Psychiatria Danubina, 2017; Vol. 29, Suppl. 3, pp 292-299 *Conference paper*

IS THERE AN OPTIMAL COGNITIVE APPLICATION TO BE USED FOR COGNITIVE REMEDIATION IN CLINICAL PSYCHIATRIC PRACTICE?

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SUMMARY

Cognitive dysfunction is a common characteristic across a number of psychiatric conditions. With growing technological advances, application based cognitive remediation (cognitive apps) is becoming steadily popular due to its accessibility, ease of use and minimal interference with the activities of daily life. However, despite a number of benefits that application based cognitive training possesses, it is not clear, whether the utilisation of these apps is a reliable approach that can be recommended in clinical psychiatric practice in order to restore cognition. In the present review, we have analysed eleven applications which trained the cognitive domains of memory, attention, language, processing speed, executive function and perception with respect to the structure and function of the applications, duration of use and measuring and monitoring of user progress and assessed them, based on the published data, for efficacy in the general population and clinical subgroups of the population. We conclude that, given that there are differences between the apps, given that there is a difference between the general population using these apps and groups suffering pathological conditions using them, given that cognitive deficits are caused by different pathological processes in different illnesses and that different illnesses present with different ranges of deficits, it is not possible to make blanket recommendations for the use of the apps. Nor is there sufficient published evidence for any of the apps to be specifically recommended for cognitive remediation. More evidence, such as trials of specific apps in different conditions, trials of specific apps against therapist guided techniques and blind trials of different apps against each other are necessary before recommendations of particular apps for particular remedial treatments can be made. Nor can 'brain training' in normal populations be seen as preventing cognitive decline or be seen as proof that cognitive remediation can improve cognition in pathological groups. Our paper serves as a useful reference to what apps are available, how they compare, and what the published evidence is, with a view to planning further research.

Key words: *cognitive dysfunction - cognitive remediation - cognitive apps – memory – attention – language - processing speed - executive function - perception*

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INTRODUCTION

Cognitive dysfunction is a common characteristic across a number of psychiatric conditions (Milan 2012). Cognitive deficits can vary between an array of conditions, but are characterized by a constellation of impairments which depend on the mechanisms of the diagnosed dysfunction. Generally, the most commonly affected cognitive domains are memory, attention, language, processing speed and executive functions. To date, there are no proposed or concrete treatment guidelines for cognitive dysfunction in psychiatric disorders. However, improvement of Cognition remains a major objective in treatment of psychiatric disorders. In Dementia, this has led to the development of a number of pharmacological options such as Modafinil, Donepezil, Rivastigmine, Galantamine and Memantine, while in Schizophrenia, the failure of Atypical antipsychotics to improve cognition despite initial promise has led to attempts to find alternative means of treatment, possibly based on Glutamate pathways. In both cases, it is expected that cognitive remediation therapy could (and in some services are) be widely applied in combination with medication, in clinical populations, including in subgroups of patients who experience mild to severe cognitive impairments.

Cognitive remediation can be defined as a group of "systematically applied set of medical and therapeutic services designed to improve cognitive functioning" (Katz 2006). At present, cognitive remediation therapy can be delivered by two generally accepted approaches: computerised cognitive remediation and paper and pencil tasks administered by a trained clinician. Computerised cognitive remediation can be further divided into therapist guided computerised cognitive training and application based cognitive training.

Therapist guided techniques allow closer monitoring of patients and ensure compliance with remediation programmes. Additionally, therapist guided approaches provide support and encouragement to patients, as well as clear instructions and advice regarding rehabilitation exercises. Therapist guided approaches offer optimum training environments to patients, limiting distractions or interferences in training thus allowing more accurate results to be obtained at the end of remediation sessions.

In stark contrast to therapist guided approaches, cognitive application based training programmes involve the patient performing rehabilitation exercises at home with minimal therapist contact. Due to a lack of therapist-patient communication, the use of home-based cognitive training applications may result in the patient becoming disheartened and disillusioned, resulting in slowed or stagnant progress and lower rankings in comparison to other users in their comparative cohort.

Therapist assisted computerised cognitive remediation provides drill and practice based training combined with strategy coaching, enabling patients to compensate for cognitive deficits and teaches adaptive techniques to improve daily functioning. Contrary to computer based cognitive training, application based training typically only employs drill and practice based training. It is a generally low support form of computerised training which may culminate in poor patient compliance.

At present, technology is an integral component of society (Mohr et al. 2013). With growing technological advances, application based cognitive remediation is becoming steadily popular due to its accessibility, ease of use and minimal interference with the activities of daily life. At present, smartphones, online technology and mobile applications are generally affordable. Clinical psychiatry is no exception to this trend (Peek 2015). Technologies within psychiatric services are growing exponentially and becoming more available to clinicians thus, more accessible to patients. The availability of such technology broadens the spectrum of treatment options for clinicians and patients alike. These cognitive applications take cognitive remediation into the comfort of the patient's own home, therefore avoiding a journey to a psychiatric out-patient clinic. Clinical populations are not the only group which benefit from application based cognitive remediation. Individuals outside clinical psychiatric groups, are becoming more aware of their existence and function as a consequence of online advertising, marketing campaigns and social media. However, while there are many benefits to application based cognitive training, do we possess enough evidence to definitively say these applications can be effectively used in clinical psychiatric practice?

METHODS

From an online search of application webpages and free versions of the applications, we selected ten applications which were screened and scrutinised. These apps were proposed by Happy Neuron, Happy Neuron Pro, Lumosity, Brain HQ, Cognifit, Fit Brains, Elevate, Peak, Mensa Brain Training, and Brainwell. All mentioned applications were selected from what is currently available and are easily accessed using basic online searches. Our evaluation of the applications took into account four aspects: structure and function of the application, duration of use of the application, monitoring of the user and suitability of use based on the diagnosis. The exercises and brain training games from each application were reviewed, compared and contrasted. Data is summarised in Table 1.

Structure and Function of the Applications

The Structure and Function of the applications were evaluated from six aspects; Memory, Attention, Language, Executive Functions, Processing Speed and Perception. Happy Neuron and Happy Neuron Pro, Lumosity Brain HQ Cognifit, FitBrains, Elevate, Peak, Mensa Brain Training, and Brainwell all trained memory. Happy Neuron and Happy Neuron Pro contained the most diverse selection of memory training activities. Happy Neuron trained verbal memory, Visual/Spatial memory, episodic memory, semantic memory, procedural memory, long-term memory, short-term memory and sensory memory. In contrast to this, Happy Neuron Pro trained Visual/Spatial Memory, Episodic memory and semantic memory. All applications trained Attention. Happy Neuron, Happy Neuron Pro, Lumosity, Brain HQ, Cognifit and Peak specifically trained focused attention. Selective attention was specifically trained by Happy Neuron, Happy Neuron Pro, Lumosity and Brainwell. Divided attention exercises were included in Happy Neuron Happy, Neuron Pro, Lumosity, Brain HQ, Cognifit. Sustained attention and concentration games were found in Happy Neuron, Happy Neuron Pro, Brain HQ, Cognifit. Response control/ inhibition tasks were noted in Brain HQ, Cognifit, Peak, and Brainwell applications. Cognifit was the only application to specifically train response time.

Language training options were provided by Happy Neuron, Happy Neuron Pro, Brain HQ, Lumosity, FitBrains, Elevate, Peak and Brainwell. Spelling exercises were included in Happy Neruon, Happy Neuron Pro, Fit Brains and Elevate. Games which improved syntax were found in Happy Neuron Pro. Vocabulary training functions were visible in Lumosity, Fit Brains, Peak and Brainwell. Reading Comprehension tasks were provided in Happy Neuron, Lumosity and Fit Brains applications. Grammar games were found in both Happy Neuron and Happy Neuron Pro applications alike. Verbal fluency/pronunciation featured in Happy Neuron, Lumosity, Elevate and Peak. The diction and eloquence components of language were only trained in the Elevate application.

Executive function training was included in the Happy Neuron, Happy Neuron Pro, Brain HQ, Lumosity, FitBrains, Elevate, Peak, Cognifit and Brainwell applications. Problem solving was the most commonly featured component of executive functions which was used in Happy Neuron, Happy Neuron Pro, Lumosity, Brain HQ, Fit Brains, Peak and Brainwell. Cognitive flexibility training was included in Happy Neuron, Happy Neuron Pro, Cognifit and Peak. Understanding of the verbal description tasks were only available specifically by Lumosity. Numerical calculation and arithmetic exercises was trained in the Happy Neuron, Cognifit and Elevate applications. Exercises in solving Estimation and planning were featured in Happy Neuron, Happy Neuron Pro, Lumosity, Cognifit and Peak. Spatial, deductive, logical and quantitative reasoning

Table 1. Brain training games

Function	Happy Neuron	Happy Neuron Pro	Lumo-sity	Brain HQ	Cogni-fit	Fit Brains	Ele-vate	Peak	Mensa Brain Training	Brain-well
Memory	+	+	+	+	+	+	+	+	+	+
Verbal memory	++	++		++	++					
Visual/ spatial memory	++	++	++	++	++	++		++		++
Auditory Memory	++	++		++	++					
Short-term memory	++	++			++				++	
Working memory	++	++	++	++	++			++		
Associative memory	++	++	++				++			
Sensory memory	++			++	++					
Lexical Memory	++				++		++			
Attention	+	+	+	+	+	+	+	+	+	+
Focused Attention	++	++	++	++	++	++	++	++		
Selective Attention	++		++	++	++					++
Divided Attention	++	++	++	++	++					
Sustained Attention and concentration	++	++		++	++	++		++	++	
Response control/inhibition	++			++	++			++		++
Response Time					++					
Language	+	+	+	+		+	+	+		+
Spelling	++	++				++	++			
Syntaxis	++									
Vocabulary Proficiency	++		++			++	++	++		++
Comprehension	++		++			++	++			
Grammar	++	++								
Verbal Fluency/pronouciation	++		++				++	++		
Diction and eloquence							++			
Executive Functions	+	+	+	+	+	+	+	+	+	+
Problem solving	++	++	++	++		++		++		++
Cognitive Flexibility	++	++	++	++	++			++		
Numerical calculation and arithmetic	++		++		++		++	++	++	++
Estimation	++				++					
Planning	++	++	++		++			++		
Spatial reasoning	++	++	++	++	++	++		++		
Deductive reasoning	++	++								
Quantitative reasoning			++					++		
Logical reasoning	++	++	++			++		++		
Critical thinking	++			++						++
Perception	+	+	+	+	+	+		+	+	+
Visual	++	++	++	++	++	++		++		++
Auditory	++	++		++	++					
Processing Speed	+	+	+	+	+	+	+	+	+	
Other	+	+	+	+	+	+	+	+	+	
Interaction across functions	++	++						++		
Mental rotations	++	++		++						
Orientation	++			++						
Agility	++							++	++	
Emotional intelligence/ interpretation	++			++	++	++		++		
Coordination	++			++	++			++		
Facial/Visual recognition	++		++	++	++			++	++	
Width of field view					++					

NOTE: Information was gathered via app webpages and free versions of apps. Width of field view unique to Cognifit. Aim is to help while driving. Cognifit also train emotional intelligence. Has 3 levels of difficulty for each game (beginner, intermediate, advanced) were included in Happy Neuron, Happy Neuron Pro, Lumosity, Cognifit, Peak and Fit Brains exercises. Decision making tasks were a specific feature of Brain HQ. Critical thinking games could be viewed among the Happy Neuron, Brain HQ and Brainwell applications. Strategy devising was featured in Happy Neuron Pro and Lumosity applications.

Visual perception was a common feature of all applications, while auditory perception was included in the Happy Neuron, Happy Neuron Pro, Brain HQ and Cognifit applications. Processing speed exercises were a specifically trained characteristic of all applications.

Some applications possessed specific and unique functions which differentiated them from others. Happy Neuron Pro has devised three separate training programmes specific to the user's needs; The Aging Well Programme, The Psychiatry Programme and the Rehabilitation Programme. Other specific application features are summarised in table 1.

Duration of Use

Each cognitive application varied in their approach to the recommended period of time a user should dedicate to training with the application. Happy Neuron sets out personalised training programmes for each user. A coach is allocated to the user and a training plan is devised. Happy Neuron Pro also devises specialised training programmes specific to the patient's needs. Therefore, duration of training times may vary. Lumosity advises users to use the application daily to train five core cognitive abilities. Brain HQ also encourages daily training sessions which challenge five core cognitive skills. Unlike Lumosity, these training sessions last for two minutes each but the user may continue for longer periods of time. FitBrains, Mensa BrainTraining, Peak and Elevate also advise daily training. Cognifit recommends two-three sessions per week lasting twenty minutes.

Measuring and Monitoring of the User

Happy Neuron users can track their progress through the application tracking tool or personalised coaching sessions. The tracking tool provides general and detailed overviews of the progression of the user's cognitive performance. In addition, graphs are also available which provide feedback on the user's strengths and weaknesses based on other user's performance which match user demographic characteristics. Personalised coaching sessions take account of past activity and adapt training sessions in accordance with this. In Contrast to Happy Neuron, Happy Neuron Pro does not compare patient performance to other users of the application. Clinicians can monitor user compliance and performance with the application. Detailed histories of game performance can also be viewed. Similarly, Cognifit also include a section for the participation of healthcare professionals. This tool allows clinicians to perform a complete cognitive screening of the patient and monitor the patient's progress.

Brain HQ provides five options for the user to evaluate their progress. Baseline-scores are awarded for the first time a new exercise is completed. After repetition of the exercise, a best score is given and the user can compare this to their baseline score to map their progress. In addition, one to five stars are given to measure specific performance each time a game is played. Training calendars and performance charts provide a detailed description of performance, percentile rank and number of stars allotted to each game. Comparisons between other users of the same age demographic can be viewed. Brainwell also provides the option of taking a "fitness test" to determine the user's baseline score.

Elevate, Peak, Fit Brains, Brainwell and Lumosity all evaluate their users based on numerical rating quotients. All of the aforementioned applications, also provide rankings, percentiles and graphs so users can compare their progress to others using the same application. Elevate, Fit Brains and Peak allow users to track their weekly and monthly training activity. Additionally, Brainwell includes worldwide averages to aid in the monitoring of the user's progress. Peak provides the user with Brain Maps, which allow users to draw comparisons to others using the application based on their age, profession etc. It also allows users to set training goals and reminders so training sessions are not missed.

DISCUSSION

A meta-analysis by Grynszpan (2011), calls attention to certain advantages associated with computerised cognitive remediation. Computer graphics allow for more dynamic testing in comparisons to paper versions as well as providing a "multi-sensory presentation" of training exercises (Medalia 2001). Immediate feedback regarding performance (Belluci 2003) is also advantageous as patients acquire results immediately after completing a training session. Due to a lack of communication with a therapist during computerised cognitive training, unbiased and objective results can be obtained (Field 1997). Stimulating and "game-like" exercises employed by computerised cognitive remediation programmes were considered more entertaining and boosted motivation among users (Field 1998).

Despite high general accessibility of cognitive training to the population due to current technological advances there can be disadvantages. One study conducted by Noyes (2008) compared the efficacy of computer versus pen and paper based tasks. The following disadvantages associated with computer based exercises were highlighted; Concerns were expressed regarding the lack of a controlled environment for remediation (Fouladi 2002, Noyes 2008). Optimum training environments with minimal distraction is essential for effective cognitive remediation. Patient attention may be affected therefore, progress and results may be lower than expected due to busy environments and the distractions of daily life, "If the distracting stimulation requires responses (i.e., dual-task performance), more attention will be required and more disruption will ensue" (Craik 2014). Essentially, therapists have no access to or control of a user's home environment at any given time.

User confidentiality, personal information and results are a privacy concern for those involved in computerised training programs (Morrel-Samuels, 2003). In today's computerised world, computer security is an ongoing issue with the increasing occurrences of cyber attacks and computer hacking.

Prolonged training on a computer screen may lead to higher rates of eye fatigue/strain (Akinbinu 2014). Additionally, a performance deficit does seem to occur for more visually- or cognitively-demanding tasks" (Dillon, 1992). Hence, the results that are obtained may not be a true reflection of patient performance.

Computer software is not completely reliable and may be susceptible to unexpected technical failures, requiring tests to be re-administered. Zandviliet and Farragher (1997) as cited in Noyes and Garland (2008) found computerised versions of tests required more administration time than paper versions.

Clinical status is subject to change and may fluctuate between relapse and remission of symptoms. This can affect the outcome of the training. Relapses of psychosis can interfere with training progress, as seen in a case study by (Thibaudeau 2017). Thus, training may be ceased for unknown periods of time.

Some patients may require extensive explanation of specific tasks by a therapist due to the nature of their impairment. Therefore, patients involved in application based training, may perform poorly due to an inability to fully comprehend specific remediation tasks. With this in mind, it may be difficult to ascertain the true progress or indeed the extent of a patient's cognitive deficit.

Basic Computer literacy is required to undergo both application based and computerised cognitive training. This is highlighted in a study by Grignon and colleagues (2009), where they note that Information technology and computer familiarity are clearly influenced by age in the general population. If this point is acknowledged, computerised cognitive remediation and application based cognitive remediation may not be as accessible or applicable and may certainly be more challenging in older populations. In a study conducted by Goodman, Syme and Eisma (2003) it is noted "decline in use with age was highly significant" when speaking on older adult's use of computers. Once again, it appears, computerised cognitive remediation is more suitable to a younger, more computer literate cohort as Noyes & Garland (2008) highlighted this point, by citing Hargreaves and colleagues (2004) who stated, "young people in the UK today are familiar with using computers".

Motivation of a user is also an important consideration when using cognitive applications in a home-based setting. Few app promoters "discuss the importance of motivation or context in the likelihood of transfer or consider how their particular training context might enhance or limit transfer to other contexts" (Simons 2016). This may also have a negative outcome on results.

The applications analysed in this paper can generally be divided into two main groups: brain training applications available to the general public and professional versions offered to patients with definite cognitive impairments in a clinical setting. General cognitive training is available to members of the public who do not have any diagnosed cognitive dysfunction. They are aimed at individuals interested in 'brain-training' and making improvements with daily cognitive functioning. These applications are becoming increasingly popular thanks to online advertising ploys, social media and so called "mass marketing of brain-training products" (Simons 2016). Unlike professional versions, progress is not typically monitored by a therapist and applications automatically alter the difficulty levels of an exercise based on user performance.

Elevate, Lumosity, Fit Brains, Happy Neuron, Mensa Brain Training, Brain HQ Peak, and Brainwell are all targeted at those who lie outside of a clinical community. Nakano (2015), conducted an Elevate Effectiveness Study and found Elevate group users of the application "consistently scored higher in a statistically significant way" and also showed overall greater improvements in comparison to the control group. The Elevate group showed improvements of 69% compared to non-users across four cognitive skills (Writing, Listening, Speaking and Mathematics).

Lumosity carried out an effectiveness study with 4,715 participants. Half trained with Lumosity, while the remainder completed online crossword puzzles to act as a control group. After ten weeks, the Lumosity group showed greater improvements in contrast control groups. The authors suggest that, while these results are promising, further research into the topic is required.

Fit Brains was used in a five-year follow-up by Willis and colleagues (2006) in ACTIVE study. This showed a five-year follow-up of a randomised controlled single-blind trial with 4 treatment groups of a total of 2832 persons with an average age of 73 years old. Ten training sessions for memory, reasoning and processing speed were completed followed by a 4-session booster training at 11 and 35 months after training in a random sample of those who completed training. Results of this study showed "Each intervention produced immediate improvement in the cognitive ability trained that was retained across 5 years".

The Bronx Aging Study also included on the Fit Brains webpage, which was published in the New England Journal of Medicine, followed almost 500 people for more than 20 years. This research found that people who participated in mentally stimulating activities, multiple times a week had a 65-75% better chance of remaining cognitively agile than those who did not participate in these activities. However, Fit Brains state that "The studies provided here are written by independent third parties and the publication of such content by Fit Brains does not imply any affiliation with Fit Brains or endorsement of Fit Brains products". Additionally, they state "software such as Fit Brains have not been evaluated by regulatory authorities and are not intended to diagnose, treat, cure, or prevent any disease”.

The largest study featured on the Happy Neuron website included scientific data provided by Bernard-Tarpin and Croisile (Bernard-Tarpin, 2012). The results of this study show a significant improvement of cognitive profile, which corresponds to training intensity but was not correlated to gender, age or educational level. Based on their findings it is recommended to train for thirty-forty minutes per session, between three and five days a week for optimum outcomes of ninety days of brain training.

No open access data was available for the efficacy of Peak, Brainwell and Mensa Brain Training. Some of the problems with ‘brain training apps’ for the general public such as Lumosity are illustrated by the fact that, in January 2016 the US Federal Trade Commission found that Lumosity made “false and unsubstantiated marketing claims” and were required to pay $2,000,000 towards consumer redress and prohibited “deceptive conduct in the future” (Commissioner Brill 2016). Commissioner Brill also cautioned “Lumosity and other companies about making representations that overstate the benefits of these products or misleadingly imply that improvements in the game setting transfer to real-world benefits” (Brill 2016). Currently the Lumosity webpage states their package “is not intended to diagnose, treat, cure, or prevent any disease” in clinical populations. Indeed, the fact that some applications are only aimed at ‘Brain Training’ for the general public is of immense importance in choosing an application; while some apps may be effective for this purpose, they may not at all hold their own when applied to patients with an ongoing pathological process which causes ongoing deterioration to their condition.

The applications which was included in professional clinical training include Happy Neuron Pro, Brain HQ and Cognifit. Most professionalized versions of the applications are recommended for use in clinical populations which include: Schizophrenia, Bipolar Affective Disorder, Depression, Attention Deficit Disorder, Behavioural disorders, Mild Cognitive Impairment, Traumatic Brain Injury, Stroke, Multiple Sclerosis, Alzheimer’s Disease, Dyslexia, Speech Disorders and Learning Disorders. However, in the scientific publications, cognitive apps oftentimes are not mentioned and the intervention description summarises the specific cognitive tests or grouped cognitive tests and not the app training packages.

Happy Neuron Pro has forty-seven scientific papers online proving its effectiveness. However, thirty-one of these papers are not published and listed as still “in-progress”. In a study entitled “Cognitive remediation effectiveness for schizophrenic patients” by Franck (2008-2011) commented that, behavioural changes were noted regarding problem solving, memory and attention. However “sufficient data is not as yet available”.

The Brain HQ webpage also include a study conducted by Fisher and colleagues (2009) which found longer duration of training and drill-and-practice methods showed positive relationship in the rehabilitation of memory and verbal learning in schizophrenic patients. Improvements were also noted in global cognition. This study concluded the findings were encouraging however, more research is required to “replicate these findings in larger, more clinically representative samples of patients”. A further study on the Brain HQ webpage, by Barnes (2009), regarding cognitive remediation in mild cognitive impairment, found that intensive computer based remediation is viable although larger trials are recommended.

The Cognifit webpage listed a study by Preiss and colleagues (2013), and found the largest cognitive improvement effects in executive functioning were recorded in Shifting, Divided Attention, and in the Global Executive Score. They also found that cognitive dysfunction in depression can be relieved using cognitive training alone, or in conjunction with pharmacological remedies and/or psychotherapy. A major limitation of the study was a lack of a comparable control group. The study results were stated as promising although they needed to be followed up with broader trials to establish their efficacy on everyday functioning in patients with depression. It also stated additional and more prolonged training may be required to improve other cognitive domains and that further personalised cognitive rehabilitation could provide more future improvements for patients, although more research on the subject would be required.

CONCLUSIONS

Although the utilisation of cognitive apps may appear promising in the general population being an appealing way of encouraging and maintaining ‘normal’ brain function, it is still debatable whether patients with particular psychiatric conditions may benefit from the training since no randomized control trials have been reported so far. Given the broad spectra of exercises used in cognitive applications, the targeted intervention seems to be difficult to perform and the choice of the app is often random. From a scientific standpoint, psychiatric disorders are associated with cognitive deficits that have disease specific patterns and are caused by various brain mechanisms. Because different psychiatric illnesses may be either neurodevelopmental or neurodegenerative in nature, they have different trajectories or prognoses. Hence we must consider that patients with different psychiatric conditions cannot be ‘remediated’ in the same way. In this respect, the targeted interventions which take into the account constellations of the disturbed cognitive functions in the specific disorders and grounded on specific neuronal mechanisms are needed.

Improvement of Cognition remains a major objective in treatment of psychiatric disorders. It is expected that cognitive remediation therapy could (and in some services are) be widely applied in combination with medication, in clinical populations, including in subgroups of patients who experience mild to severe cognitive impairments. Cognitive remediation is therefore a psycho-social intervention which can enhance the treatment of these conditions, but is not likely to be effective as sole treatment. This is why we have, in the past advocated that cognitive testing should be seen as part of the assessment for the 'Recovery Model' of treating such illnesses as schizophrenia (Agius 2015). It is also true that patients with illnesses such as schizophrenia do have different trajectories of deterioration (Shmukler 2015).

Under these circumstances, We conclude that, given the differences between the apps content, a difference between the general population using these apps and groups suffering pathological conditions using them, given that cognitive deficits are caused by different pathological processes in different illnesses and that different illnesses present with different ranges of deficits, it is not possible to make blanket recommendations for the use of the apps. Nor is there sufficient published evidence for any of the apps to be specifically recommended for cognitive remediation. More evidence, such as trials of specific apps in different conditions, trials of specific apps against therapist guided techniques and blind trials of different apps against each other are necessary before recommendations of particular apps for particular remedial treatments can be made. Nor can 'brain training' in normal populations be seen as preventing cognitive decline or be seen as proof that cognitive remediation can improve cognition in pathological groups. Our paper serves as a useful reference to what apps are available, how they compare, and what the published evidence is, with a view to planning further research.

It is important that doctors, if they are to recommend a particular app, should have a working knowledge of how it works, what it measures and what it can improve, whether it does indeed give the expected results. The data presently available, and described in this paper does not demonstrate that this required information is presently available for the apps reviewed.

Acknowledgements: None.

Conflict of interest: None to declare.

Contribution of individual authors:

Avriel McDonnell carried out the main search and analysis;

Mark Agius suggested the project, drafted conclusions, corrected the script, gave advice, and contributed to the analysis;

Yuliya Zaytseva led the development of the project, supervised the project, gave advice, and contributed to the analysis.

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