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Efficacy of computerized cognitive training using mobile devices to promote cognitive functioning in community-dwelling older adults with or without risk of mild cognitive impairment: A multi-centre longitudinal study

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Abstract

Objective: To investigate the efficacy of a 5-month computerized cognitive training programme (CCT) "Exercise your Brain" using mobile devices in improving cognitive functioning in community-dwelling older adults with and without risk of mild cognitive impairment (MCI).

Methods: One hundred thirty-four older adults were recruited from 5-day activity centres for the older adults in Hong Kong using convenience sampling to participate in a 5-month CCT training. Participants were stratified into older adults with and without risk of MCI.

Results: There was significant improvement ($p < 0.001$) in MoCA 5-min for the whole sample after 5-month CCT ($d = 0.72$) and the effects were maintained at 3-month follow-up. The group at risk of MCI improved their cognitive functioning immediately after intervention more than the non-MCI group ($p < 0.001$, $d = 1.37$ vs $d = 0.55$). In the task-based performance, there was significant interaction effect between memory and calculation with and without risk of MCI when years of formal education was a covariate, and that the non-MCI group had the highest improvement in Judgement (6.23%) and memory (5.43%), compared with that (1.47% and 2.33%) in the group at risk of MCI. The risk-of-MCI group had the highest improvement in attention (2.67%) and eye-hand coordination (4.87%), compared with that of the healthy older adults.

Conclusion: Cognitive functioning in both older adults with or without risk of MCI was enhanced immediately after CCT using a mobile device and endured over a three-month follow-up. The training effect on the group at risk of MCI was significantly greater than that for the non-MCI group. With recent advances in mobile technology, remote cognitive training in terms of using mobile devices for older adults as primary and secondary preventions is applicable and practicable.

Keywords

Computerized cognitive training, mobile devices, mild cognitive impairment, older adults

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Introduction

Mild cognitive impairment (MCI) is the symptomatic stage in the continuum of cognitive decline that might has a risk of progressing to Alzheimer's Disease (AD).[1] MCI subtypes are defined by presence or absence of memory impairment (amnestic vs. non-amnestic), particularly MCI due to AD is characterized by memory impairment, longitudinal decline in cognitive function, and lack of evidence for vascular, traumatic, or other medical causes of cognitive decline.[2] The long-term conversion rate of amnestic MCI to AD is 72% in 5 years,[3] and estimated that 10% to 15% of individuals living with MCI develop dementia each year.[4] The incidence rate of MCI at present is estimated to be 80.9 per 1000 people in a year, an increasing prevalence of MCI is expected in the future, posing a burden to the healthcare system.[5] Older adults with MCI present with a mild cognitive decline in domains including memory, language, and executive functioning that is not severe enough to require help in their usual daily activities, however, changes in attention/ executive function may increase risk and difficulty in instrumental activities of daily living such as preparing meals, using household appliances, handling finances, and safety concerns from family members.[2]

Cognitive training refers to a range of structured and repetitive guided tasks associated with specific cognitive domains that can be used to improve or maintain cognitive functioning and to slow down cognitive deterioration.[6] Cognitive training has the potential to target diminished cognitive functions, thus older adults with or without MCI can benefit from training. The reason for using cognitive training on these populations is that repeated cognitive tasks can improve the trained cognitive domain enabling general cognitive functioning to improve as well as other non-trained domains.[7] To date, the largest sample size ($n = 2832$) study on healthy older adults showed cognitive training to generate a promising and long-lasting effect on the targeted cognitive domains.[8] A narrative review focusing on the transfer of skills of cognitive training found that it improves performance on the trained tasks, but less evidence that such training improves performance on closely related tasks, and little evidence that training improves everyday cognitive performance.[9] Another narrative review concluded that cognitive training is a promising preventive therapeutic technique in healthy older adults as well as a secondary prevention method for those considered to be at risk of dementia.[10] A randomized controlled trial also found significant improvement in global cognition for healthy older adults after receiving a 12-week computerized cognitive training (CCT) in the experimental group than the control group.[11] A recent review on the use of CCT during the COVID-19 pandemic shows that CCT in terms of telehealth is particularly beneficial for the older adults to maintain their physical activity, cognitive functioning and mental health during lockdown or social isolation at homes.[12]

Although CCT has been used for 1–2 decades for cognitive training in the ageing population, it is of particular attention because of the huge interest in interventions to delay or prevent cognitive decline nowadays. A recent meta-analysis of 18 randomized controlled studies of CCT interventions in adults with MCI concluded that CCT provided a significant but small increase in global cognitive function as well as marginal improvement in domain-specific cognition compared to that in the controls.[13] A systematic review addressing the efficacy of cognitive training involving people with MCI has also reported significant improvements in memory and in other measures of cognition.[14] The main advantage of CCT over conventional cognitive training (paper and pencil) is that the difficulty level of computerized tasks is automatically adjustable to match the individual's cognitive needs,[15] and that it is highly accessible which does not require delivery by trained experts.[13] Recent studies also indicate that CCT induces a positive effect in healthy older adults in enhancing cognitive functioning.[16,17] Interestingly, CCT produces greater cognitive amelioration in people with MCI, as reflected in a meta-analysis that reported larger effect sizes in comparison to healthy older adults.[18] Another study investigated the effects of CCT programmes on older adults with MCI, comparing two CCT programmes–"Bettercog" and "COMCOG". The results of the study revealed significant effects of CCT programmes in improving the cognitive function of older adults with MCI and dementia.[19] A narrative review indicated the potential of cognitive training in postponing cognitive decline in people with MCI, although the author raised a number of unresolved issues including the choice of appropriate intervention and outcome measures, and the issue of generalization to daily life.[20]

Recent advances in mobile technology have excelled the use of CCT programmes as a means of cognitive rehabilitation in which older adults are prescribed gamified cognitive exercises from their own personal electronic devices such as smartphones or tablets regardless of time and place.[21] A recent scoping review searched 34 studies concluded that few challenges in using cognitive training apps for older adults with MCI – heterogeneity of participants with various degrees of cognitive impairment, wide variation in the intervention such as contents, duration and frequency of training, and the importance of incorporating physical abilities in conjunction with cognitive evaluation in the studies.[22] It is therefore particularly important that the training tasks should be specific to the cultural and social contexts of the users. Therefore, the Hong Kong Society for the Aged (SAGE; https://www.sage.org.hk/; referred to in this study as the Organization) developed an app called "Exercise Your Brain" for smartphone or tablet users – a cognitive training programme aiming to provide free cognitive stimulation to maintain the cognitive functions of older adults in Hong Kong (Figure 1). Recent research has shown that multi-domain cognitive training has an effect on

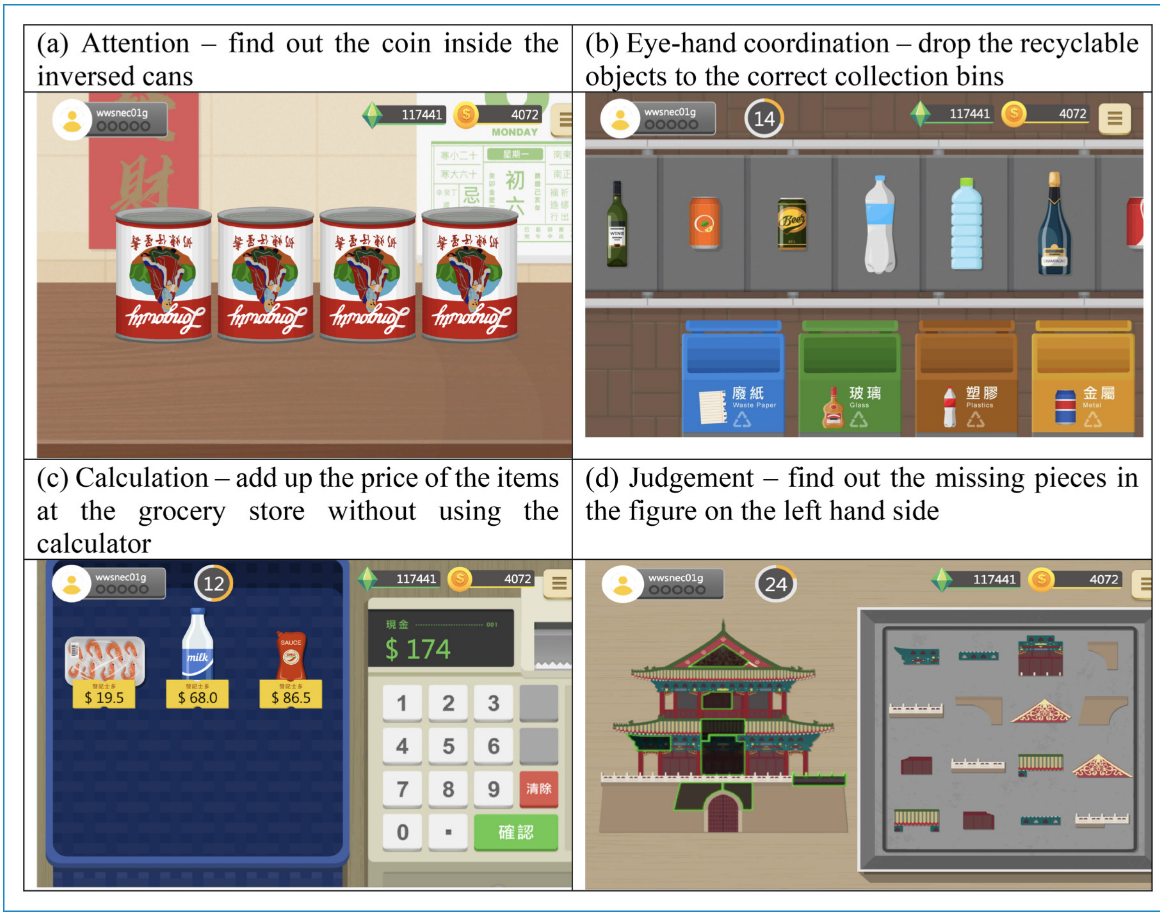

Figure 1. Sample of "Exercise your Brain". (a) Attention – find out the coin inside the inversed cans. (b) Eye-hand coordination – drop the recyclable objects to the correct collection bins. (c) Calculation – add up the price of the items at the grocery store without using the calculator. (d) Judgement – find out the missing pieces in the figure on the left hand side.

maintaining brain grey matter volume and preserving cognitive functions, delaying the declination of cognitive function.[23] Compared with single domain training, multi-domain cognitive training has more advantages in maintaining the training effect as well.[24] Therefore, the programme consists of five cognitive domains–memory, eye-hand coordination, attention, calculation, and Judgement. The first version of this programme has already been launched freely to the public (https://www.game.e123.hk/). Therefore, the aim of this study was to evaluate the efficacy of a CCT via the mobile app that was applicable for both Androld and iOS versions - "Exercise your Brain" on improving the cognitive functioning of older adults with or without MCI residing in community dwellings in Hong Kong. Based on the thinking outlined above, we hypothesized that: (1) global cognitive functioning of all participants would improve after the realization of the programme, (2) the group at risk of MCI would improve more from the CCT than the non-MCI group, and (3) the task-based performance of the CCT for all participants would improve after each domain-specific cognitive training.

Methods

Participants

This was a prospective longitudinal efficacy study that was carried out from May to Dec 2021, involving the use of CCT as a single intervention for older adults with or without risk of MCI and with a follow-up for outcome measurement. Participants were community-dwelling older adults recruited by convenience sampling from five activity day-centres of different districts in Hong Kong. The activity day-centres are district elderly community centres that provide comprehensive and diverse community support services, among others, are educational, social, recreational, meal and laundry, and career support activities, etc., at the district level to enable older adults to lead a healthy, respectful and dignified life.[25] Participants from these centres were older adults aged ≥ 60 years old, with or without disabilities, who resided in the community dwellings. The Hong Kong Montreal Cognitive Assessment 5 min Protocol (MoCA 5-min) was used to assess participants' global cognitive functioning.[26] The MoCA 5-min has advantages of fast administration, it is also useful for persons who cannot draw or refuse to use a pen; therefore, it can be administered over phone. There are other versions of Mini MoCA developed by different authors but in general Mini MoCA appears to be a valid measure for the quick assessment of general cognitive functioning among older adults.[27] By comparing participants' performance to the norm according to the age, two groups of participants were then identified according to the results of the test: 1) non-MCI group (equivalent to MoCA 5-min total score >16th percentile), and 2) risk-of-MCI group (equivalent to MoCA 5-min total score within 7–16th percentile).[26] The later were older adults presenting suspected MCI, i.e., not age-related cognitive decline, because they have not been diagnosed based on the clinical research criteria for MCI.[28]

To be included in the study, participants had to be: (1) aged between 60 and 85 years old, (2) of normal vision (at least 0.4 in the best eye using a Snellen Eye Chart,[29] or adequately corrected with corrective devices), and (3) resided in community dwellings. Those with: (1) physical impairments in the preferred hand that prevented them from using smartphones or tablets, (2) a diagnosis of a neurological disease such as stroke, Parkinson's disease, Huntington's disease, head injury, or any major mood or addiction disorders before joining the study, and (3) no experience of using smartphones before, were excluded.

Ethical approval was obtained from the organization and the Human Subjects Ethics Committee of the Hong Kong Polytechnic University (Reference number: HSEARS20210730001). Informed and written consent was sought from each participant by the investigators before data collection.

Study design

This was a five-month pre-post multi-centre feasibility study for CCT using mobile devices for older adults with and without risk of MCI residing in the community dwellings in Hong Kong. Participants' recruitment and screening were carried out by the organization before study commencement. After the training of each cognitive domain, participants were individually assessed by investigators blinded to the training group allocation, using the MoCA 5-min. After a 2-week "wash out period", a new domain for the cognitive training was introduced, the sequence was repeated for 5 different cognitive domains and a follow-up assessment was conducted three months after the finalization of the study.

Intervention

The cognitive training was conducted simultaneously in five community centres of the Organization. The participants used the tablets provided by the Organization with the app pre-installed. Participants were instructed to use their dominant or preferred hand to use the app on the tablets. They played the app on their own, investigators only supervised and assisted the participants during the training when required, as well as to ensure adherence to the training during the intervention period.

The app consisted of 5 cognitive domains - memory, eye-hand coordination, attention, calculation, and judgement. There were 5 tasks in each domain-specific training, so a total of 25 tasks in the whole programme, for example, 'Memory 4' stands of Task 4 in the memory domain and 'Judgement 2' stands for Task 2 in the judgement domain. The graphics of the tasks in the app are designed according to the cultural context in Hong Kong, examples of environments include Hong Kong tea restaurant, shopping malls, public housing estates, etc. and historical objects such as stamps, coins, old kitchenware, etc. Each task had 5 levels of difficulty from levels 1 to 5. Each participant should complete all 5 levels of a task - start with Level 1 of every single task of each cognitive domain. The participants performed one domain-specific training randomly selected each month, and one task for about 30 mins each day, 5 days per week (excluding weekends and Sundays); hence, a total of 5 tasks were performed each week. In order to standardize the training duration, the participants had to continue the task at the same level within the specific training time even though it might be underchallenged. This procedure was repeated in the second week, so each task was performed twice within two weeks, a total of 5 h, i.e., 300 mins, training per each block. After the first domain-specific cognitive training, there was a two week "wash-out period" before performing another domain-specific cognitive training. This was to reduce the training effects of the previous domain-specific cognitive training being carried over to the next training phase (Figure 1). During the wash-out period, app usage for training at home was not permitted. Cognitive domains were trained sequentially, rather than in parallel, which allowed us to investigate whether task-based performance on the CCT improved for all participants following each domain-specific training block, as per the study objectives. To reduce the history effects, the type of domain-specific cognitive training was allocated to the participants based on a randomized order that was different among the 5 centres. The total duration of training was 25 h throughout the entire study period.

Outcome measurements

The primary outcome was global cognitive functioning measured using the MoCA 5-min. This is in line with the measurement of global cognitive function as primary outcome in the recent meta-analysis for CCT intervention for people with MCI.[13] The MoCA 5-min is a valid and reliable cognitive test administered over the phone that has been demonstrated to be equally useful as the clinically administered MoCA in detecting cognitive impairment in patients with stroke or transient ischemic attack.[26] It was adopted in this study due to its convenience in administration time and validity in people with MCI as well as for post-intervention phone follow-up evaluation. In addition, age and education adjusted norms for the test were available for accurate classification of participants' performances.[23] The MoCA 5-min baseline, post-whole intervention and 3-month follow-up scores were compared for all participants. Likewise, the baseline and post-training of the MoCA 5-min results were compared to determine the differences in terms of changes in cognitive function related to each specific domain of the cognitive training.

The secondary outcome was the task-based performance derived from the domain-specific scores of each cognitive domain in the CCT, including variables such as the highest task levels achieved, total time, and accuracy scores, which were recorded automatically by the app. The task level was used to describe the stage and difficulty of each task domain. The highest task level achieved by each participant was collected to determine participants' cognitive ability in the respective domains. Accuracy score refers to the percentage of questions that were answered correctly. This reflected participants' performance and was used as an indicator to evaluate improvement between the first and second week of performing each task. Total time was defined as the time needed for participants to respond to the question shown in the task, which reflects the participant's processing speed; hence a shorter total time refers to a higher processing speed.

Demographic data including age, gender, years of formal education, past major occupation history, self-reported health conditions, and past experience of using smartphone or mobile devices were collected from each participant.

Statistical analysis

Data analyses were performed using IBM SPSS Statistics 22.0. Independent t-tests for continuous data and chi-square tests for categorical data were used respectively to compare the baseline differences in demographic variables among the two groups of participants with and without risk of MCI. Participants were stratified into 2 groups – non-MCI or risk of MCI, according to the corrected percentile cut-off score considering their age and levels of education.[26] Pearson's r was used to examine the relationships between demographic variables, and between the MoCA 5-min baseline and variables of interest such as age, years of formal education, and smartphone usage. Mauchly's sphericity test was used to make sure the assumption of sphericity was met in repeated measures ANOVA (RANOVA) and repeated measures ANCOVA (RANCOVA). RANOVA was used to examine the MoCA 5-min after the overall CCT programme and at 3-months follow-up relative to the baseline for all participants as a whole sample. Significance values were adjusted by the number of groups at $p = 0.025$ when doing group comparisons. To evaluate the training effect of each domain-specific in cognitive training - memory, attention, eye-hand coordination (coordination), calculation, judgement, RANCOVA was conducted to compare the domain-specific scores of cognitive training between groups after each domain-specific training as compared to the baseline. Age, years of formal education, and years of smartphone usage were treated as covariates in the analyses.

Results

A total of 145 participants were recruited by convenience sampling from the five community centres for the elderly in this study. There were 11 dropouts due to family and medical issues. Of the participants who completed the training, 134 were included in the data analysis, of which 86 were labelled as healthy older adults (non-MCI), and 48 were identified as at risk of MCI. The CONSORT flow diagram is shown in Figure 2. The sample included almost twice as many non-MCI older adults might probably due to the demographic characteristics of the participants engaging in the centres' activities that about 15% of the participants were suffered from MCI. Female participants were a majority (77.6% of the sample) and the mean age was 76.12 (SD = 5.93). The mean MoCA 5-min total score of the sample was 20.42 (SD = 5.07). Compared with the group at risk of MCI, the non-MCI group had a larger proportion of females (81.4% vs 70.8%), was slightly younger (75.98 vs 76.38), more educated (6.52 vs 6.46 years of formal education), had more experience using smartphones (4.46 vs 3.08 years) and scored higher in the MoCA 5-min baseline (23 vs 15.7) (Table 1). Except for the baseline MoCA 5-min scores ($p < 0.001$) and years of smartphone usage ($p = 0.011$), no significant differences in demographic variables were found between the two groups (Table 1). This indicates that participants with risk of MCI had a shorter year duration of smartphone usage (4.46 *vs*. 3.08).

Relationship among demographic variables and between the primary outcomes at baseline. There were significant correlations between years of formal education and gender ($r = 0.318$, $p < 0.001$), years of formal education and age ($r = -0.315$, $p < 0.001$), years of formal education and years of smartphone usage ($r = 0.316$, $p < 0.001$), Snellen test scores and age ($r = -0.242$, $p = 0.005$), Snellen test scores and hypertension ($r = -0.246$, $p = 0.004$), and years of smartphone usage and age ($r = -0.249$, $p = 0.004$).

The relationships between baseline MoCA 5-min scores and other factors were examined. There were significant correlations between the MoCA 5-min scores with age ($r = 0.34$, $p < 0.001$), years of smartphone usage ($r = 0.379$, $p < 0.001$), and years of formal education ($r = 0.4$, $p < 0.001$).

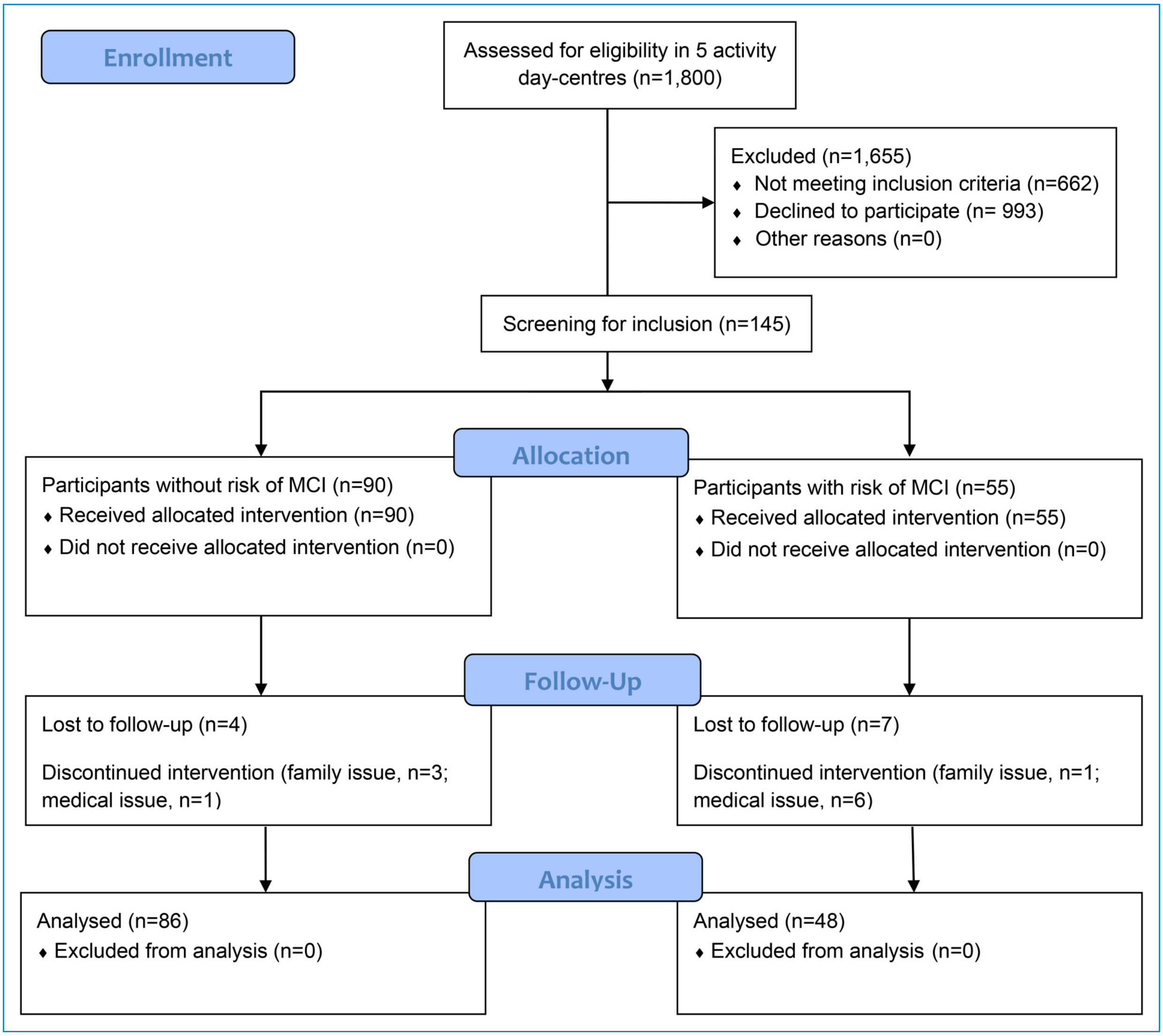

Figure 2. CONSORT flow diagram.

Effects of cognitive functioning for all participants and for risk-of-MCI and non-MCI groups. Table 2 shows the MoCA 5-min scores and the mean changes of baseline, post-training, and follow-up. A significant pre/post-training effect on all participants' cognitive function was found (mean change = 3.39, $p < 0.001$) and a large effect size was observed ($d = 0.72$). The improvement was maintained at the 3-month follow-up as reflected in the identical posttreatment scores.

A significant group effect ($F = 26.74$, $p < 0.001$) was found in the MoCA 5-min change of score baseline vs post-training between the MCI and non-MCI groups. For the non-MCI group, there was an increase in the mean MoCA 5-min score (2.07) post-training and a medium effect size was observed ($d = 0.55$), however, the increase in the mean MoCA 5-min score was larger than in the MCI group (5.77) and a larger effect size was observed ($d = 1.37$) (Table 2).

The RANCOVA results revealed that there were significant interaction effects on the domain-specific scores of cognitive training with years of formal education, the time of completing Memory-1 ($p = 0.042$), Memory-2 ($p = 0.027$), Memory-4 ($p = 0.000$), Memory-5 ($p = 0.000$), Attention-1 ($p = 0.018$), Attention-4 ($p = 0.004$), Calculation-1 ($p = 0.001$), Calculation-3 ($p = 0.001$), Calculation-4 ($p = 0.001$), and the accuracy score of Memory-4 ($p = 0.000$), Calculation-3 ($p = 0.001$), Calculation-4 ($p = 0.001$), Calculation-5 ($p = 0.033$), and Judgement-4 ($p = 0.017$), therefore, years of formal education was used as covariates in the RANCOVA for domain-specific scores. Apart from this, there were significant interaction effects between Calculation-1 and years of smartphone usage ($p = 0.020$).

Table 3 shows that there was significant interaction between total time of memory tasks of all levels, accuracy score of Memory-4 ($p = 0.001$) and having risk of MCI,

Table 1. Demographics and baseline scores.

Variable	All Mean (SD) or n(%)	Non-MCI (n = 86) Mean (SD) or n(%)	Risk of MCI (n = 48) Mean (SD) or n(%)	t/ X^2	p
Age (years)	76.12 (5.93)	75.98 (5.65)	76.38 (6.45)	−0.372	0.711
Years of formal education	6.50 (4.07)	6.52 (3.79)	6.46 (4.59)	0.930	0.88
Years of smartphone usage	3.97 (3.02)	4.46 (2.98)	3.08 (2.91)	2.590	0.011*
Baseline MoCA 5-min score	20.4 (5.07)	23.0 (3.84)	15.7 (3.37)	10.997	<0.00*
Snellen Chart score	0.71 (0.18)	0.69 (0.18)	0.73 (0.19)	−1.126	0.262
Gender (n)					
Male	22.4%	18.6%	29.2%	1.978	0.160
Female	77.6%	81.4%	70.8%		
Comorbidity (n)					
OA knee	17.2%	17.4%	16.7%	0.13	0.909
Diabetes	23.9%	20.9%	29.2%	1.150	0.284
Heart disease	18.7%	16.3%	22.9%	0.894	0.344
COPD	0.7%	1.2%	0%	0.562	0.453
High cholesterol	40.3%	45.3%	31.3%	2.545	0.111
Kidney disease	0%	0%	0%		
Hypertension	56.7%	58.1%	54.2%	0.198	0.656
Insomnia	11.9%	10.5%	14.6%	0.497	0.481
Prostate diseases	3%	3.5%	2.1%	0.210	0.647
Cancer	3.7%	2.3%	6.3%	1.321	0.250
Cataract	17.2%	18.6%	14.6%	0.350	0.554
Glaucoma	2.2%	2.3%	2.1%	0.008	0.928
Floaters	0.7%	1.2%	0%	0.562	0.453
Nyctalopia	0.7%	1.2%	0%	0.562	0.453
Macular degeneration	3.0%	2.3%	4.2%	0.361	0.548
Hearing loss	2.2%	2.3%	2.1%	0.008	0.928

Note: X^2, Chi-square. Note: *p ≤ 0.05; p-values were between-group comparison; OA = Osteoarthritis; COPD = Chronic obstructive pulmonary disease

as well as between total time of Attention-5 ($p = 0.015$), Calculation-1 ($p = 0.015$), and accuracy score of Calculation-4 ($p = 0.030$) and having risk of MCI.

There were significant between-group differences between participants with or without risk of MCI in accuracy scores of Memory-1 ($F = 12.17$, $p = 0.000$), Memory-2 ($F = 3.934$, $p = 0.049$), Memory-4 ($F = 4.988$, $p = 0.027$), Coordination-2 ($F = 4.62$; $p = 0.033$), Coordination-3 ($F = 3.929$, $p = 0.05$), Attention-2 ($F = 12.45$, $p = 0.001$),

Table 2. Comparison of MoCA 5-min scores across time within and between groups.

Group	(1) Mean (SD) (pre)	(2) Mean (SD) (post)	(3) Mean (SD) (follow-up)	Mean change (2, 1)	Mean change (2, 3)	Mean change (1, 3)	Within group *p* (post-hoc)	Between group *p* (post-hoc)
All (n = 134)	20.41 (5.07)	23.82 (4.33)	23.79 (4.45)	3.39¶	−0.22	3.37¶	<0.001 (1, 2); <0.001 (1, 3)	
Non-MCI (n = 86)	23.03 (3.83)	25.10 (3.38)	24.98 (3.28)	2.07	−0.12	1.95		<0.001* (1, 2); <0.001* (1, 3)
Risk of MCI (n = 48)	15.74 (3.37)	21.51(4.89)	21.67 (5.44)	5.77¶	0.15	5.92¶	<0.001 (1, 2); <0.001 (1, 3)	

Note: *$p < 0.05$ for within-group comparison; ¶$p < 0.025$ for between-group comparison.

Attention-4 ($F = 5.187$; $p = 0.025$), Calculation-3 ($F = 4.969$; $p = 0.028$), Judgement-1 ($F = 4.717$; $p = 0.032$), Judgement-2 ($F = 5.015$; $p = 0.027$), and Judgement-4 ($F = 7.677$, $p = 0.006$), as well as the total time of Attention-1 ($F = 3.116$; $p = 0.080$), Attention-5 ($F = 4.163$; $p = 0.043$), Judgement-4 ($F = 7.155$, $p = 0.008$), and calculation tasks of all levels (Table 3).

Figure 3(A) and (B) show the mean improvement score for accuracy and total time used in each cognitive domain. As shown in Figure 3(A), the accuracy scores for both groups had improved in all five domains. The non-MCI group had the highest improvement in judgement (6.23%) and memory (5.43%), compared with the risk-of-MCI group in judgement (1.47%) and memory (2.33%). The risk-of-MCI group had the highest improvement in attention (2.67%) and eye-hand coordination (4.87%), compared to people in the non-MCI group in attention (1.12%) and eye-hand coordination (1.89%). Both populations had similar improvements in calculation (3.89%, 4.05%). As shown in Figure 3(B), the reaction time used (seconds) for both groups in calculation, attention, eye-hand coordination, and memory were shortened. The risk-of-MCI group had the highest improvement in calculation (4.14 s) and attention (7.96 s), compared with participants in the non-MCI group in calculation (2.87 s) and attention (3.55 s). Both populations had similar improvements in eye-hand coordination (1.26 s, 1.57 s) and memory (0.8 s, 0.85 s). In contrast to the other four domains, the reaction time used for both groups in judgement were minimally lengthened (–0.13 s, −0.23 s).

Discussion

This study evaluated the efficacy of a multi-centre programme – "Exercise your Brain" for cognitive training in older adults with or without risk of MCI in the community. Our study found a significant improvement in an adequate sample size to support a large effect, suggesting CCT through the use of mobile devices is feasible and usable. The findings demonstrated that cognitive functioning in both the risk-of-MCI and non-MCI groups were enhanced immediately after the intervention as shown in the MoCA 5-min as well as the domain-specific training scores. Our finding of a significant improvement for older adults after receiving cognitive training is congruent with previous studies in the literature suggesting that cognitive training is effective in improving cognitive abilities,[16,30] and that CCT is a promising approach for improving global cognitive function in people with MCI.[13,18] The use of cognitive training could have led to improvement in cognitive functioning due to its engaging and interactive properties.[31] Following this line of thought, another study of older adults receiving iPad training found that greater improvements in episodic memory and processing speed occurred after a 3-month 15 h/week dosage as compared to those in the control

Table 3. Comparison of domain-specific training scores pre/post training between groups.

Domain	Non-MCI (86)		Risk of MCI (n = 48)		Between-group comparison		Interaction effect
	Mean (SD) (pre)	Mean (SD) (post)	Mean (SD) (pre)	Mean (SD) (post)	*F* value	*p* value	*p* value
Total time (sec.)							
Memory-1	99.56 (13.96)	95.20 (12.18)	98.16 (22.48)	94.24 (21.79)	0.308	0.580	0.042*
Memory-2	89.22 (29.05)	185.16 (58.03)	101.07 (38.20)	196.60 (65.75)	1.509	0.222	0.027*
Memory-3	33.80 (11.65)	60.37 (5.05)	37.46 (14.44)	60.19 (5.26)	2.301	0.132	0.021*
Memory-4	80.44 (54.67)	116.51 (37.30)	97.65 (15.57)	110.82 (23.38)	0.577	0.449	0.008**
Memory-5	56.28 (8.62)	80.44 (18.79)	61.04 (10.77)	76.56 (15.96)	0.059	0.809	0.041*
Coordination-1	27.53 (9.42)	34.00 (8.25)	29.15 (13.15)	33.22 (10.48)	0.004	0.948	0.255
Coordination-2	20.91 (12.74)	15.65 (2.37)	19.54 (4.41)	14.84 (1.82)	1.138	0.288	0.778
Coordination-3	22.53 (5.70)	19.06 (3.04)	23.40 (5.76)	20.87 (3.70)	2.780	0.098	0.340
Coordination-4	20.84 (3.60)	35.54 (9.36)	20.84 (2.77)	33.77 (8.78)	0.988	0.320	0.268
Coordination-5	13.11 (2.09)	19.42 (1.25)	13.27 (0.48)	19.21 (1.88)	1.942	0.166	0.797
Attention-1	74.21 (6.81)	94.24 (10.69)	76.03 (7.96)	98.03 (13.80)	3.116	0.080*	0.316
Attention-2	71.59 (11.96)	77.25 (9.40)	81.13 (27.55)	80.51 (12.68)	6.284	0.014*	0.138
Attention-3	35.58 (9.58)	21.86 (3.07)	33.80 (0.47)	22.75 (2.55)	1.390	0.241	0.076
Attention-4	81.14 (21.27)	140.05 (35.93)	86.83 (4.30)	138.22 (38.35)	0.035	0.851	0.790
Attention-5	66.10 (13.43)	226.31 (51.53)	69.70 (14.54)	203.84 (46.27)	4.163	0.043*	0.015*
Calculation-1	45.39 (12.93)	105.55 (20.10)	58.40 (23.78)	105.86 (21.38)	5.945	0.016*	0.015*
Calculation-2	72.35 (24.39)	120.51 (34.65)	91.67 (34.40)	138.07 (33.91)	10.632	0.001**	0.858
Calculation-3	60.92 (17.04)	109.44 (31.65)	75.00 (21.67)	114.36 (31.36)	4.969	0.028*	0.244
Calculation-4	51.03 (16.24)	124.57 (34.27)	63.55 (28.46)	125.95 (32.43)	4.367	0.039*	0.030
Calculation-5	43.93 (11.95)	39.93 (12.48)	44.60 (13.13)	38.33 (9.94)	0.056	0.814	0.522
Judgement-1	48.58 (10.96)	33.59 (3.80)	50.68 (12.75)	35.09 (9.17)	0.509	0.477	0.832
Judgement-2	31.28 (6.71)	31.00 (5.86)	31.00 (11.06)	31.37 (8.66)	0.228	0.634	0.597
Judgement-3	89.80 (25.52)	120.31 (23.24)	100.25 (30.10)	125.13 (26.16)	2.028	0.157	0.527
Judgement-4	155.29 (23.40)	147.56 (19.47)	164.25 (18.70)	157.05 (15.98)	7.155	0.008**	0.855
Judgement-5	28.68 (3.06)	27.71 (3.43)	28.27 (2.70)	26.79 (3.44)	1.535	0.218	0.492
Accuracy score (%)							
Memory-1	83.38 (14.05)	70.65 (16.50)	71.24 (25.25)	61.25 (18.96)	12.17	0.000**	0.245

(continued)

Table 3. Continued.

Domain	Non-MCI (86) Mean (SD) (pre)	Non-MCI (86) Mean (SD) (post)	Risk of MCI (n = 48) Mean (SD) (pre)	Risk of MCI (n = 48) Mean (SD) (post)	Between-group comparison *F* value	Between-group comparison *p* value	Interaction effect *p* value
Memory-2	88.74 (12.72)	60.56 (18.98)	84.36 (17.90)	54.36 (20.21)	3.934	0.049*	0.394
Memory-3	92.78 (18.98)	52.76 (19.24)	85.34 (26.16)	47.19 (23.57)	3.550	0.062	0.824
Memory-4	71.00 (38.85)	88.00 (14.37)	88.90 (12.85)	86.54 (12.85)	4.988	0.027*	0.001**
Memory-5	61.67 (19.28)	25.93 (20.39)	56.55 (23.11)	27.22 (23.23)	0.305	0.582	0.365
Coordination-1	94.73 (21.27)	42.10 (15.92)	88.96 (28.86)	38.81 (19.68)	1.597	0.209	0.508
Coordination-2	78.29 (22.32)	56.54 (18.65)	72.09 (23.71)	48.07 (17.04)	4.622	0.033*	0.520
Coordination-3	97.00 (6.04)	76.83 (11.63)	92.83 (14.28)	74.15 (9.68)	3.929	0.05*	0.945
Coordination-4	44.67 (23.70)	58.12 (18.99)	33.99 (17.00)	49.29 (21.61)	5.803	0.018*	0.750
Coordination-5	52.87 (19.80)	53.43 (14.65)	56.35 (13.96)	47.20 (15.23)	1.013	0.316	0.061
Attention-1	97.53 (6.00)	97.36 (6.83)	97.23 (6.34)	96.26 (18.87)	0.025	0.874	0.470
Attention-2	93.19 (8.80)	77.25 (17.25)	88.38 (14.20)	69.26 (18.87)	12.45	0.001**	0.238
Attention-3	85.63 (13.66)	77.27 (14.29)	82.16 (14.97)	73.15 (13.69)	1.502	0.223	0.705
Attention-4	92.56 (23.45)	86.83 (12.68)	96.42 (5.96)	81.13 (13.11)	5.187	0.025*	0.228
Attention-5	87.45 (19.18)	83.86 (14.71)	83.92 (17.55)	73.24 (21.70)	10.599	0.001**	0.110
Calculation-1	90.44 (14.16)	34.73 (27.05)	83.56 (16.39)	33.47 (28.09)	2.190	0.141	0.527
Calculation-2	86.33 (18.73)	19.36 (37.20)	81.75 (19.98)	8.79 (25.47)	4.622	0.033*	0.366
Calculation-3	91.12 (12.39)	51.57 (24.28)	82.45 (17.01)	49.68 (22.19)	4.969	0.028*	0.244
Calculation-4	91.05 (16.48)	46.67 (29.19)	84.37 (24.69)	45.61 (27.92)	2.230	0.138	0.030*
Calculation-5	53.85 (25.92)	23.62 (13.43)	46.14 (28.94)	22.10 (14.30)	2.005	0.159	0.215
Judgement-1	78.25 (19.48)	47.65 (18.45)	68.76 (23.31)	40.75 (19.02)	4.717	0.032*	0.725
Judgement-2	74.22 (17.77)	66.17 (16.08)	64.84 (23.24)	60.46 (20.62)	5.015	0.027*	0.174
Judgement-3	76.78 (17.37)	58.12 (13.84)	75.86 (14.14)	52.85 (15.86)	0.479	0.490	0.101
Judgement-4	67.79 (17.65)	79.05 (18.64)	58.85 (23.88)	65.37 (23.91)	7.677	0.006**	0.059
Judgement-5	60.40 (18.56)	31.84 (21.77)	60.55 (18.42)	31.53 (20.93)	0.075	0.785	0.770

Note: $*p \leq 0.05$; $**p \leq 0.01$

group.[32] Likewise, a recent randomized controlled trial involving older adults at risk of MCI reported significant improvements in global cognition after receiving cognitive training with or without non-invasive brain stimulation.[33]

In addition, our study found that the risk-of-MCI group had a larger improvement than their counterparts without MCI, indicating that the training effects on cognitive functioning were even more marked in older adults at risk of

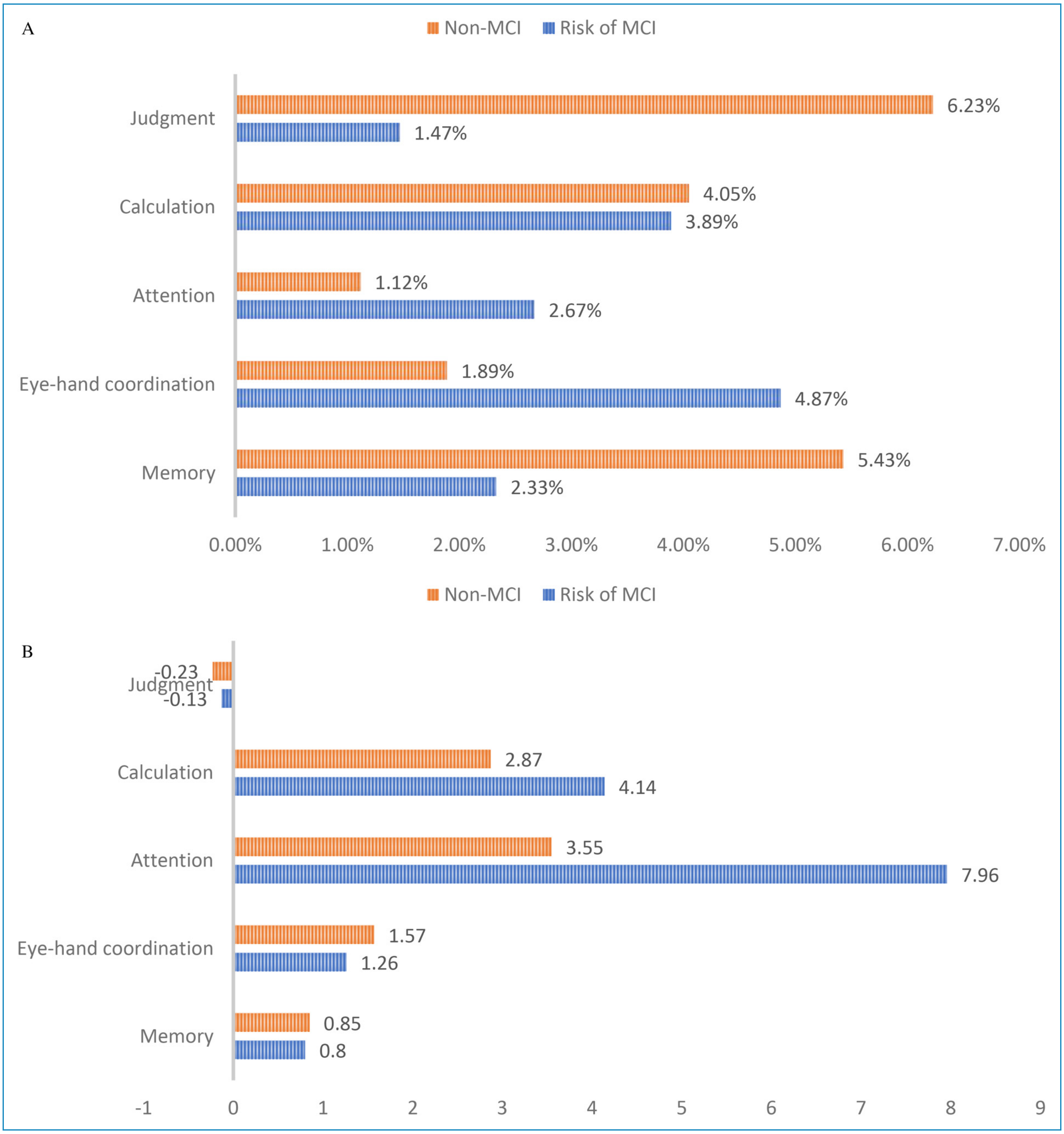

Figure 3. Improvement score for accuracy and total time used in task-based domain-specific performance after intervention. (A) changes in accuracy scores of domain-specific cognitive performance (%). (B) Changes in reaction time of domain-specific cognitive performance (sec.).

MCI. Their average improvement in the MoCA 5-min score was 36.7%, and a large effect size was observed. Similar patterns have been found in a recent systematic review and meta-analysis. Our findings are congruent with the meta-analysis results of 18 RCTs, small-to-moderate positive effect sizes were found in various cognitive domains for MCI subjects after receiving CCT.[23] In fact, in our study the MoCA 5-min score in the risk-of-MCI group improved from 15.74 to 21.51, i.e., a 5.77-point difference, while 21 is the cut-off score for the 16th percentile in the majority of age- and education-adjusted norms. Although no minimal clinically important difference (MCID) cut-off for MoCA 5-min has been developed, previous studies for the MCID for MoCA suggested that it is between 1 and 2 MoCA points or a good reliability with a minimal detectable change of 5.1 points,[34] or a standard deviation > 0.2 points on MoCA.[35] Hence, we estimated that the risk-of-MCI group had improved more than the required MCID in terms of the MoCA 5-min score. Another study also found that 31.48% of participants with MCI improved to normal cognitive levels after cognitive training.[36] In addition, there was a training effect on older adults in the non-MCI group in our study, as reflected in their MoCA 5-min scores. The average improvement in the MoCA 5-min score was 10.8% and a medium effect size was observed. Similar patterns have been found in previous studies that reported small-to-moderate effect sizes for improving cognitive functioning in healthy older adults, but the efficacy varied across different cognitive domains.[17] Moreover, in this study, the effects on global cognitive improvement in terms of the total MoCA 5-min scores for both groups with or without risk of MCI were maintained at 3 months after intervention. This is consistent with the previous reviews that CCT or technology-based cognitive training are promising interventions for preserving cognitive function or decelerate the progression of cognitive decline in people with MCI.[13,18,22,23]

It could be argued that CCT produced larger effects on the risk-of-MCI group, as there might be ceiling effects in the non-MCI group. However, this claim may not be plausible as the average MoCA 5-min total score for the non-MCI group after the programme was 25.51, 5 marks below the full score, evidencing that the performance of the non-MCI group in the MoCA 5-min was not at ceiling. In this study, the participants were exposed to a new intensive CCT that may have stimulated existing neural circuits. This phenomenon takes place even in the presence of MCI.[37] The reason why the group at risk of MCI benefitted more from the CCT than the non-MCI group is difficult to explain given the lack of neuroimaging resources in our assessment process. However, we can speculate that using CCT to stimulate people at risk of MCI may produce more behavioural gains than the non-MCI group because of the multi-domains in CCT.

Our study found significant improvements in cognitive functioning in every domain following use of the CCT programme, largely congruent with other studies using different contextual approaches in cognitive training. Age-related decline occurs in processing speed, visuospatial processing, working memory, verbal memory, and cognitive control, and that visual gameplay has potential to ameliorate age-related cognitive decline particularly in the visual domain.[38] Another observation is the marked improvement in accuracy score of eye-hand coordination domain of participants with risks of MCI found in our study is in line with a study in which older adults showed significant improvements in a cognitive screening test following a cognitive training with a large content of eye-hand coordination tasks.[39] The time improvement of memory, attention, and calculation domain are in line with a study that older adults showed significant improvement in the MoCA scores with some returning to normal ranges from the level of MCI.[36] However, another study delivering a cognitive training for older adults with MCI showed improved decision making but no significant effects on cognitive functioning,[40] while the accuracy score of judgement domain in our study showed significant cognitive improvement.

The improvements in the MoCA 5-min score had a similar trend with the task-based cognitive domain improvements in accuracy and shortened completion time for most of the participants. However, a mild increase in time use was recorded for both populations in the judgement domain. This finding is expected as judgement is under the category of executive functioning. Components in this category require combination and interaction of elementary processes such as visuospatial abilities, working memory, and processing speed.[41] The mild increase in time used for the judgement domain is also consistent with the finding that longer response times have a closer relationship to correct decision making.[42] As a result, it is common that participants require more time to complete tasks for improvement in the judgement domain.

Our study found cognitive functioning to be correlated with three factors of age, years of formal education, and years of smartphone usage. Moreover, we found significant interaction effect between years of formal education with particular the completion time of memory and calculation between groups with and without risks of MCI. The association between cognitive functioning and age is possibly due to age-related cognitive decline along with neuronal loss and dysfunction, and changes in neuronal structure.[43] It's not surprising to find the level of formal education as a confounding factor to domain-specific cognitive performance in the older adults. The recent commission report of Lancet stated that 45% of risk factors leading to dementia are potentially modifiable, one of them is less education in early life which contribute to 5% of the modifiable risk factors.[44] This suggests that age and education level establish a greater cognitive reserve, to the extent that cognitive improvement might not be affected.[45]

In discussing the minimized effect of years of smartphone usage on older adults' performance, a study investigating older adults' attitudes toward computer use showed 93.5% of the participants to possess a positive attitude to learning the new technology.[46] The finding on the association between cognitive ability and years of smartphone usage is congruent with a study,[47] showing that frequent usage of smartphones is associated with better cognitive performance in older adults. The important functions of smartphones to older adults include not just calling, display of date and time, and incoming calls with the caller's picture, but use of various apps using visual scanning and executive functioning. These functions improve their temporal and reality orientation, and provide opportunities for exposure to cognitive stimulation such as the attention and memory needed for using mobile devices.[48] Added to that, guidance and assistance were given during the training by the staff, minimizing the knowledge gap between participants with different experience in using smartphones. Hong Kong has a high smartphone penetration rate (88.6%), and that one in two people aged 65 or above own a smartphone in Hong Kong.[49] With recent advance in mobile technology, social connectivity and engagement is getting more common, remote cognitive training app in terms of using mobile devices for older adults as primary prevention to improve their cognitive reserve and secondary prevention to delay cognitive decline is becoming applicable and practicable,[50,51] thus, the use of cognitive training through mobile apps via smartphones or tablets might be a potential area for exploration for the ageing population.

This study has limitations. The first limitation was the inhomogeneity of the sample because participants were recruited based on convenience sampling from five activity day-centres. Second, the study did not include a control group. The use of a randomized controlled study could help to prove the effectiveness of the cognitive training programme on the targeted populations. Third, we did not assess the generalization of the improved cognitive functioning to daily functions by using an outcome measure associated with everyday cognition to confirm the functional transfer effects of cognitive training. In addition, the MoCA 5-min is not a fully comprehensive assessment tool in measuring overall cognition – it consisted of the tasks on attention, memory, executive function/language, and orientation, but other cognitive domains were not assessed. In future, if adequate time and manpower permitted, a more holistic cognitive assessment should be administered to all participants. Moreover, parallel versions of the MoCA 5-min had not been developed, so we could not exclude the testing effect given the design of repeated testing in the study. Lastly, although the participants included in this study were stratified to with or without risk of MCI according to the cut-off score of the MoCA 5-min, we lacked their medical histories and confirmed diagnoses of MCI by a physician. Last but not least, under-challenging of the cognitively healthy participants for some of the cognitive training tasks might be one of the extraneous factors for the between-group differences.

Conclusion

This study shows the efficacy of CCT using an app in mobile devices in improving the overall cognitive function of older adults with and without risk of MCI, our findings show that older adults at risk of MCI benefited more as shown from both the MCID on global cognition improvement and individual task-based domain-specific performance of the CCT. Further study on the generalizability to real-life settings and long-term effectiveness in the form of a randomized controlled trial and longitudinal follow-up is warranted.

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Ethics approval statement

Ethical approval was obtained from the organization and the Human Subjects Ethics Committee of the Hong Kong Polytechnic University (Reference number: HSEARS2021 0730001).

Authors' contribution

KNKF, WWSW, DKFL, DSHK designed the app and the study. AWKS, KCHC, JYLC, AMHL, and RCYW did the data collection. KNKF, PCG, AWKS, KCHC, JYLC, AMHL, and RCYW did the data analysis and prepared the manuscript draft. KNKF, PCG and JSYL edited the draft. All authors read and approved the final manuscript.

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Declaration of competing interest

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Patient consent statement

Informed and written consent was sought from each participant by the investigators before data collection. Ethical approval was obtained from the organization and the Human Subjects Ethics Committee of the Hong Kong Polytechnic University (Reference number: HSEARS20210730001).

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