to moderate, and they may also represent randomness of the data. Additionally, with one exception, male gender seemed to offer an advantage in spatial span task. In conclusion, these results were preliminary, and further analyses are needed to make more definite conclusions.

4.2 CCT improvement and background

The second research question studied the association between demographic and health information with the improvement of the CCT tasks. The associations were small and incoherent. Age associated negatively with the time performance in the classic memory game. The result suggested that the performance improved more if the participant were younger. The association, however, was small. This association is line with literature (see for example Shaw & Hosseini, 2021).

Higher education was associated to the baseline results but not with the task improvements. These results fit the Seblova's and colleagues (2020) views, that education may be associated with the starting level of performance but does not moderate aging changes or in this case, task improvement. Complimentary analyses are needed.

Significant associations were lacking between the MMSE scores and CCT task improvement. The only significant connection was found between MMSE baseline and card turns in the classic memory game. This association was negative, meaning that if the participant had a better baseline score in MMSE, the more the card turns declined and therefore, improved. The MMSE predicts the memory performance in the current studies relatively well (see for example Styliadis, Kartsidis, Paraskevopoulos, Ioannides & Bamidis, 2015; Xin Yan et al., 2016). The results, therefore, are line with contemporary science.

In the current literature, MMSE score's improvement is linked to performance improvement in CCT tasks (see for example, García-Casal et al., 2017). In this study, the changes in MMSE scores produced mixed correlations. Contrary to the hypothesized association, the changed MMSE scores was positively linked to the card turns, meaning that if the MMSE scores improved, the card turns increased too. The small connection may come from the possibility that the task may have become more easier and thus unappealing. Due to the low correlation and small group size, the results should be interpreted with caution. In addition to the classic memory game's card turns, the MMSE score improvement were significant with items recall task. If the MMSE scores increased, the participants memorized more items. These results are in line with current literature (García-Casal et al., 2017).

Depression scores did not offer significant associations with the CCT tasks besides two tasks, the improvement of response time difference in the two task -game and with the one-back task. The current literature suggest that depression is associated poorer cognitive performance (see for example, Parkinson et al., 2020). Contrary to our hypothesis, the greater the depression scores were, the more the participant's response time improved in the two task-game. In the processing speed domain, however, the differentiation time increased more if the depression scores were high at the CCT baseline visit. The results may be incoherent, because the depression scores may not have represented the participant's up-to-date scores, as ZSDS scores were not measured after six months.

The correlational associations seemed to be rather small and mixed. The results may indicate randomness of the data and should be taken with caution. The lack of significant results may also suggest that background characteristics are not important determinant of task improvement.

4.3 CCT baseline and CCT improvement

The third research question investigated the association of CCT task baseline performance with the improvement in each task. The results indicated that the poorer the performance was at the CCT task baseline, the greater the improvement was. The results were significant in all tasks studied. These findings may indicate that if cognitive capacity is already high, the capacity to improve results may be lower. This may also explain why the participant's educational years did not provide an advantage in task improvement.

In other words, the results may suggest that the subjects, whose performance was low at baseline, do not use their potential cognitive capacity completely. This phenomenon has been discussed before in the literature. The disuse of cognitive abilities was first offered by Zinke and his colleagues (2014). They hypothesized that when the participants were offered exercises, that were scaled to their performance level, the learning effect were minimized, and they were able to reactivate the participants passive resources (Zinke et al., 2014). FINGER study included scaled exercises in the CCT. In this study, however, the scaled exercises were left out due to the comparability. The transfer effects of the scaled exercises improvement to the non-scaled tasks cannot be excluded. In the future, it would be meaningful to find out if the CCT task baselines are associated with the scaled or non-scaled exercises differently.

The second possible reason behind the improved performance is the compensation effect suggested by Karbach, Könen and Spengler (2017). The compensation effect suggests that low-performing individuals benefit from interventions that focus on more general processing capacities (Karbach et al., 2017.) By focusing on general processing, individuals can compensate their low performance in some cognitive domains with other cognitive processing resources (Shaw & Hosseini, 2021). FINGER study included variety of tasks from different cognitive domains which means that the cognitive processing resources may in fact be a contributing factor in CCT improvement.

Additionally, it should be considered whether the starting level is more important determinant to task improvement than the background characteristics. Shaw and Hosseini (2021) were the first researchers, that conducted meta-analysis that included all the cognitive domains from different studies. This is the first study, to our knowledge, that analyzed all the cognitive domains. Nonetheless, these results need complimentary analyzes. The results give a strong encouragement to investigate the baseline associations more. Future analyses should study the association between the different cognitive domains, for example, is some cognitive domain’s baseline more important to the performance improvement than the others, like Karbach and colleagues (2017) findings suggested. Deeper understanding on singular trajectories would complement these results as well as the understanding between different task types and their associations to the improved performance.

4.4 Training amount and improved CCT tasks

The fourth research question examined the relationship between training amount and improved CCT task performance. The amount of training was positively linked to the items recall task. No significant links were found with the other task's improvement, even in subjects who trained over 25–50%. It must be noted, however, that the singular tasks taken into this study may not be as sensitive as the whole task battery. Further analyses should focus on forming sum variables from the whole task battery and studying how the connections change after that.

4.5 CCT task improvement and ADL

The final research question investigated the association between CCT task improvement and the ADL. Contrary to the hypothesized association, no significant associations were found in this study. Firstly, the population of this study is at risk for MCI. The ADL is not linked with MCI but are linked with AD (Rosenvall et al., 2021). The lack of significant associations may originate from the fact that the population of this study does not have MCI or dementia diagnosis and therefore, the ADL is not disturbed. Secondly, the population in FINGER research functioned relatively well, and the ceiling effect of the questionnaires may have disturbed the results (for more, see Kulmala et al., 2019). Future studies should investigate with tools where the ceiling effect is not present to investigate the association of ADL and CCT more effectively.

4.6 Strengths and limitations

This study had several strengths. It included double blinding and a broad, national study population. Additionally, FINGER research is a longitudinal study that offers deeper insight into the long-term effects of the multidomain intervention and offers the opportunity to study the association between the components behind future possible diagnoses.

When interpreting the results, however, some limitations should be considered. First, the multidomain study design created challenges in differentiating the contributing factors. The intervention at hand was carried out gradually in a step-by-step manner, but determining the influencing factors was still difficult. Moreover, the complexity of the intervention may have contributed to the participants' adherence with the CCT tasks. Overall, the results suggested that the intervention was beneficial to the participants.

The second limitation, which was also a strength of the study, is that people with high or low cognition were not included in the study population. The study included people who already were at high risk of receiving an MCI diagnosis but did not have clinically observed symptoms. This provided an opportunity to investigate the preventive factors more deeply.

The final limitation is the timeline of the exercises. The study participants were instructed on how many times per week they needed to do the exercises, and they were not able to do them beforehand. However, the software that recorded the performance, started from the task the participant's performed the latest. This means that the timeline of some participants' performance may have been longer than six months.

5 Conclusion

To conclude, the results suggested that the CCT training was helpful especially when the participants' starting level was low and despite of the participant's background features. The background characteristics seemed to be linked more to the baseline, than to the improvement of the CCT tasks. The starting level of the CCT offered moderate to strong associations with the improvement in each task. The result illustrates a new way of looking the relationship between the baseline and its improvement. In the future, the link should be studied with subgroup analyses to investigate this relationship further. Moreover, it may be beneficial to consider whether the baseline of the performance is stronger indicator to the improvement of the CCT tasks than the background characteristics.

The information provided herein can be utilized to create new intervention tools in the field of dementia.

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