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Computerized Cognitive Training in the Older Workforce: Effects on Cognition, Life Satisfaction, and Productivity

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Abstract: Background: The accelerated aging of the world's population will lead to an increase in the number of older people in the workforce. Computerized Cognitive Training (CCT) is effective in improving cognitive outcomes, but its benefits for older workers remain controversial. We investigate the real-world efficacy of CCT in the workplace, focusing on employees aged 50+ years from a public sector agency. Methods: Case managers (n = 82) were randomized to either an intervention group (24 40 min CCT sessions two times per week) or a waiting list passive control group. Cognitive ability, well-being, job satisfaction, and productivity outcome measures were collected and assessed before and after CCT or the comparable control wait time. Results: Participants undergoing CCT improved on a task of executive functioning (p = 0.04). There was a trend toward a change in work productivity after CCT (p = 0.09), with the control group showing a significant decrease (p = 0.02), while the intervention group remained stable. Conclusions: CCT during office hours has a positive effect on cognition and well-being without affecting productivity among white-collar office workers. CCT could be considered as an intervention to support the older workforce in managing the cognitive and behavioral challenges of changing workplace demands.

Keywords: older employees; 50+; computerized cognitive training (CCT); productivity; well-being

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1. Introduction

The ongoing demographic shift, characterized by a declining proportion of young individuals and an increasing proportion of older people in the population due to falling fertility rates and enhanced life expectancy [1,2], is fundamentally altering our global landscape. By 2030, the United Nations predicts that one in six individuals worldwide will be over 65 years old. Concurrently, this demographic transition will see a surge in the older workforce: The anticipated rise in the percentage of older workers (aged 55–64) relative to the total working population (aged 15–64) from 2014 to 2035 is projected to increase from an average of 12.1% in 2014 to an average of 24.8% in 2035 [3]. These shifts at the population level are already exerting significant pressure on workforce well-being and productivity.

1.1. Older Workforce

For quite some time, it has been established that cognitive abilities are the most significant predictor of work performance [4]. From a work standpoint, it is anticipated that older employees may encounter greater challenges due to issues with focus, resulting in difficulty inhibiting irrelevant information; reduced memory capacity, slowing learning of new skills; and slower processing reducing productivity [4]. A meta-analysis conducted by Kubeck and colleagues showed that, compared to younger counterparts, older workers also struggle with learning new procedures, often requiring more time for mastery [5].

Not all work processes entail high demands. Tasks posing difficulties for the older workforce typically involve prolonged cognitive effort (e.g., scanning through pages of numbers or symbols) or those with time constraints (e.g., swiftly completing a project) [6–11]. Conversely, long-term repetitive and mentally undemanding work negatively impacts older workers' fluid cognitive functions [12]. Irrespective of job demands, whether high or low, it would be advantageous for the older workforce to receive support aimed at preserving and maintaining their cognitive capacity to sustain productivity until retirement.

1.2. Cognitive Aging

It is widely acknowledged that cognitive performance typically diminishes with advancing age [13], particularly in fluid abilities such as attention, processing speed, and reasoning [12]. These functions are crucial for swift and efficient action control and goal-directed behavior, especially under the complex conditions often encountered in the workplace. They tend to decline first from middle adulthood, with variations in pace among individuals. Such functions encompass short-term memory, working memory, action planning and preparation, orientation and control of attention, searching for relevant information in the environment, the inhibition of irrelevant information and reactions, multitasking, task-switching, and self-monitoring including error detection and correction. The changes in cognitive functions that accompany aging become particularly pertinent in the ever-evolving modern work environment, marked by the introduction of new technologies such as increased electronic communication or new electronic devices to learn and master, which only add to the complexity of the workplace [14].

There are several theories of cognitive aging that might bear on our research. Salthouse [15] proposed that cognitive aging is associated with a slowed speed of processing and that the slower speed of processing leads to evident declines in cognitive functioning. At the same time, West [16] elaborated the frontal lobe model, which is based on prefrontal cortex temporal integration, supported by four specific processes: prospective memory, retrospective memory, interference control, and the inhibition of prepotent responses. The frontal lobe is consistently found to be the most susceptible to aging effects, resulting in declines in cognitive control, specifically sustained attention, selective attention, inhibitory control, working memory, and multitasking abilities.

1.3. Cognitive Training (CT)

Over the past two decades, Cognitive Training (CT) has emerged as a particularly popular intervention approach. CT and computerized cognitive training (CCT), often referred to as brain training, aim to maintain or enhance cognitive abilities and processes through structured tasks designed to engage specific cognitive functions [17]. These approaches have been applied across various domains and populations [18]. Early on, researchers began exploring the use of CT and CCT in healthy aging individuals as a means to mitigate age-related cognitive decline, with numerous studies reporting positive effects [19]. They have found that regular CT among healthy older adults can help maintain or even improve certain cognitive functions, leading to greater functional abilities and reduced pathological processes in aging brains [20–22]. Furthermore, the benefits of CT/CCT may have longer-lasting effects [23] and/or potentially impact other domains such as mobility [24,25]. However, there is a notable gap in research regarding the use of CT/CCT with middle-aged adults. Gates et al. 2019 reported in their review of 317 publications on cognitive training with midlife adults that they found only one CCT article, which was of low quality. The authors were unable to determine whether CCT is effective in maintaining global cognitive function among healthy adults in midlife and recommended future research on the effectiveness of CCT with midlife adults [26].

With an increasing number of reports on the efficacy of CT/CCT, there has been a rise in systematic reviews, both with [27] and without meta-analyses [28]. However, recent systematic reviews present conflicting results [29,30]. Some reviews demonstrate clear benefits to trained abilities, such as executive function [31] and processing speed [32], particularly in older adults. Conversely, other reviews provide mixed evidence regarding the benefits of CT [33–35].

Despite the mixed evidence reported in reviews of CT efficacy among unimpaired older adults, researchers in this field still regard affordable and easily administered interventions like CT as promising avenues to mitigate age-related cognitive decline and maintain cognitive health well into late adulthood [36].

1.4. Cognitive Training with Older Workers

An extensive search has identified only four publications specifically related to CT in the workforce [37–40], each differing in various features of CT and the sampled workers. Among these, only Gajewski et al. [38] applied CT specifically with workers aged between 40 and 57 years. The others included workers of all ages and students. In terms of the CT methods employed, Gajewski et al. [34] utilized paper–pencil training tasks, whereas the others utilized CCT. Borness et al. [37] delivered online training sessions lasting 20 min, three times a week, targeting various cognitive domains such as memory, attention, language, executive function, and visuospatial abilities. Lampit et al. [39] utilized tasks focusing on attention, memory, and visuospatial skills, conducting one-hour sessions three to four times a week over a duration of six months. Miller et al. [40] delivered CCT online through the BrainHQ.com program, with participants categorized into long-training and short-training groups, with average durations of 30 h and 7 h, respectively.

The outcomes of CCT effectiveness also exhibit considerable variability; [37] did not find a positive impact of CCT on cognition or well-being among white-collar office workers. Similarly, Lampit et al. [39] reported that CCT participants did not show improvement in sustained attention tasks, although they did demonstrate significantly enhanced productivity in bookkeeping tasks. Conversely, Gajewski and colleagues [38] reported improvements in the accuracy of complex memory-based task switching immediately after and three months after the completion of the CT among manufacturing workers with long-term repetitive and unchallenging types of work. Additionally, Miller and colleagues 2019 found that after CCT, participants showed overall improvements in attention, executive function, and decision-making.

From this brief review, it is evident that there are mixed results regarding the effectiveness of CCT within the workforce. Such outcomes could be influenced by various key determinants of CCT, including the type of CCT (single domain, multi-domain), delivery method (paper–pencil, online), duration, dose (i.e., session duration), frequency (e.g., sessions per week or month), and the presence of a control group [41]. In summary, CT/CCT within the workforce context shows potential effectiveness, but further research is warranted, particularly concerning CCT with older workers.

1.5. Purpose of the Present Study

The present study aimed to assess the effectiveness of CCT for inducing changes in cognitive functions among administrative workers. To our knowledge, this is the second study to investigate trainer-guided CCT in an office setting. The study was structured as a randomized controlled intervention trial (RCT) with a wait list control group, incorporating pre- and post-CCT assessments. In addition to examining general training effects on cognitive functions, our focus extended to evaluating the differential impact of CCT on work productivity and well-being, encompassing self-evaluations of life and job satisfaction, mood, and general health.

We hypothesize that CCT will: (i) enhance cognitive functioning, preferably evidenced by far-transfer effects, (ii) improve self-evaluation outcomes related to perceived life and job satisfaction, mood, and general health, and (iii) not impede work productivity even though the CCT sessions were conducted during regular work hours.

2. Methods

2.1. Participants

The participants for the study were recruited from employees of the Pension and Disability Insurance Institute of Slovenia (ZPIZ) and worked as insurance implementation clerks (e.g., case managers for retirement or disability requests). The workforce at PIDS consists primarily of women (81%). The insurance officer is responsible for determining/acknowledging rights for pension and disability insurance and issuing informational calculations. During the handling of individual cases, an insurance officer is responsible for the following: obtaining all relevant/necessary data, calculating the retirement date, calculating the amount of the pension, entering and organizing all records, sending the decision with calculated pension and other documents to clients, and providing verbal information to clients if needed. A pool of 82 potential participants was identified from the employee registry of the Institute (see Figure 1). Inclusion criteria included being above 50 years of age, currently working as a case manager, and having signed the consent form. From this pool, 76 participants agreed to participate and were then randomly assigned to either the intervention or control group (see also Section 2.2. Study design). At this stage, 10 subjects from the intervention group and two subjects from the control group were excluded due to incomplete responses on the neuropsychological tests. Thus, at the beginning of the CCT, there were 28 participants in the intervention group and 36 subjects in the control group. Basic demographic characteristics are presented in Table 1. All participants were right-handed, had normal or corrected-to-normal vision, and reported no history of cardiovascular disease, neurological, or psychiatric conditions. The study commenced on 6 September 2022 and concluded on 22 December 2022. The COVID-19 pandemic was officially declared over, but the situation remained unstable due to the recurrence of new COVID-19 variants. This was the primary reason we decided to conduct group psychological testing and computerized cognitive training online. All procedures were conducted in accordance with the Declaration of Helsinki and were approved by the Ethics Committee of the Science and Research Centre Koper. Written informed consent was obtained from all participants prior to their involvement in the study.

Table 1. Demographic data for intervention and control group.

	Intervention Group (n = 19)		**Control Group (n = 23)**		
	Mean	**SD**	**Mean**	**SD**	***p* Value**
Age	54.55	3.19	55.72	3.94	0.31
Gender	F 20, M 0		F 32, M 4		
Education (years)	15.11	0.94	15.39	1.41	0.45

2.2. Study Design

Each participant was randomly assigned to either the intervention or passive control group (e.g., wait list). The randomization process was conducted using a random number generator in Microsoft Excel software (Microsoft 365, Microsoft Co., Redmond, WA, USA). Prior to the CCT study, all participants underwent neuropsychological testing, followed by the administration of a demographic questionnaire, general health questionnaire, job satisfaction questionnaire, Cognitive Change Questionnaire, WHO-5 well-being questionnaire, and life satisfaction questionnaire.

Participants in the intervention group underwent 24 sessions of CT with the maze navigation task, while participants in the control group awaited the potential replacement of drop-out participants from the intervention group. After 12 weeks, when the CCT was completed, all participants from both the intervention and control groups were invited for a second round of neuropsychological testing using the same tests but in an alternative version and were asked to respond to the same questionnaires as in the initial testing.

Of the initial 28 participants assigned to the intervention group, two dropped out after the initial CCT session, six dropped out after two to four CCT sessions, and one did not complete the post-CCT neuropsychological testing, resulting in 19 subjects who completed the CCT and both pre- and post-CCT testing. In the control group, 13 participants did not attend the second testing session, resulting in a total of 23 participants in the control group (see Figure 1).

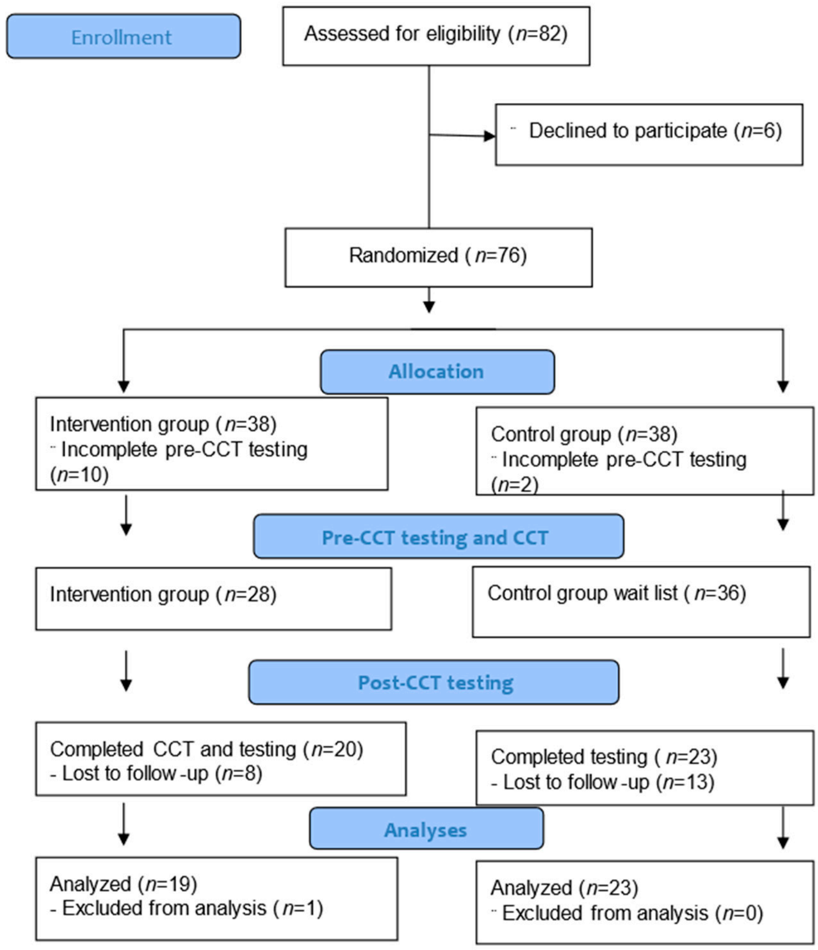

Figure 1. Study flow diagram.

2.3. Training Procedures

Among many available tasks for CCT, we opted for virtual maze navigation. Based on our previous research and that of others, maze navigation training has been shown to improve both mnemonic and executive functioning across different age groups and populations [36,42–46]. Given the heavy emphasis in the jobs of the people in our study on reasoning through requests, documentation, and the familiarity and recall of the specific laws related to aging and disability pensions and other health laws, our choice of task appeared well suited. CCT was offered as a health-promoting activity at the participants' workplace, either at the Pension and Disability Insurance Institute (ZPIZ) headquarters in Ljubljana, Slovenia, or at two regional offices. To familiarize the intervention group with CCT and the online virtual maze training, the first two sessions were held in the company's conference rooms, with groups of nine to ten participants. During these initial sessions, an experimenter, research assistants (RAs), and an IT support specialist supervised and assisted participants with issues such as logging in and navigating the virtual maze. Subsequent CCT sessions were conducted online via a link to the company's intranet, allowing the experimenter and IT support specialist to observe and assist participants with any logistical questions, such as logging into the server or navigating the virtual maze application. Participants conducted their training alone in an office or at home (remote work). The CCT was carried out in three small groups of nine to ten participants, scheduled on Tuesdays and Thursdays between eight am and twelve pm during working hours, with each session lasting approximately 45 min over a duration of 12 weeks.

2.4. Computerized Spatial Navigation Training (CCT) Protocol

Participants in the intervention group were tasked with navigating mazes using the arrow keys on the keyboard, with each session lasting approximately 45 min across 22 CCT sessions. They traversed through several virtual maze environments, each designed to increase in complexity through the number of turns as the participant progressed through successively more complex levels, (task titration, see Figure 2). The tasks were displayed on a 17-inch flat panel LCD monitor positioned approximately 60 cm in front of the participants. All virtual environments were created using modified versions of Brain Powered Games: Maze Training, 2016.

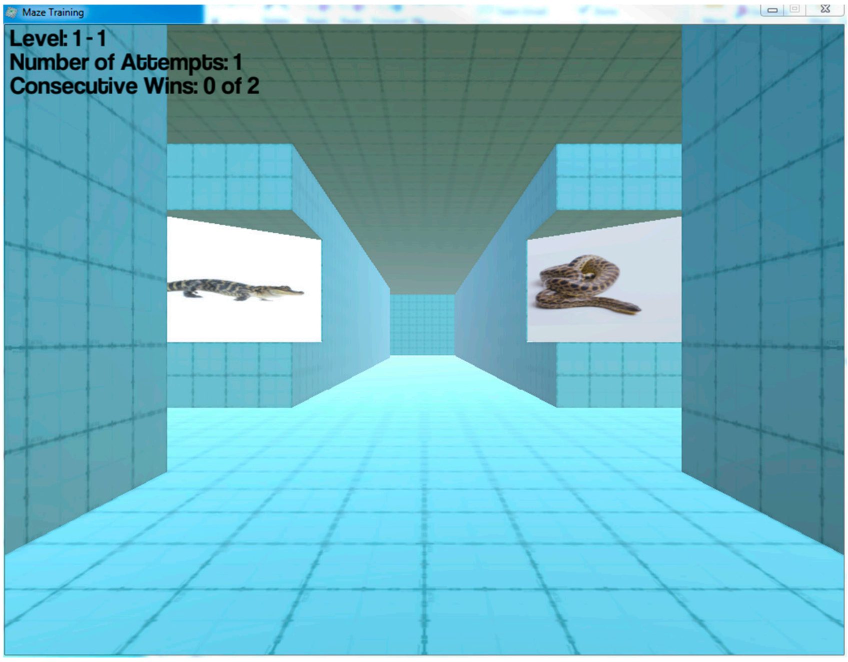

Figure 2. Illustration an intersection within the computer-based spatial navigation application for CCT. At this intersection, participants must decide which direction they want to take—left, straight ahead or right—within a virtual maze offering three available paths.

The CCT task was presented from a first-person perspective and consisted of a series of interconnected hallways and alleys, with three available paths at each intersection or decision point. Some hallways led to the goal area, indicated by a trophy, while others led to dead ends. At each decision point (intersection), a pair of nonverbal cues (e.g., pictures of animals) was displayed at opposite corners. Participants were instructed to select the correct path as quickly and efficiently as possible, aiming to move toward the goal area (represented by a trophy picture) while staying in the center of the path. Upon reaching the goal area, participants were "transported" back to the starting point to begin another learning trial for the same virtual environment. Participants began CCT with maze navigation featuring one intersection and progressed up to environments with nine intersections.

For each environment, participants were required to navigate to the goal area until successfully completing two consecutive trials without errors. Upon reaching this criterion, participants could advance to the next level of maze navigation. To mitigate practice effects across repeated testing, alternate forms with different spatial layouts were utilized for all levels of maze complexity.

2.5. Outcome Measures

All outcome measures, including questionnaires and tests, were obtained in a group setting prior to the start of CCT. Groups of employees consisting of 10 to 15 participants were comfortably seated in a conference room. After distributing brochures containing tests and questionnaires to each participant, the experimenter administered the tests by reading standard instructions aloud to all participants simultaneously. The only difference was that in some tests (e.g., AVLT, Digit span), participants were instructed to write their responses instead of verbally responding to the task at hand. Additionally, another trained experimenter supervised the test administration, overseeing participants' responses. Following the initial neuropsychological testing, 12 participants were excluded from further participation in the research project due to incomplete responses in their testing brochures (e.g., lack of responses, clearly incorrect responses, failure to follow test instructions).

2.5.1. Neuropsychological Tests

Tests assessing various cognitive domains were administered to evaluate the transfer of cognitive skills following CCT maze navigation from both proximal and distal domains. To streamline the administration of cognitive tests, a small group testing approach was adopted. Tests were conducted in small groups consisting of five to ten participants, with appropriate modifications made to the test instructions. When selecting neuropsychological tests, priority was given to choosing tests that could be effectively administered in a group testing setting. For most of the selected tests, standard instructions were utilized. Further details regarding modifications to the test applications are provided for each test individually.

The Rey Auditory Verbal Learning Test: [47–50] The Auditory Verbal Learning Test (AVLT) is a neuropsychological assessment tool designed to evaluate auditory verbal memory. Memory domains assessed include learning across trials representing immediate learning and delayed recall representing retention [49,51]. The AVLT comprises two lists (A and B), each containing 15 words. During the test, the administrator reads the 15 words from list A at a rate of one word per second. Following the presentation of the list, the participant is asked to recall and write down the words on paper, with no specific order required. This process is repeated five times, with the participant recalling the words on separate sheets of paper for each repetition. Subsequently, the participant is instructed to listen to list B, which serves as interference. Afterwards, another recall of words from list A is conducted. The participant is then asked to recall the words from list A after a delay of 20 to 30 min, reflecting longer term recall. To ensure accuracy in scoring, any confabulations (fabricated responses), intrusions, or substitutions are disregarded when counting correctly written words [49,51].

Verbal Fluency: This test measures the number of words recalled (written on paper) by a participant, typically within a specified category or in response to a particular letter, within a set time limit. This test assesses the recall of longer term verbal storage and general verbal abilities and has also been related to basic executive functions [52–54]. We utilized two basic types of verbal fluency tests:

(a) Letter Verbal Fluency (LVF) Test: In this test, participants were instructed to write down as many words as possible that begin with the letter "F" in the first testing session and "S" in the second testing session, within a time limit of 60 s.
(b) Semantic Verbal Fluency (SVF) Test: Participants were asked to verbally generate and write down as many words as possible from the semantic categories of 'animals' during the Pre-CCT testing and 'fruits & vegetables' during the post-CCT testing. They were allotted 60 s for each category.

The final raw score was determined by summing the words written in the test brochure within the specified time limit for each category in each task. Repetitions of the same word or intrusions (incorrect words) were not included in the final score.

Digit Span: The Digit Span test is a subtest of the Wechsler Adult Intelligence Scale-III (DSpan) [55]. This test assesses direct verbal digit recall and the components measure both basic attention and working memory/concentration. The test involves two different tasks. In the first task, the individual is required to recall numbers in the same order as they are originally presented (Digits Forward), while in the second task, the individual is asked to recall the given numbers in reverse order (Digits Backwards). The experimenter reads a continuous sequence of numbers, one per second, that are then repeated. Each task consists of two attempts for each sequence of numbers, ranging from two to nine in the Forward task and from two to eight in the Backward task. During group testing, the experimenter reads all the sequences, from the lowest to the highest sequence. The result represents the number of correctly recalled numbers written in the testing brochure. Reliability coefficients over time range between 0.66 and 0.89, depending on the length of the interval and the age of the individuals [56].

Digit Symbol Substitution Test: The Digit Symbol Substitution Test, initially introduced to measure information processing speed [55], is a component of the Wechsler Battery of Intelligence Tests [49]. This test assesses psychomotor abilities by presenting the individual with a line containing nine numbers and corresponding symbols, and serving as a key [56]. Each number is paired with a specific symbol. Initially, the test subject completes a trial section to familiarize themselves with the symbols associated with each number. Upon receiving a signal from the experimenter, the subject proceeds to fill in the blank fields with the appropriate symbols beneath each number. The objective is to fill in as many blank fields as possible within a limited time frame. In our study, we restricted the solving time to 60 s. The result is determined by the number of correctly written symbols within this time limit. The Digit Symbol Substitution Test demonstrates high reliability and stability over time [56,57], with reliability coefficients ranging from 0.82 to 0.88. Furthermore, the test exhibits sensitivity in identifying dementia and monitoring its progression.

Pattern Comparison: The Pattern Comparison test [58,59] assesses cognitive abilities related to perceptual speed. In this test, participants are presented with 30 pairs of patterns, each consisting of 3-, 6-, or 9-line segments. Within a time limit of 30 s per page, participants are instructed to indicate whether the patterns in each pair are the same (by writing "S") or different (by writing "D"). This test exhibits high reliability, with coefficients of 0.85 among students and 0.90 among older adults. Additionally, it is highly correlated with measures of perceptual speed [58].

For all the above-listed neuropsychological tests, the primary outcome measures were the number of correct responses.

2.5.2. Questionnaires

Job Satisfaction Questionnaire (MSQ): Job satisfaction is commonly understood as the array of feelings or affective responses linked to the job environment, or simply put, "how people feel about different aspects of their jobs" [60]. In 1967, Weiss et al. developed the short version of the Minnesota Satisfaction Questionnaire (MSQ), which employs a 5-point Likert-type scale comprising 20 items. This instrument has shown strong stability over time [61]. A systematic review by Van Saane [62] reported that the MSQ had an internal consistency of 0.92, a test–retest reliability of 0.89, and a convergent validity of 0.83.

General Health Questionnaire: This questionnaire developed by the research team is composed of three questions asking a participant to evaluate on a five-point scale (1 = very bad to 5 = very good) their overall health, and, separately, their physical and then mental health.

Cognitive Change Questionnaire (CCQ): The CCQ [63] used during the COVID-19 pandemic was modified for the self-assessment of cognitive change in this study. The questionnaire comprised nine items, self-reporting changes observed in everyday cognitive functions, specifically related to the speed of information processing, short-term storage, prospective memory, attention, and executive control. Participants were instructed to compare their cognitive functions before and after CCT, using a seven point scale. For items one to five, the scale ranged from 1 = "much less often" to 7 = "much more often" compared to before the CCT. For items 6–9, the scale ranged from 1 = "much easier" to

7 = "much harder" than before the CCT. Scores on the CCQ range from 9 to 35, with higher scores indicating a greater self-perceived decline in cognitive functioning.

Satisfaction With Life Scale (SWLS): The SWLS [64] is a five item scale designed to measure overall life satisfaction based on an individual's own subjective criteria. This scale has been widely utilized and demonstrates internal consistency and temporal stability estimates ranging from 0.54 for a 4 year interval to as high as 0.89 for a two week interval [65]. Participants rate their agreement with each statement using a seven point scale, ranging from 1 = "strongly disagree" to 7 = "strongly agree". Scores on the SWLS range from 5 to 35, with higher scores indicating greater life satisfaction.

The WHO-5 Well-Being Index: As observed in Ref. [66], this is a widely used questionnaire designed to measure well-being [66]. It consists of five items, such as "Over the last month I have felt cheerful and in good spirits," which are rated on a six point Likert scale. Responses range from 0 = "never" to 5 = "all the time". Higher scores on the WHO-5 indicate a greater state of well-being. The WHO-5 has been validated in numerous studies and has demonstrated good psychometric properties [67].

2.6. Productivity

Productivity is measured by a standard company measure, "ponder", a composite measure of employee productivity expressed as the accumulation of all normed procedures generated in a certain time period (usually within a year, but it can be shorter). For example, completing the decision process for a calculated pension is evaluated with 180 ponders. For the productivity of the employees involved in our study before the administration of CCT, the ponders reflect employees' productivity in the year 2022 (baseline value), while the productivity/ponders of employees during and after CCT represent productivity adjusted for the first eight-month period of the year 2023 (post-intervention value). A higher number of ponders represents higher employee output.

2.7. CCT Satisfaction Measure

To obtain participants' attitudes and opinions of the CCT experience, they were asked to respond to two questions related to their satisfaction with the CCT program and with the administration of the CCT. This was conducted using a four-point scale where 1 = completely satisfied and 4 = completely unsatisfied. A lower number represents a higher satisfaction with CCT and the administration of CCT.

Productivity measures were recorded and provided by the work organization, while other measures were collected by the research team.

2.8. Statistical Procedures

The data were analyzed using IBM SPSS Statistics 22.0 software for Windows (SPSS, Inc., Chicago, IL, USA), and results are presented in tables displaying means ± standard deviations. Prior to analysis, the homogeneity of variances was assessed using Levene's test, while the normality of parameter distributions was examined using the Shapiro–Wilk's test. For variables with questionable assumptions regarding normality, the nonparametric Mann–Whitney U test was employed. Additionally, the outcome measures underwent a two-way analysis of variance (ANOVA) with the time-point variable (Pre-CCT, post-CCT) treated as a within-subject variable and the group (intervention, control) as a between-subject variable. To further elucidate the differences between the two groups, the η^2 coefficient was calculated, with values of 0.01 representing a small effect size, 0.06 a medium effect size, and values above 0.14 indicative of a large effect size [68].

3. Results

3.1. Sample Univariate Description

The demographic results of the participants in the intervention and control groups are presented in Table 1. Independent sample *t*-test analyses showed that there were no statistically significant differences between the intervention and control groups for any of the variables. The intervention and control groups did not differ in age or years of education.

Participants from the intervention group exhibited above average satisfaction with CCT and its administration (1.75 and 1.51 on a 4-point scale, with a mean value of 2.50).

3.2. CCT Effectiveness

The performance scores for all neuropsychological tests for both groups from pre- and post-CCT are presented in Table 2.

Table 2. Means (M) and standard deviations (SD) of the neuropsychological test of the intervention and control group for pre- and post-CCT.

Test		Pre-CCT		Post-CCT		RM ANOVA				
						Time	Group	*Interaction (Time × Group)*		
		M	SD	M	SD	*p* Value	*p* Values	*F* Value	*p* Value	Partial η^2
VF-L						**<0.001**	0.24	4.387	**0.04**	0.099
	Intervention	9.16	2.79	17.32	3.82					
	Control	9.39	2.81	15.13	3.43					
VF-S						0.06	0.14	2.31	0.14	0.061
	Intervention	20.00	6.71	19.72	6.61					
	Control	22.45	4.27	20.03	5.35					
Digit Span Forward						0.44	0.91	0.98	0.33	0.024
	Intervention	6.32	1.06	6.37	1.01					
	Control	6.52	1.28	6.21	1.68					
Digit Span Backward						0.06	0.61	0.223	0.63	0.006
	Intervention	5.84	1.17	6.16	1.54					
	Control	5.52	1.56	6.04	1.65					
AVLT Learning						0.33	0.24	0.15	0.70	0.004
	Intervention	10.35	1.37	10.23	1.06					
	Control	9.95	1.56	9.68	1.57					
AVLT-IR						0.27	0.23	1.49	0.23	0.037
	Intervention	9.11	3.09	9.05	1.93					
	Control	7.68	3.76	8.82	3.02					
AVLT-DR						**0.02**	0.35	0.91	0.35	0.023
	Intervention	8.58	2.17	9.79	1.62					
	Control	9.23	2.69	9.77	2.62					
Coding						**0.02**	0.60	0.05	0.83	0.001
	Intervention	51.11	8.31	54.05	9.07					
	Control	52.43	11.89	55.96	12.67					
Comparison						0.08	0.12	0.28	0.12	0.007
	Intervention	20.37	3.37	20.26	3.56					
	Control	20.09	4.24	18.32	2.55					

Notes: Primary outcome measures were the number of correct responses for all tests. (VF-L: Verbal Fluency Letter, VF-S: Verbal Fluency Semantic, AVLT-IR: Auditory Verbal Learning Test—Immediate Recall, AVLT-DR: Auditory Verbal Learning Test—Delayed Recall). Significant *p*-values are highlighted in bold.

Mixed ANOVAs did not show any significant main effects for the group ($p > 0.14$) across any of the outcome variables. However, the mixed ANOVA for the Verbal Fluency

Letter test showed that there was a significant interaction effect between time and group f [F(1,40) = 4.387, p = 0.043, η^2 = 0.099] (See Figure 3). A subsequent post hoc analysis indicated a significant improvement in both groups ($p < 0.001$), though there was a significant difference between the post-CCT score for the groups (p = 0.05), demonstrating that participants in the intervention group significantly increased their performance on the Verbal Fluency Letter test more than participants in the control group (from 9.16 to 17.32 vs. 9.39 to 15.13, respectively).

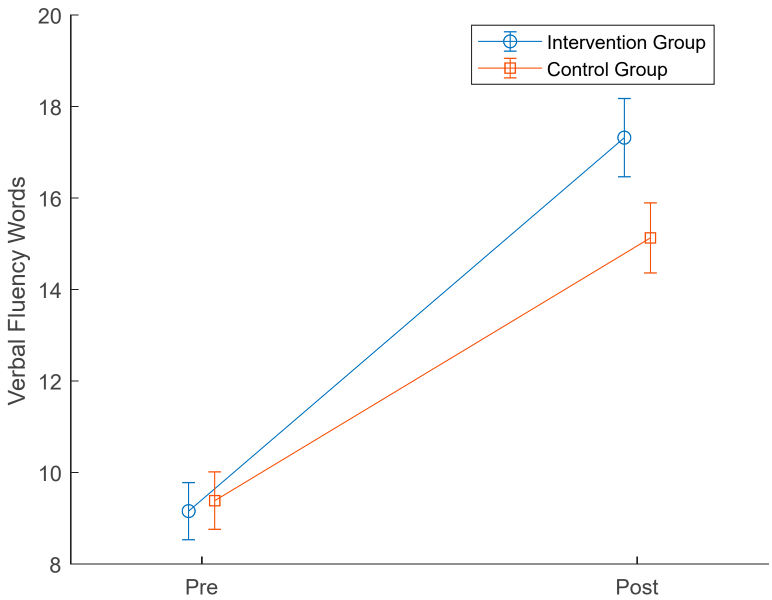

Figure 3. The average scores on the Verbal Fluency Letter test for participants in the intervention group (blue color) and control group (orange color) for pre- and post-CCT (error bars represent standard error of the mean).

A mixed ANOVA also demonstrated a significant main effect of time for the AVLT Immediate Recall and Delayed Recall (p = 0.02) and Coding tests (p = 0.02). On each of these tests all participants on average improved their performance. For the comparison test, there was a tendency (p = 0.08) for a decrease in performance after CCT. Specifically, there was a significant decrease in performance in the control group (p = 0.04), while there was no significant change in the intervention group (p = 0.87).

3.3. CCT Effects on Productivity and Well-Being

The responses for all the questionnaires for both groups from pre- and post-CCT are presented in Table 3. Mixed ANOVA showed that there were no significant main effects for group or time nor significant interaction effects. However, there was a non-significant trend for work productivity (p = 0.09). When this was evaluated further, it was revealed that there was no change in productivity between pre- and post-CCT for the intervention group (p = 0.49), but a significant decrease in productivity in the control group (p = 0.02) (see Figure 4).

In addition, although the Cognitive Change Questionnaire did not show any significant differences between the intervention and control group, a further evaluation was carried out to evaluate the relationship between the CCQ and health scores for each of the groups. Here, there was a significant negative correlation between the CCQ and health score for the control group ($r = -0.46$, p = 0.04) but not for the intervention group: (r = 0.01, p = 0.98): control participants with higher self-evaluated cognitive issues also showed a lower self-evaluated health status (see Figure 5). There was also a trend for a negative correlation between the CCQ and well-being for the control group ($r = -0.41$, p = 0.06) but not for the intervention group ($r = -0.07$, p = 0.90).

Table 3. Means (M) and standard deviations (SD) of the productivity and well-being questionnaires of the intervention and control group for pre and post CCT.

Questionnaire	Pre-CCT		Post-CCT		RM ANOVA				
					Time	Group	Interaction (Time × Group)	Partial η^2	
	M	SD	M	SD	*p* Value	*p* Values	*p* Value	*p* Value	
Work productivity					0.086	0.433	3.015	0.09	0.070
Intervention	118,740	17,620	118,660	24,750					
Control	117,700	28,910	106,400	38,310					
Life Satisfaction					0.28	0.89	0.43	0.52	0.011
Intervention	21.17	4.23	22.44	4.93					
Control	21.86	5.77	22.18	5.56					
Well-being					0.73	0.48	1.34	0.26	0.034
Intervention	14.33	4.72	15.00	4.50					
Control	14.23	5.51	13.00	6.06					
Job satisfaction					0.74	**0.03**	0.46	0.50	0.014
Intervention	37.00	9.83	38.22	8.85					
Control	44.12	9.84	43.71	6.85					
Health					0.95	0.33	0.57	0.46	0.015
Intervention	11.11	1.37	12.37	4.07					
Control	11.45	3.88	10.41	3.13					

Notes: Significant *p*-values are highlighted in bold.

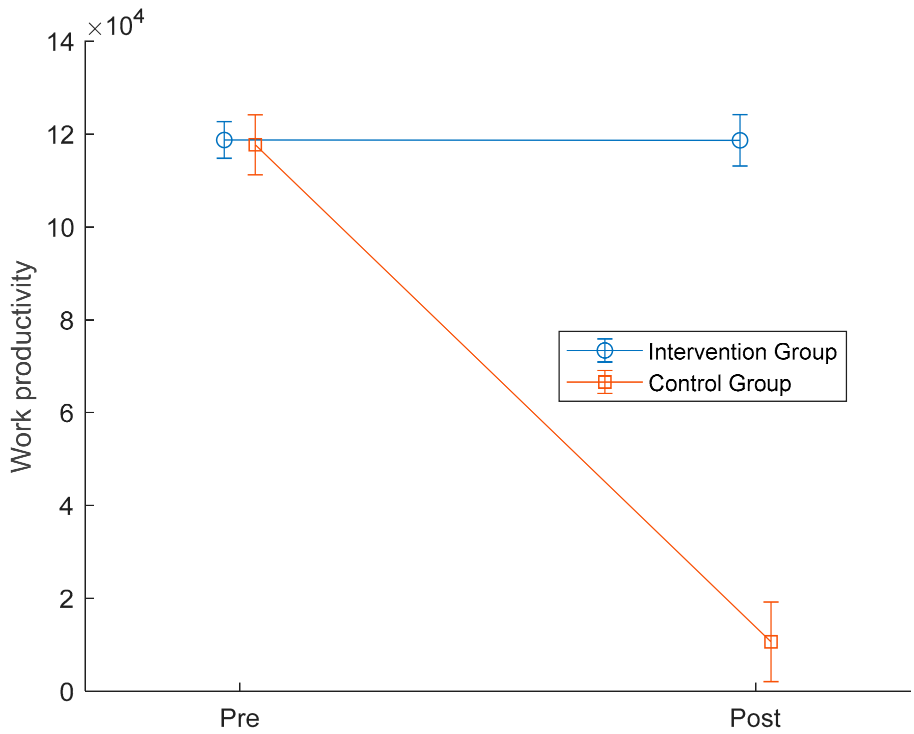

Figure 4. Line graph of the average productivity for participants in the intervention group (blue color) and control group (orange color) for pre- and post-CCT (error bars represent standard error of the mean).

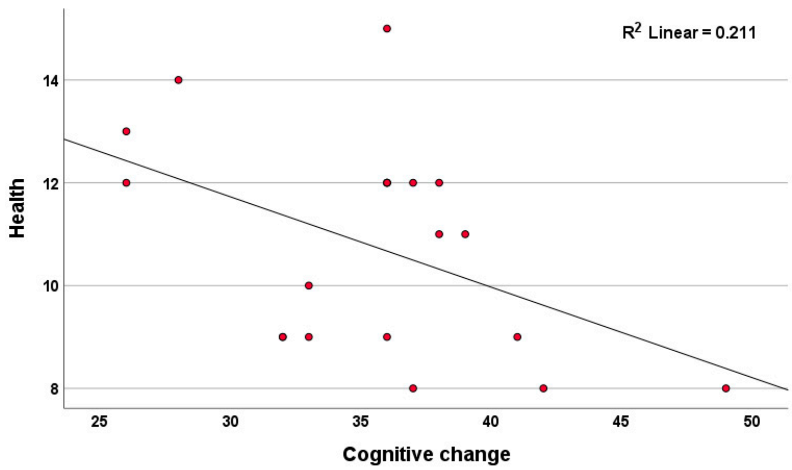

Figure 5. Scatter plot for the self-evaluated cognitive change scores and health status for the control group.

On a four-point scale, a one-sample *t*-test showed that participants from the intervention group were slightly more satisfied than average with the CCT ($t = -1.68$, $p = 0.11$) and highly satisfied with the administration of the CCT ($t = -3.34$, $p = 0.004$).

4. Discussion

The current study demonstrates positive outcomes showing that a short course of CCT, conducted in an office setting during working hours, is effective for middle-aged workers in terms of enhancing aspects of their fluid cognitive functions while maintaining work productivity. Thus, the outcomes support our first hypothesis that CCT will enhance cognitive functioning, as evidenced by moderate but significant performance improvements on the VF-L measure related to executive functioning. We cannot accept the second hypothesis since we did not observe improved self-reported well-being or life satisfaction after the CCT in the intervention group. We also accept the third hypothesis that CCT administered during regular work hours did not decrease the productivity of middle-aged workers involved in CT. These workers, performing moderately demanding jobs during the three-month engagement in CCT, did not show any decline in productivity. On the contrary, during the period of CCT administration, the older workers in the passive control group showed decreased productivity. Furthermore, those employees in the control group who self-evaluated increased difficulty in their cognitive functioning also reported a significant decline in their overall health status. In other words, CCT appears to have a sustaining or perhaps protective effect.

4.1. CCT and Cognitive Functioning

Findings from this study are comparable to those reported by Muller et al. [40], which showed that employees improved in executive functioning after CCT. They are also partially aligned with Gajewski [38], who reported improvements in task switching among manufacturing workers engaged in repetitive tasks. Additionally, our study's findings are consistent with Marusic [44], which reported improved executive functioning in healthy older adults after CCT during a 14-day bed rest period.

It is exciting to see improvement in VF-L in middle-aged employees after CCT. However, an intriguing question arises from this finding: can this improvement be considered a near or far transfer from two perspectives: (i) the task utilized in CCT, and (ii) the neurocognitive instrument used to evaluate executive functioning? Specifically, CCT with virtual maze navigation is not based on any specific cognitive function but is rather task-based, encompassing a variety of cognitive functions, primarily working memory and executive functioning, for proper maze navigation. One can argue that maze navigation engages multiple cognitive functions, including attention, working memory, decision-making, and executive functioning. This statement is supported by studies showing strong correlations between spatial navigation performance, both in-person and online in virtual reality, with spatial memory [69], episodic memory [70], and executive functioning [71,72]. Thus, adopting the notion that near transfer encompasses the same construct in the training task and the cognitive test [73], the improved performance on VF-L can be, or should be, considered near transfer.

The claim that improved performance on VF-L shows near transfer must also consider the similarity of the task and test instrument in terms of their delivery and testing modality. Somewhat surprisingly, the greatest effect of the virtual maze navigation training, a purely visuospatial task, occurred on the VF-L test, which is a purely verbal test measuring working memory and executive functioning. Our previous study with virtual maze navigation CCT [74] also showed an increase in executive functioning, but it was measured with the TMT-B test, which is also primarily a visuospatial task. Therefore, our finding of significantly increased performance on VF-L could also be considered far transfer.

Another intriguing finding in our study is the difference between the two verbal fluency tasks, VF-L and VF-S. After CCT we observed the transfer in VF-L but not VF-S. Despite their traditional wide adoption in clinical and diagnostic practice, there is ongoing scientific discussion regarding the relationship between semantic and letter verbal fluency tasks and what brain functions underlie their performance. In the VF-S task, the constraint is that all produced words should belong to one semantic category (e.g., animals). In the VF-L task, the constraint is that all produced words should start with one letter (e.g., S). In general, verbal fluency tasks engage multiple neurocognitive functions, including executive functions, memory, and language components. The difference between the two tasks is often explained by the fact that in VF-S, one can follow associations for word production, whereas in VF-L, associations must also be monitored for their phonemic fit, which places additional executive function demands. In this study, the significant finding in letter fluency may further emphasize the role of executive functioning.

In this study, it is also noticeable that there is a lack of transfer (i.e., improved performance) in memory testing with AVLT and in the speed of processing as measured by the Coding and Comparison tests. In the AVLT Delayed Recall and Coding tests, we observed significant improvements in both the intervention and control groups. The most parsimonious explanation could be that delayed recall and processing speed are susceptible to practice effects and/or that the underlying neural networks underlying these two tasks are not specifically involved in training with virtual maze navigation and therefore did not improve primarily in the CCT group.

The initial publication of CCT within the workforce by Borness et al. [37] did not support the effectiveness of CCT in an office-based workforce but rather noted that documentary watching in the active control group appeared a more effective intervention. It is very likely that this initial report dampened further attempts to conduct CCT with an older workforce. Therefore, it is very important that our study adds to the CCT workplace literature with older, middle-aged workers in several regards: its (i) demonstrating that CCT is feasible in the workplace and can improve some cognitive functions, albeit to a limited degree; (ii) indicating that devoting regular work hours to CCT does not cause a decline in productivity (e.g., highlighting the importance of a adding productivity measurement to the study); (iii) showing that CCT maintains performance on the simple attentional test, and that the self-evaluation of cognitive abilities after the CCT was at the same level as Pre-CCT in the intervention group while there was an indication of decline in the control group; and (iv) most importantly, confirming that CCT was not associated with any negative effects during or after the training.

4.2. CCT and Work Productivity

Results also showed that the CCT affected productivity not by increasing it, but by maintaining it. Productivity outcomes clearly demonstrated that employees in the intervention group maintained their productivity, while the productivity of participants in the control group significantly dropped. The decreased productivity among the control group participants is difficult to interpret. The most likely explanation for such an outcome is that the period at the end of 2022 was challenging for this agency due to an increased workload related not only to completing outstanding cases but also to pension and disability legislative changes that needed to be incorporated into the work process. Thus, it is very likely that toward the end of 2022, there was increased stress in the workplace due to the pressure related to finishing certain tasks and adapting to legislative changes. The key point is that participants in the intervention group maintained the same level of productivity despite dedicating two hours of their weekly working quota to CCT. It is also important to note that participants from the intervention group rated their satisfaction with the CCT process and its administration above average. This outcome is significant for future studies, conveying the message that the time devoted to CCT is unlikely to decrease the productivity of employees engaged in it.

4.3. CCT and Well-Being

An unexpected pattern was observed between the association of self-reported changes in cognitive performance during the three month period of the administration of CCT and self-evaluated health status and well-being. Participants from the control group who reported a worsening of their cognitive functioning showed a lower self-evaluated health status (Figure 5), while participants from the intervention group did not report any decline in their health-status and well-being. These findings may suggest that the CCT's effects are not only the improvement of cognitive performance but also the preservation and maintenance of health and well-being while maintaining productivity at the same level. To the best of our efforts, we could not find publications in this regard.

None of the studies on the effectiveness of CCT for employees have investigated the effects of CCT on participants' well-being, life satisfaction, or health status. According to Nedeljko et al. [75], digital technologies have the potential to improve the quality of working life for older workers [75]. Thus, our study is the first to report the effects of CCT on older employees' well-being. Employees in the intervention group reported their health status and well-being as unchanged after CCT, while participants in the control group expressed a significant decline. The closest comparisons regarding the effectiveness of CCT on self-evaluated life satisfaction can be found in reports on the effectiveness of CCT with older adults. A few studies have reported improved self-evaluated well-being after CCT [76]. Similarly, Gordon et al. [77] reported that an online brain training program, MyBrainSolutions, positively affected well-being. The maintenance of well-being after CCT is consistent with findings reported in a review article by Sheng et al. [78], who noted significant improvements in well-being in older adults with subjective memory complaints. However, there are a few other meta-analyses investigating the effects of commercial video and action video games as tools for enhancing individuals' well-being, particularly in terms of cognitive and emotional enhancement [79–81].

Our findings are also in line with conclusions from a meta-analysis that reviewed publications related to the effectiveness of interventions for improving subjective well-being among workers [82]. They reported that mindfulness and cognitive-behavioral approaches may be useful for improving employees' well-being. We can now add that CCT can also help maintain older workers' well-being. Furthermore, a systematic literature review of cognitive intervention studies among individuals with mild cognitive impairment [83] suggested that some interventions were equally or more effective on subjective measures of mood and quality of life than on objective measures of cognitive domains. Therefore, an improvement or even no change in well-being and life satisfaction scales at the end of the CCT might be considered a desirable treatment outcome. In other words, the benefits of CCT may translate into the daily functioning and mood of the participants, which should be the ultimate goal of any cognitive program or intervention. This also supports the argument that CCT in the workplace may have more distal/far-transfer effects on workers and their life's well-being.

4.4. Limitations of the Study

Despite its strengths, our study has several limitations. In addition to the small sample size, our sample was heavily biased by female participants. The use of a passive control group could also be considered a limitation, but due to the limited training staff, adding an active control group was not feasible. The testing of CCT efficiency for the older workforce was also limited because we focused exclusively on case managers, without including other job roles at ZPIZ in terms of complexity and educational level. It should be noted that ZPIZ indicated that the case manager was the most frequent job requiring a master's degree level for education. Furthermore, our study lacks additional long-term post-CCT evaluations of cognitive and emotional outcome measures. For instance, Borness et al. [37] reported improved quality of life, psychological well-being, and decreased stress levels six months after the CCT, albeit in the active control group. Additionally, in our study, we evaluated cognitive functioning based on group testing, which not only limited the selection of neuropsychological tests for cognitive evaluation but also posed challenges for the standardized administration and supervision of cognitive testing. The administration of online cognitive tests would have been a better approach, but at the time of the CCT, we did not have such tests available (e.g., the Slovenian version of computerized batteries like NIH Toolbox or CogState). Future research may explore how these listed shortcomings might affect specific cognitive domains and vice versa. The lack of findings in other areas was unexpected and may warrant expanding our training battery in the future. Future studies could consider a multimodal approach that incorporates other important cognitive dimensions as well as aspects of mobility and emotional well-being.

5. Conclusions

Our study, conducted in an office setting during regular office hours, contributes to the general view that CCT can be useful and effective for the older workforce and does not represent a burden for either employers or employees. Consistent with our expectations, CCT was effective in improving aspects of executive functioning while maintaining work productivity. Thus, CCT may be an important tool in business to improve adaptability and potentially attenuate cognitive decline in the aging workforce. Future research can develop shorter, more focused CCT or multimodal short interventions that could be offered as brief units during breaks or even work hours, supported by both employers and employees [84]. In other words, CCT could enhance self-perceived health, improve emotional functioning, and increase cognitive functioning, and job satisfaction, leading to maintained or even improved productivity in the older workforce. This may, in turn, prolong employment and prevent premature retirement as the workforce ages.

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Data Availability Statement: Data will be available by request to the first author after the conclusion of her PhD study.

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