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Effect of 3D-MOT training on the execution of manual dexterity skills in a population of older adults with mild cognitive impairment and mild dementia

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ABSTRACT

Computerized cognitive training tools are an alternative to preventive treatments related to cognitive impairment and aging. In this study, the transfer of 3D multiple object tracking (3D-MOT) training on manual dexterity concerning fine and gross motor skills in 38 elderly participants, half of them with mild cognitive impairment (MCI) and the other half with mild dementia (MD) was explored. A total of 36 sessions of the 3D-MOT training program were administered to the subjects. The Montreal Cognitive Assessment (MoCA) test was used to assess the baseline cognitive status of the participants. Two batteries of manual motor skills (GPT and MMDT) were applied before and after the 3D-MOT training program. The results showed an interaction effect of training and improvement in manual dexterity tests, from the first training session until the fifteenth session, and after this range of sessions, the interaction effect was lost. However, the training effect continued to the end of the thirty-six-session program. The experimental results show the effect of cognitive training on the improvement of motor skills in older adults. This type of intervention could have a broad impact on the aging population in terms of their attention, executive functions, and therefore, their quality of life.

KEYWORDS

Cognitive training; manual dexterity; mild cognitive impairment; mild dementia; multiple objects tracking

Introduction

Aging is a gradual and continuous process of natural change accompanied by a decline in physical and mental abilities. Rates of physical limitations in activities of daily living (ADL) increase parabolically with aging. At a young age, limitations in usual activities increase from 6.5% to 16.9%. At age 65, the trend rises to 26.9% and again to 45.3% at age 75 and older (Adams et al., 2013; Manini, 2011). The probability of losing mobility doubles with each 10-year increase in age after 65 (Guralnik et al., 1993).

It is estimated that between 6 and 22% of people over 65 have Mild Cognitive Impairment (MCI) or Alzheimer's disease (AD), and 50% of those over 85 years have developed AD (Ataollahi Eshkoo et al., 2015; Carment et al., 2018). MCI can be considered a stage between normal cognition and dementia, while still not fully understood, the cognitive decline goes beyond the expected changes inherent to normal aging (Apostolo et al., 2016; Knopman & Petersen, 2014; Petersen et al., 1997). While this deterioration is noticeable to the individual or those around them, this decline does not meet the criteria for dementia. Initially, it was considered that the main domain affected in MCI was memory, currently described as the amnesic type, it is now

understood that one or more cognitive domains (non-amnesic type) may be affected in MCI (Petersen et al., 1999). The amnesic type is associated with an increased risk of developing AD (Petersen, 2011). Although there is no specific test to confirm the diagnosis of MCI, it is usually made by a thorough neurological and neuropsychological examination together with, in some cases, the use of analytical tests and brain imaging tests. The importance of early detection and follow-up of MCI lies in the high risk of individuals developing dementia, which has been reported to be 10–15% after five years of follow-up (Petersen, 2016).

Dementia is not a specific disease; it has been defined as any impairment of cognition significant enough to interfere with ADL. According to the fifth edition of the Diagnostic and Statistical Manual of Mental Disorders (DSM-5), dementia is categorized as a Neurocognitive Disorder (NCD). NCDs have been classified into six principal domains of cognitive function—complex attention, executive function, learning and memory, language, perceptual-motor function, and social cognition (APA, 2022; Sachdev et al., 2014).

Although the fundamental causes of age-related cognitive decline are incompletely understood, psychophysical and neuropsychological evidence suggests that a significant

contribution comes from poorer signal-to-noise conditions and the function of the regulated neuro-modulatory system of the brain (Avery & Krichmar, 2017). Brain plasticity and behavior are dynamic processes modified by experience in response to intrinsic and extrinsic factors throughout life. Experience-dependent plasticity promotes changes in brain structure and function depending on the type of experience attempted through specific cognitive training. Interventions in healthy older adults, post-stroke, MCI, MD, and dementia patients using cognitive training have proven to be a valuable tool to improve and recover cognitive domains (Ballesteros et al., 2015; Kerr et al., 2011). Examples related to sensorimotor training of older adults showed improvement in the Digit Symbol test and the Trail Tracing Test (Bugos et al., 2007) as well as in executive functions (Bugos, 2019) and memory (Cheung et al., 2018). In bilinguals and musicians, time-locked brain responses related to inhibitory control were improved; assessed with event-related brain potentials in a visual go-no-go task, particularly in the N2 and P2 waves (Moreno et al., 2014). These studies used intervention programs with a domain-specific activity and measured the effect on cognitive functions before and after training.

Another type of intervention is computerized cognitive training, also applied to older adults and populations with neurodegenerative diseases (Assed et al., 2016; Yu et al., 2009). These investigations suggest that cognitive stimulation can help improve psychosocial functioning, including depressive symptoms and various neurocognitive aspects (Cotelli et al., 2012; Hill et al., 2017; Tardif & Simard, 2011).

There is compelling evidence that part of the changes related to manual dexterity slowness includes loss of grip strength, slowing of movements, loss of precision, coordination, and eye-hand coordination (Seidler et al., 2010). In addition, cognitive decline is believed to affect manual dexterity when some of the cognitive domains involved are attention, processing speed, and short-term memory; this decline can impact the quality of life of those living with MCI and MD and, in the long term, lead to loss of functionality (Colella et al., 2021; Vasylenko et al., 2018).

One of the most active areas in visual cognition research has been the study of attention. A perceptual-cognitive task proposed for the first time in 1988 by Pylyshyn and Storm (1988) to study multifocal attention and complex motion information is known as multiple object tracking (MOT). MOT is a visual task where the observer tracks specific objects moving around a space while ignoring other physically indistinguishable objects, called distractors (Alvarez and Scholl, 2005). The MOT task was created with several distinctive elements to test the visual indexing hypothesis. According to the visual indexing theory, some indexes may be connected to an environment object that can be seen, and each index maintains its connection to the item even when it moves or changes appearance (Fencsik et al., 2007). The MOT task needs continuous sustained attention for a considerable amount of time, in contrast to many other paradigms that call for participants' quick attentional changes.

Using the MOT task enables researchers to examine various visual attentional characteristics, such as selectivity,

capacity limitations, and persistent processing effort (Styrkowiec & Chrzanowska, 2018). Some studies have shown that this task can improve five domains, namely: selective attention (the ability to attend to/focus on/cognitively process a given thing), divided attention (the ability to selectively attend to multiple loci at once), sustained attention (the ability to maintain selective attention over time), inhibition of attention (the ability to not attend/focus on/cognitively process a given thing), and information processing speed (the time needed to integrate perceptual stimuli consciously) (Legault & Faubert, 2012; Parsons et al., 2016; Romeas et al., 2019). Cognitive training (Lövdén et al., 2012; Stine-Morrow & Basak, 2011) has positive effects on functional or structural changes in the brain, highlighting that combined training enhances brain stimulation (Park & Bischof, 2013; Park et al., 2021; Parsons & Faubert, 2021). Despite these encouraging results, there is relatively little evidence that task-based training induces a substantial change in cognitive processes or functions that transfers to everyday life.

While cognitive decline is inevitable with aging, training interventions can delay it or improve some skills related to attention and psychomotor speed (Park et al., 2014; Spaner et al., 2019; Zelinski, 2009). Spaner et al. (2019) observed enhanced selective attention, psychomotor speed, and cognitive flexibility in healthy older adults after 3D-MOT training through Stroop test scores. The Stroop test has been supported as an accurate measure of attention and cognitive flexibility (Barbarotto et al., 1998; Bench et al., 1993). Previous works have suggested that cognitive training may benefit other laboratory-based cognitive tests (near transfer) but have limited utility for real-world performance (Flegal et al., 2019; Harris et al., 2020); this is what is known as far transfer, namely, if the training is transferred beyond the laboratory, to new tasks and contexts of real-world (Sala & Gobet, 2019). However, this topic is still controversial. According to a critical systematic review by Vater et al. (2021) on the 3D-MOT task known as Neurotracker, the literature shows certain limitations of this tool, for example, a total absence of preregistered studies, absence of the far-transfer effects or evidence not very solid or not appropriate, and methodological concerns in published studies.

This study aims to examine the effect of 3D-MOT training after 36 sessions on the Grooved pegboard test (GPT) and the Minnesota Manual Dexterity Test (MMDT) in older adults with mild cognitive impairment and mild dementia. It was hypothesized that the learning curves of the 3D-MOT training would score higher for the MCI group than for the MD group because of cognition status. Furthermore, the effect of the training 3D-MOT using repeated measurements would show a better execution in two manual dexterity tests in both groups without differences between groups since the same transfer effect is expected at the end of training (Ashendorf et al., 2009; de Paula et al., 2016; Hoogendam et al., 2014).

Materials and methods

This is an exploratory, longitudinal, prospective, and quasi-experimental study.

Participants

Inclusion criteria

Older adults (≥ 65 years) with a clinical diagnosis of MCI or MD. No evidence of depressive disorders or other psychiatric conditions in their clinical history.

Exclusion criteria

Older adults with severe hearing and/or visual deprivation, impaired fine or gross motor skills, Parkinson's disease, arthropathies, amputation of some limbs, and uncontrolled comorbidities.

The diagnosis of MCI and MD was previously made in the neurology consultation of our hospital; half were diagnosed with MCI according to international clinical criteria considered in The Key Symposium celebrated in Stockholm, Sweden, in 2003 (Winblad et al., 2004), a meeting that resulted in the publication of the international criteria for MCI. The other half of the subjects were diagnosed with MD due to Alzheimer's disease according to the NIA-AA and NINDS-AIREN criteria (McKhann et al., 2011; O'Brien & Thomas, 2015).

Of a total of 168 participants (≥ 65 years), only 38 completed the study. Of the total eligible older adults, 123 were excluded, 121 of them for having one or more exclusion criteria and two for missing data. A flow chart of the selection of the study population is shown in Figure 1.

The research protocol was approved by the ethics and research committee of the institution where the study was held, under the tenets of the Declaration of Helsinki, and all participants provided written informed consent.

Measures and tests

Functional assessment

The Lawton Instrumental Activities of Daily Living (IADL) Scale and the Barthel Index (BI) for Activities of Daily Living (ADL) were applied to evaluate the functional capacity of older adults. The Lawton IADL Scale is an instrument to assess independent living skills; it takes 10 to 15 min to administer and covers eight functional domains, with a summary score from 0 (low functionality) to 8 (high functionality) (Graf, 2008; Lawton & Brody, 1969). The BI is a generic measure that assesses the patient's level of independence concerning performing some basic ADL. The BI assesses 10 aspects of ADL with scores ranging from 0 (totally dependent) to 100 points (totally independent) (Mahoney & Barthel, 1965). In addition, the Geriatric Depression Scale (GDS) was used to rule out depression (Yesavage et al., 1982). The GDS is one of the most widely used self-assessment scales of depression in geriatric populations, with a sensitivity and specificity of 82–90 and 75–94%, respectively (Kørner et al., 2006). The Charlson Comorbidity Index (CCI) is considered the gold standard for measuring and assessing comorbidity in clinical research based on the International Classification of Diseases (ICD) (Charlson et al., 1987). In general, the CCI score is considered as 0–1 pts for patients with no comorbidity, 2 pts with low comorbidity, and >3 pts with high comorbidity. In this work, the CCI was applied only as a tool to verify functional impairment in the participants.

Montreal Cognitive Assessment (MoCA version 7.1)

The Montreal Cognitive Assessment (MoCA) test was applied to assess the baseline cognitive status of older participants. This brief, sensitive and specific screening tool

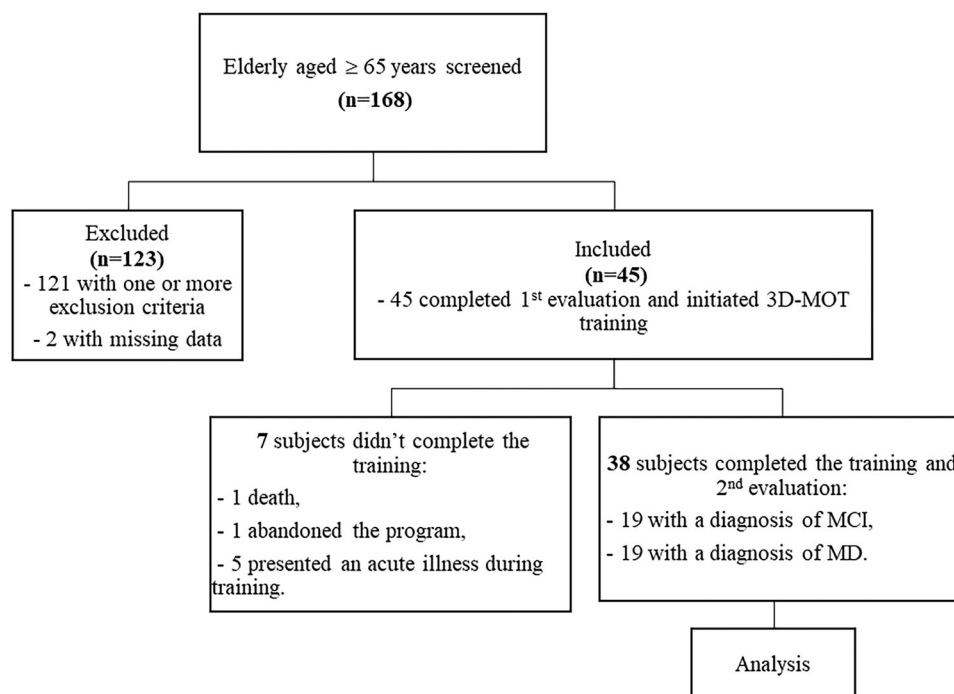


Figure 1. Flow chart of patient recruitment during the study.

detects MCI and MD (Gauthier et al., 2006; Hobson, 2015; Nasreddine et al., 2005). It assesses multiple aspects of executive functions, such as visual-spatial abilities, attention, concentration, working memory, language, and orientation (Aguilar-Navarro et al., 2018; Julayanont & Nasreddine, 2017). It is widely used around the world and translated into 36 languages and dialects. The total possible score is 30 points, and it is administered in 10 min. The score range for MCI is 19–25.2 and for Alzheimer's dementia 11.4–21.

Grooved Pegboard Test (GPT)

The GPT is a standardized test that assesses hand-eye coordination, psychomotor speed, and manual dexterity control, requiring sensory-motor integration (Strauss et al., 2006). This test requires more complex visual-motor coordination than typical pegboard tests; psychologists consider it the most used test to assess motor function (Vasylenko et al., 2018). Previous studies have demonstrated associations between the GPT with various diagnoses that have primary or secondary fine-motor issues (Bezdicek et al., 2014; Kanj et al., 2022; Ruff & Parker, 1993; Schmidt et al., 2000; Tolle et al., 2020).

Minnesota Manual Dexterity Test (MMDT)

The MMDT (Lafayette Instrument Company) is used to measure hand-eye coordination, gross motor skills of the arm, and hand dexterity (Desrosiers et al., 1997; Tesio et al., 2016). The person's abilities are scored relative to speed and correct execution of two subtests: The placing test (MMDT-P) and Turning Test (MMDT-T) (Wang et al., 2018). These two tasks should be completed as quickly as possible, so a high score indicates a lower capacity to execute the task that requires hand dexterity. This test is recommended for use with older adults (Duncan et al., 2015; Yancosek & Howell, 2009).

3D-Multiple Object Tracking (3D-MOT)

The training program used is called Neurotracker. Neurotracker (CogniSensAthletics, Inc., Montreal, Quebec, Canada) is a computing tool for tracking multiple objects in three dimensions (3D). The training involves different cognitive functions, such as attention, processing speed information, working memory, and visual perception (Faubert, 2013; Parsons et al., 2016; Trick et al., 2005).

Neurotracker training (NT) consists of a visual task in which a person tracks two numbered spherical targets between six identical distractors, during which time she/he must keep their gaze fixed on a central point of the screen using 3D stereoscopic glasses. Each training block consists of 20 trials, and a speed threshold in m/s is obtained at its end. The initial speed of the spheres is 0.3 m/s, and it increases or decreases by 0.05 log according to a one-up-one-down staircase procedure (Levitt, 1971), that is, after a correct answer, the target's speed shifts by 0.05 log units and decreases by the same proportion after each incorrect answer, resulting in a threshold criterion of 50% (Harenberg

et al., 2016; Legault & Faubert, 2012; Parsons et al., 2016; Tullo et al., 2018). Older adults completed 36 sessions, divided into four sessions per day, three times a week.

Statistical analysis

The statistical analyses were performed with the Statistical Package for the Social Science, SPSS version 26 (IBM, Armonk, NY, USA). Qualitative variables were expressed as percentages and quantitative variables as means and standard deviations. In addition, descriptive statistics were performed with the *t*-test for independent groups to compare age, body mass index, education, Lawton Brody, Barthel, Geriatric Depression Scale, and MoCA tests, while Gender and CCI were compared with the Chi-square test.

We expected a better performance in the 3D-MOT training in the MCI group compared with the MD group. To know the trend of the learning curve across the sessions, thirty-six 3D-MOT sessions were carried out by participants independently for each group. The first 3D-MOT training session was used as a covariate, and the subsequent sessions were divided into seven segments, each of five sessions. To study the effect of 3D-MOT training during sessions on motor tasks, an average value of the 3D-MOT scores per segment was made, and this average value was compared between pairs of subsequent segments. Statistical differences were found between segments one and two, two and three, but there were no significant differences between segments three and four, four and five, five and six, and six and seven.

The central hypothesis of this study concerned the transfer effect of the 3D-MOT training on the manual dexterity test. Therefore, we expected interaction between the 3D-MOT and each manual dexterity test separately and no effect on the covariate first session of the 3D-MOT on the dexterity tests or in the between-group analysis for the MCI and MD groups. To conduct these tests, the GPT, MMDT-T, and MMDT-P scores were transformed to fit a normal distribution: reciprocal transformation was applied to GPT and MMDT-P, and logarithmic transformation was applied to MMDT-T. Then we performed a two-way repeated-measures analysis of variance (ANOVA) in 3D-MOT sessions and manual dexterity tests using the transformed scores as repeated measures and diagnosis (MCI and MD) as a between-group factor. To carry out the repeated ANOVA analysis, the average value of segment one was called the 3D-MOT initial average value, and the average value of segment seven was called the 3D-MOT final average value.

Finally, the manual dexterity tests were hypothesized to improve after 3D-MOT training. For that matter, GPT, MMDT-T, and MMDT-P were compared using the Wilcoxon signed rank test before the 3D-MOT training and one month later at the 3D-MOT training period end.

A rational polynomial function based on extrapolation of the measured data in the learning process of the 3D-MOT task was used. This method uses the least squares fit of a rational polynomial model to describe the transient

3D-MOT score's data and also gives an analytical expression of the 3D-MOT's learning process (Wong-Loya et al., 2015). The function has the form $(a+bN)/(1+cN)$, and it was used for the learning curve fits, where N is the number session, a , b , and c are the constants to be determined. The ratio b/c gives the asymptotic 3D-MOT score limit.

Table 1. Demographic, functional, and cognitive characteristics of MCI and MD groups.

	MCI $n = 19, M \pm SD$	MD $n = 19, M \pm SD$	df	t	p -Value
Age (years)	74.11 $\pm$ 6.47	75.74 $\pm$ 6.15	36	-.796	.431
BMI	23.99 $\pm$ 3.46	23.52 $\pm$ 2.21	36	.499	.621
Education	8.95 $\pm$ 5.9	4.26 $\pm$ 1.45	36	3.360	.0019*
Lawton Brody	7.26 $\pm$ 0.93	6.05 $\pm$ 1.39	36	3.146	.0033*
Barthel	87.11 $\pm$ 6.08	82.11 $\pm$ 7.13	36	2.325	.0258*
GDS	1.79 $\pm$ 1.75	2.79 $\pm$ 1.44	36	-1.925	.062
MoCA	20.79 $\pm$ 2.02	14.32 $\pm$ 3.54		6.921	<.001*
				χ^2	
Gender (% female)	73.7%	84.2%	1	.633	.426 [†]
CCI			2	1.556	.459 [†]
0 (n , %)	9 (47.4)	11 (57.9)			
1 (n , %)	8 (42.1)	6 (31.6)			
2 (n , %)	2 (10.5)	2 (10.5)			

M: mean; *SD*: standard deviation; *df*: degrees of freedom; MCI: mild cognitive impairment; MD: mild dementia; BMI: body mass index; GDS: Geriatric Depression Scale; CCI: Charlson Comorbidity Index; MoCA: Montreal Cognitive Assessment.

*Significant *t*-test for independent groups, $p < 0.05$.

[†]Chi-square test.

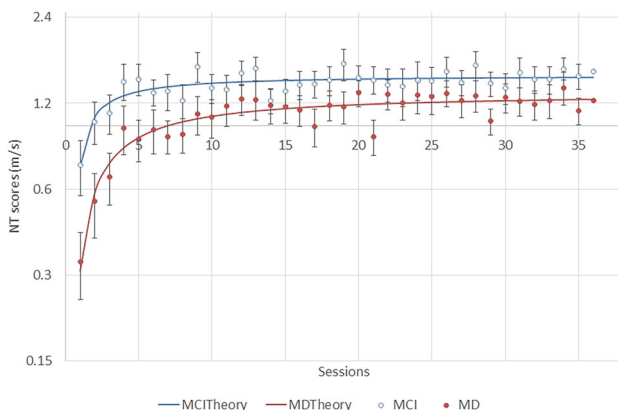


Figure 2. Average speed threshold scores as a function of 3D-MOT training sessions for MCI and MD group. Error bars represent SEM.

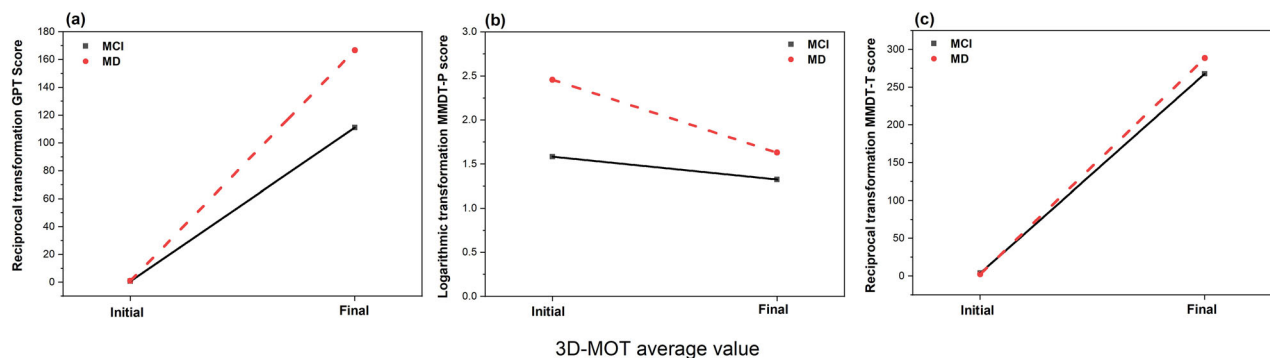


Figure 3. Profile graphics of interaction of manual dexterity test and 3D-MOT average measures on (a) estimated GPT score, (b) logarithmic transformation MMDT-T score, and (c) reciprocal transformation MMDT-P score.

Wilcoxon tests were performed to determine if the 3D-MOT speed threshold distributions of MCI and MD were significantly different.

Results

Table 1 shows the functionality scales and demographic characteristics of MCI and MD groups.

Figure 2 shows the 3D-MOT scores as a function of the number of sessions for each group. It can be observed that the learning curve increases considerably in the first five sessions, being more evident for the MD group. Around the 15th session, the learning rate, measured by the cumulative summation of the slopes, reached 84% (MCI) and 90% (MD) of their total value of 100%. This means that the learning has practically reached the consolidation training regimen; the learning rate is low beyond this session. The 3D-MOT sessions' scores showed significant statistical differences at the end of the training ($p < 0.001$).

For the MCI group, the parameters of the rational function are $a = -2.557$, $b = 6.272$, $c = 4.16$ and $a = -0.2925$, $b = 0.7899$, $c = 0.6023$ for the MD group. Both learning curves reach a plateau of around 1.6 m/s for the MCI group and 1.4 m/s for the MD group.

Effect of 3D-MOT training on the GPT, MMDT-T, and MMDT-P tests

Figure 3 shows the profile graphics of the interaction of transformation scores of manual dexterity tests (a) GPT, (b) MMDT-P, and (c) MMDT-T with the 3D-MOT initial and final average values. The two-way repeated ANOVA showed a statistically significant effect on the transformed GPT score by the 3D-MOT training program interaction (session $\times$ GPT), $F(1,35) = 15.191$, $p < 0.0001$, $\eta^2 = 0.303$. Also, a significant main effect was observed in all variables with training sessions.

The interaction effect of the GPT test with the 3D-MOT training occurs in the 3D-MOT-initial average value (Figure 3a), where the MD group was slower than the MCI group, represented by higher scores. There was a main effect between this test's initial and final transformed scores. As expected, the covariance effect was significant only on 3D-MOT training and not for the manual dexterity test: $F(1,35) = 10.299$, $p = 0.003$, $\eta^2 = 0.227$, and not

significant for the GPT, $F(1,35) = 2.790$, $p = 0.104$, $\eta^2 = 0.074$. The ANOVA analysis between groups was not significant $F(1,35) = 1.462$, $p = 0.235$, $\eta^2 = 0.040$.

Similar to GPT results, the repeated measures ANOVA showed a significant interaction of sessions $\times$ MMDT-T, $F(1,35) = 31.655$, $p < 0.0001$, $\eta^2 = 0.475$, and for the interaction session $\times$ MMDT-P, $F(1,35) = 15.341$, $p < 0.0001$, $\eta^2 = 0.305$.

Additionally, there was an interaction effect between both MMDT tests and the 3D-MOT initial and final average value, in both groups according to the ANOVA tests: MMDT-T, $F(1,35) = 1237.160$, $p < 0.0001$, $\eta^2 = 0.972$, and MMDT-P, $F(1,35) = 83.960$, $p < 0.0001$, $\eta^2 = 0.706$. The transformed values of the manual dexterity tests, GPT and MMDT, improved at the end of the 3D-MOT training in both groups, reducing both tests' execution time. This improvement showed a dependence on training regardless of the study population. A relevant main effect on MMDT-P was observed, $F(1,35) = 15.398$, $p < 0.0001$, $\eta^2 = 0.306$, but in the complementary Minnesota sub-test, MMDT-T the main effect was not significant $F(1,35) = 3.663$, $p = 0.065$, $\eta^2 = 0.094$. The between-group effects were also not significant for MMDT-T [$F(1,35) = 1.380$, $p = 0.248$, $\eta^2 = 0.038$], and MMDT-P [$F(1,35) = 1.479$, $p = 0.232$, $\eta^2 = 0.041$].

In all cases, a slower performance was observed in the MD group than in the MCI group. However, the interaction effect was observed only in the MMDT-T test at the 3D-MOT initial training (see Figure 3c) but not in the MMDT-P test (see Figure 3b).

Table 2 shows the non-transformed scores of manual dexterity tests (GPT, MMDT-T, and MMDT-P) at the beginning and the end of the thirty-six sessions of the 3D-MOT training program.

Discussion

Participants were predominantly female, 73.7 and 84.2%, in the MCI and MD groups, respectively. As expected, those in the MCI group had more years of education than the MD group ($p = 0.0019$) and scored higher on the Lawton IADL and BI scales ($p = 0.0033$ and $p = 0.0258$), respectively, and as such had preserved independence and physical functionality. Years of education are one of the main factors of cognitive reserve (CR) associated with the protective effect on the progression of MCI to dementia (Allegri et al., 2010;

Nelson et al., 2021). Our results show that the years of education in the MCI group is almost double that in the MD group, which could contribute to the differences found in their functional capacity and cognitive performance (Sobral et al., 2015).

The 3D-MOT training and manual dexterity tests (GPT and MMDT with both subtests) results in older adults showed a better performance in participants of the MCI group than in the MD group. However, all subjects benefited from motor manual dexterity skills at the end of the training paradigm.

The 3D-MOT has been used in several studies to improve reaction times, psychomotor speed, and neurocognitive processes, such as cognitive flexibility and selective attention in different populations. For example, Spaner et al. (2019) reported improved motor function as part of the Trail Making Test and the Stroop test as psychomotor speed. In sports, reaction time improvement was found when 3D-MOT was combined with a second motor task in badminton athletes (Romeas et al., 2019). However, there is not always a positive effect on motor skills after training with the 3D-MOT; the transfer effect was not observed in children with atypical mild traumatic brain injury (Vater et al., 2021).

Nonetheless, our study reduced the time required to perform both, GPT and MMDT tests significantly after training. After the 3D-MOT training sessions, this improvement could be explained by the effect on attention, eye movement coordination, and eye-hand coordination since the motor skill tests were applied before and after 36 sessions (~1 month). However, the likelihood of a learning effect influencing the results is low since the test requires memory, attention, and processing speed for its performance. Tolle et al. (2020) studied that in individuals with Parkinson's disease, completing the motor task involved a serious need for cognitive preservation. Other studies have reported the transfer between cognitive domains; however, until this study, the impact of cognitive training on gross and fine motor manual dexterity had not been evaluated despite evidence of the relationship between both (Greenwood & Parasuraman, 2016). The improvement in manual dexterity tests can also be attributed to experience-dependent plasticity, as demonstrated in other studies where piano instruction, moving music, and bimanual coordination improved executive functions during and at the end of intervention programs. In this case, experience-dependent plasticity with the 3D-MOT affected the execution speed improving motor skills in subjects with MCI and MD (Bugos, 2019; Bugos et al., 2007; Kerr et al., 2011; Moreno et al., 2014).

There is a relationship between "psychomotor" tasks and neuropsychological functioning, as reported by Ashendorf in 2009 (Ashendorf et al., 2009), where a population of older adults showed poor performance in motor skills tests and had lower scores in applied cognitive tests.

Culham et al. (1998) investigated for the first time the neuronal activation involved during multi-object tracking by functional magnetic resonance imaging (fMRI). They included two groups of subjects under two conditions: (1) Attentive Tracking (With attention), Distinguishing

Table 2. Manual dexterity scores of tests: GPT and MMDT, pre and post the 3D-MOT training from MCI and MD groups.

Group	Test	Pre-training (s)	Post-training (s)	Z	p-Value
		Me (IQR)	Me (IQR)		
MCI $n = 19$	GPT	138 (65)	93 (49)	-3.824	<.0001*
	MMDT-P	250 (68)	230 (50)	-3.622	<.0001*
	MMDT-T	282 (140)	240 (75)	-3.823	<.0001*
MD $n = 19$	GPT	158 (187)	124 (166)	-3.140	<.002*
	MMDT-P	277 (89)	241 (80)	-3.162	<.002*
	MMDT-T	294 (178)	239 (121)	-3.703	<.0001*

Me: median; IQR: interquartile range; MCI: mild cognitive impairment; MD: mild dementia; GPT: Pegboard Grooved Test; MMDT-P: Minnesota Manual Dexterity Test-Placing Test; MMDT-T: Minnesota Manual Dexterity Test-Turning Test.

*Significant Wilcoxon signed rank test, $p < 0.05$.

illuminated targets, and (2) Passive Viewing (Without attention), not paying attention to any particular target. They observed that in frontal and parietal areas, there was a doubling of the signal change produced by motion stimuli when items were attentively tracked. Other regions of brain activation were in the middle temporal area (MT) and visual area V3A. Their results suggest that this process is mediated by a network of areas that include parietal and frontal regions responsible for changes in attention, eye movements, and MT, the latter considered responsible for the perception of movement (Wolf et al., 2018). Thus, MOT is related to global attention and could improve brain activity in MT and medial superior temporal (MST) areas. Another study by Parsons and colleagues (Parsons et al., 2016) at the University of Montreal, examined the effects of 3D-MOT training in a group of young non-athletic adults. Neuropsychological and electrophysiological tests [using quantitative electroencephalography (qEEG)] were performed before and after 3D-MOT training, and it was compared with a non-3D-MOT training control group. The results revealed that 3D-MOT training leads to neuroelectric brain function activity in regions involved in attention (Theta/Beta), visual processing, and plasticity (gamma). In addition, the changes observed in the gamma band are centered in the occipital cortex, the brain region responsible for visual processing. Finally, a recent study performed by Parsons and Faubert (2021), was demonstrated that a closed-loop learning paradigm that incorporates cerebral performance, as well as cognitive performance (workload), optimizes a person's ability to learn a novel task (3D-MOT).

The results obtained with the 3D-MOT training showed an increase in the speed thresholds as the number of sessions in both groups augmented, reaching higher values in the MCI group, Figure 2. On the other hand, the training shows a learning function that reaches its plateau simultaneously for the two groups of older adults, which reveals that they obtained similar benefits (Figure 2).

This work found an interaction effect between the 3D-MOT training program and manual dexterity tests: GPT, MMDT-P, and MMDT-T (Figure 3). The 3D-MOT training program session segmentation and the comparison between thresholds' average values per segment determined that 15 sessions are enough to achieve such an interaction effect. From the 16th session, the interaction effect is absent. We include initial and final averaged sessions where the interaction effect was observed for initial and final comparisons. These results reveal that a 2-week 3D-MOT learning program is enough to improve motor tests.

Nevertheless, whether the improvement in manual dexterity tests is permanent or only occurs while the 3D-MOT training sessions are completed needs to be explored. The improvement in the manual dexterity tests was observed regardless of the MCI or MD group, showing an interaction effect that can be statistically translated as a transfer effect of the training with the 3D-MOT (Figure 2). There is evidence that, during associative memory tasks, object recognition and attention significantly activate the hippocampus, a structure crucially involved in the pathogenesis of

Alzheimer's disease (Dickerson & Eichenbaum, 2010). Serrien and Sovijärvi-Spapé (2016) observed that fine control of manual motor skills is based on different neuronal patterns, which could be activated with 3D-MOT training.

However, despite the intriguing findings of the current experiment, it is essential to note that the approach utilized had some limitations. First up, this study is exploratory, the sample size is small, and we do not have a control group, this latter due to the difficulties in the participation of individuals with normal cognition in our setting, which could be attributed to a cultural phenomenon where there is resistance to use cognitive training when there are no cognitive deficits. Since the recruitment of individuals with normal cognition could not be completed, our result, although promising, should be reevaluated in a follow-up study with a different design that can answer these questions. In addition, there was a higher proportion of women in both groups. Although some studies have reported a higher prevalence of cognitive impairment in women than in men (Au et al., 2017; Liu et al., 2022; Podcasy & Epperson, 2016), a larger sample size with equivalent proportions of women and men is advisable.

Another limitation is the lack of a complete cognitive assessment, as this was not one of our objectives but could give valuable information on the cognitive profiles of individuals who could benefit from this program.

Also, there were some variables included in the analysis that had significant differences in the tables but were not mentioned in the results as covariates, or herein. How may these additional variables possibly affect these results; for example, could education or overall global cognition influence performance on this task? Indeed, the number of education years is higher in the MCI population than in the MD population and that might have an impact on the performance of the task presented here. However, such covariate analysis was out of the scope of the present work, but it would be important if we want to compare performance between populations. Herein, we examined the effect of 3D-MOT training after 36 sessions on the Grooved pegboard test (GPT) and the Minnesota Manual Dexterity Test (MMDT) in older adults with mild cognitive impairment and mild dementia.

The implications of this work are important because motor skills depend heavily on the instrumented skills of daily life and influence the preservation of functionality, so the search for tools that could improve them is of particular interest in the health area related to taking care of older patients. In this regard, these results show the importance of considering computerized cognitive training tools are an alternative to preventive treatments related to cognitive impairment and aging.

In the future, the duration of improvement in manual dexterity needs to be tested to assess whether it is permanent or only occurs while the 3D-MOT training sessions are completed. Moreover, to compare performance between frailty groups and those studied here, a reference group of healthy aging subjects will be added to complete the present study. A covariate analysis of variables, such as education, global cognition, etc. should be included in that population comparison to assess their influence on the performance of this task.

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Disclosure statement

J.F. was the Chief Science Officer of CogniSens Athletics Inc., who produced the commercial version of the 3D-MOT used in this study. Prior to the completion of this work, J.E.L. was a researcher associate at the same company. In this capacity, both authors hold shares in the company.

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