ARTICLE

Coach your cortex

Is 'brain training' a sales con or evidence-based exercise?

Dan Hackley investigates

Recent years have seen a surge in the popularity of 'brain training' software; games and applications that purport to stimulate the brain and improve cognitive performance. Sales are nourished by the assumption that cognitive abilities can be maintained or improved by exercising the brain, by analogy with the way physical fitness is improved by exercising the body. But is there any evidence to substantiate these claims, or is this a marketing ploy riding on the popular wave of self-improvement? This article aims to examine the available evidence for the efficacy of software claiming to enhance general cognitive function, and in turn allow us to provide appropriate evidence-based advice to patients.

questions

Is it possible to improve on basic cognitive functions such as attention, concentration, memory, reasoning and processing speed?

resources

Owen, A.M., Hampshire, A., Grahn, J.A. et al. (2010). Putting brain training to the test. *Nature, 465*(7299), 775–778.
www.sharpbrains.com

The all-time best-selling video game in the UK, selling over 17 million copies worldwide, is called 'Dr Kawashima's Brain Training'. Developed by Nintendo, it incorporates 11 different cognitive exercises, including sudoku, reading aloud, a Stroop test, word memory, speed counting and connecting a maze. The idea is to play regularly and improve your 'brain score'. Nintendo claim that their game was 'inspired' by the work of Dr Ryuta Kawashima (a Japanese neuroscientist), and use non-scientific marketing language to draw analogies to physical exercise, though they have avoided claiming that the game has been scientifically validated.

Similar games have been released on a variety of hardware platforms, including the Apple iPhone (Brain Challenge, Brain Exercise with Dr Kawashima, Brain Toot), PlayStation Portable (Mind Quiz) and PC (Brain Train Age). There are also a number of online examples, including www.lumosity.com, www.cognifit.com and www.sharpbrains.com. But do they work?

Efficacy

This question of efficacy was recently addressed in a study organised through the BBC popular science television programme *Bang Goes the Theory*. Their 'Brain Test Britain' study (Owen et al., 2010) was a six-week randomised controlled trial where viewers of the programme were invited to practise a series of computer-based online tasks three times a week in order to ascertain whether cognitive abilities could be improved through the use of training software. 11,430 participants (aged 18-60) completed the study. Benchmark assessments conducted before and after the training programme measured reasoning, verbal short-term memory, spatial working memory and paired-associated learning. Significantly improved performance was seen across all the training tasks, but there was no significant improvement on the untrained before-and-after assessments. In other words, participants improved at the specific tasks, but there was no evidence for generalised improvement in cognitive function following training, even for tasks which involve similar cognitive functions to those trained.

This concept is central to most of the research on cognitive training; the distinction between improved performance on specifically trained tasks versus a more generalised improvement in cognitive function. As we shall see, this issue of generalisability remains a problem for researchers intending to demonstrate the efficacy of various cognitive interventions.

Although this was a large and substantial study, it has drawn criticism due to high dropout rates, questionable outcome measures and selection bias (Almond, 2010; Zelinski, 2010). It does, however, provide data on a demographic group that has otherwise received little attention in studies of computerised cognitive training – healthy younger adults. While there are a number of articles looking at cognitive training in younger adults with affective disorders (Naismith et al., 2010; Wolinksy et al., 2009), schizophrenia (Nemoto et al., 2009; Vinogradov et al., 2009), children with ADHD (Abikoff, 1991) and preschool children (Thorell et al., 2009), the evidence base examining these interventions in healthy 18- to 60-year-olds remains very limited.

The majority of the existing research in this field focuses on the healthy elderly, in the context of disease-modifying interventions to delay or slow progression to mild cognitive impairment or

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Alzheimer's disease. Two of the largest studies conducted in this population are the American ACTIVE and IMPACT studies.

The ACTIVE (Advanced Cognitive Training for Independent and Vital Elderly) study (Ball et al., 2002) was the first multicentre, randomised controlled trial to examine both the immediate and long-term effects (up to five years post-intervention) of cognitive training on daily functioning and cognitive abilities in older adults. Participants were included if they were over 65, living independently and possessed 'good cognitive status' – a score on the Mini Mental State Examination of ≥ 22/30. Three intervention groups received 10 group sessions and four booster sessions of memory, reasoning or speed of processing training, with a control group receiving no intervention. Outcome measures included tests closely related to the training tasks, general simulations of everyday tasks, and performance of activities of daily living and driving. The authors conclude that performance improved significantly on the measures that were specifically trained: again, this improvement did not generalise to measures of everyday function.

Is exercising the brain analogous to the way physical fitness is improved by exercising?

In 2009 the IMPACT (Improvement in Memory with Plasticity-based Adaptive Cognitive Training) study (Smith et al., 2009) evaluated the effect of a computerised cognitive training programme in 487 adults over the age of 65 with an MMSE score of 26 or greater. Unlike most previous studies, an audio-based training programme ('Brain Fitness Program' from Posit Science) was used. This choice was based on the hypothesis that in older adults, the quality of sensory information processing may be linked with cognitive ability. Forty training sessions were spread over eight weeks. The primary outcome also measured auditory-related performance (as part of the Repeatable Battery for the Assessment of Neuropsychological Status), though other tests were also used to circumvent any potential ceiling effects. Significant improvement on the trained tasks was found; and, unique to this study, the improvement also generalised to most of the untrained standardised measures (effect size 0.23). No such similar effect was observed in the control group who underwent a learning-based training programme with similar amounts of training time and computer use to the experimental group.

Although these results are promising, the degree of observed generalisation would appear limited; all of the measures were restricted to auditory memory and attention, the study focused on memory-related tasks as opposed to more general cognitive function, and the observed effect size was small.

Both of the above studies were included in a recent meta-analysis (Papp et al., 2009) that aimed to review the studies published after 1992 on cognitive training in the healthy elderly and to assess and compare the efficacy of different cognitive interventions. Eight smaller randomised controlled trials were also included, though the authors acknowledge that the two larger trials dominate the analysis. In their analysis, similar types of training in the various studies were grouped together to reflect the categories used in the ACTIVE study. Small effect sizes were found for improvement in memory, reasoning, processing speed and multimodal training. They conclude that training improves immediate performance on related tasks though overall found no evidence for generalisability of training and scant evidence for long-term effects or delay of progression to dementia (largely due to insufficient follow-up periods). The authors do acknowledge that combining effect sizes across differing training regimens may have dampened the effect of gains in more specific tasks, a limitation which may have nullified the findings of generalisability of the IMPACT study. Overall, more research is needed, in particular of long-term benefits.

Cognitive impairment

Although not a demographic targeted by most brain-training games, similar studies have been carried out using participants with pre-existing diagnoses of dementia or cognitive impairment. Findings of these studies are similar to those conducted in the healthy elderly. A number of studies report significant cognitive improvements, though these are generally domain-specific and without generalisation (Cherry & Simmons-D'Gerolamo, 2005; Davis et al., 2001; Hoffman et al., 1996). A Cochrane systematic review (Clare et al., 2003) combined nine RCTs that compared cognitive training with control conditions in early-stage Alzheimer's. Despite a wide diversity of outcome measures, no significant positive effects of cognitive training were observed, though the evidence base was acknowledged as limited. A more recent literature review (Yu et al., 2009) explored the effects of various non-pharmacological interventions in early-stage dementia. Here, cognitive training was divided into

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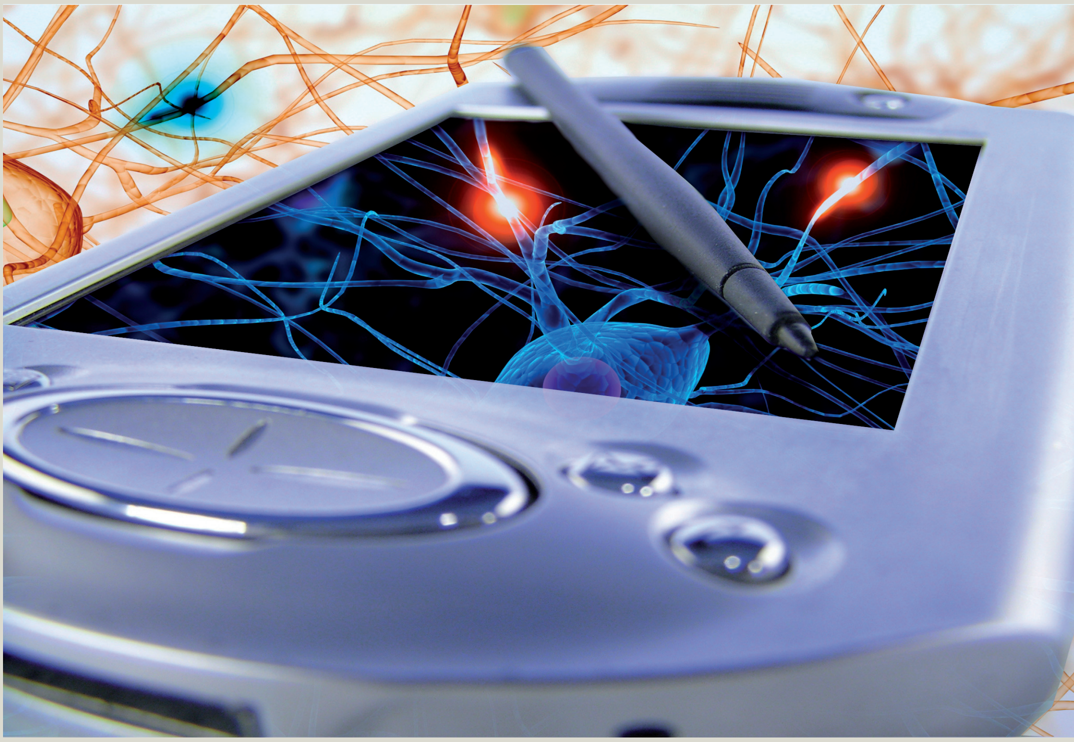

cognitive stimulation (active or passive), memory rehabilitation, reality orientation and neuropsychological rehabilitation. The emerging evidence suggested that cognitive training interventions improve cognition, with an average improvement of 1.5 points on MMSE. However, the selection criteria for the review were broad and poorly defined, little assimilation of the data was attempted and no comment was made on the generalisability of these observed improvements.

Generalisability

Generalisability therefore remains a key outcome in these kinds of study. It may be defined as the spread or transfer of performance gains from specifically trained tasks to untrained, more general abilities. It implies a shift from more basic forms of learning derived from repetitive practice to improvement of more general cognitive functions, such as memory, attention, reasoning and speed of information processing.

The literature on skill learning does indeed confirm that we are capable of improving on effectively any task with practice, though this improvement tends to be specific with little transfer even to similar tasks (Mackrous & Proteau, 2007; Seidler, 2004; Sowden et al., 2002). In many studies, generalisability has been assumed to be associated with delayed cognitive decline, especially if there has been evidence of any long-term benefits. This concept relates to the 'brain health' model that nourishes the sale of commercially available 'brain training' games. The issue of generalisability is thus a link between study conditions and real-world function; if these gains are transferable, then they may confer a beneficial effect on everyday cognition, function and performance – or in financial terms, healthcare costs.

A review article by Green and Bavelier (2008) addressed this issue of generalisation by aiming to identify those training regimens that led to generalised and persistent improvements, and to clarify those factors that contributed to a more general learning outcome. Learning was noted to be highly specific throughout cognitive, motor and perceptual domains, though they identified three training paradigms where learning has been shown to be more generalised – action video games, music and athletics. Action video games were shown to be particularly effective in terms of generalisability of learning to untrained tasks, though these tended to be visuospatial tasks. These games were defined as fast-paced and unpredictable, requiring monitoring of the entire screen with rapid decision-making. This complexity was considered to demand a greater degree of parallel information-processing in different domains, a feature shared with musical and athletic tasks. Other shared characteristics that were identified included small incremental increases in difficulty, optimal levels of motivation and arousal, feedback and reward, and variability of the task itself. This would seem to imply that in order to elicit performance gains that are generalisable, the training tasks should themselves be of a general or complex rather than a specific nature.

In the brain

Learning, the cognitive process of acquiring skill or knowledge, has thus been shown to be an ability that continues throughout life and that works best when the rehearsed material is as similar to the intended or measured outcome as possible. Research is ongoing into the structural and neurochemical

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correlates of this process. Cognitive training has been shown to increase metabolic demands of various brain regions, with other regions becoming more active in the resting state following training (Mazoyer et al., 2009). This may imply synaptic potentiation and neurogenesis, which is known to continue throughout life with neural stem cells remaining active in various regions (Gage, 2002). Neurogenesis in the hippocampus has been linked to learning and memory (Kempermann et al., 2002; Neves et al., 2008).

Valenzuela & Sachdev (2009) further examine the link between neurobiological mechanisms and cognitive function and place this in the context of the environmental enrichment paradigm. This paradigm is based on evidence suggesting that individuals with greater education or cognitively demanding occupations are at lower risk of developing dementia. In their article they found mental stimulation to be a robust trigger for both brain-derived neurotrophic factor and nerve growth factor (proteins involved in neural cell proliferation) and a prompt for increased synaptic plasticity and synaptogenesis, particularly in the hippocampus.

These effects are not unique to cognitive training, however. Antidepressants and physical exercise have both been shown to exert similar neurogenerative effects (Ernst et al., 2006). Indeed, a robust evidence base has developed for the direct beneficial effects of physical exercise on cognitive function in a variety of populations. Meta-analyses have quoted effect sizes varying from 0.25 when examining acute and long-term effects (Etnier et al., 1997) to 0.48 in sedentary older adults (Colcombe & Kramer, 2003), to 0.57 in those aged over 65 with cognitive impairment (Heyn et al., 2004), where beneficial effects on physical fitness, positive behaviour and cognitive function were noted. A more recent review of the subject (Hillman et al., 2008) confirms this beneficial effect of exercise throughout the lifespan, with effect size varying depending on the aspect of cognitive function measured (0.68 for executive tasks, 0.48 for controlled tasks, 0.44 for spatial tasks and 0.3 for speed tasks). The magnitude of these effects has been found to be related to the length of the fitness intervention, the type of intervention and the duration of training sessions (Colcombe & Kramer, 2003). These effect sizes are significantly larger than most of those quoted for any cognitive-training interventions.

Overall, the relevant underlying neurobiological mechanisms behind any observed improvements in cognitive performance following training remain unclear. As mentioned at the beginning of this article, companies targeting the commercial or entertainment-based cognitive training market often use pseudoscientific or unsubstantiated claims to enhance product sales. Indeed, it is clear from the advertising market that neuroscientific information tends to bolster consumers' interest in a product be it a shampoo, anti-ageing cream or brain-training programme. However, as Weisberg et al. (2008) succinctly demonstrate in their article 'The seductive allure of neuroscience explanations', the appeal of a 'scientific' explanation often clouds individual reasoning or judgement to the extent where explanations may be uncritically accepted, even where the information presented is irrelevant to the explanation.

"the appeal of a 'scientific' explanation often clouds individual reasoning"

Conclusions

The commercial 'brain training' industry is a substantial, global and growing field, with increasing numbers of companies jumping on the bandwagon to promote their software or services to the general public. This growth has been potentiated through the use of advertising to cultivate a public perception of efficacy of these products, sometimes bolstered with small self-sponsored studies (which are seldom peer-reviewed). Published research has been carried out on cognitive training in a wide variety of populations, including healthy adults, those at risk of cognitive decline, and those with cognitive impairment or dementia. In all of these groups, the research data generally shows similar patterns; increased cognitive performance is usually seen for the specific tasks being trained, though this improvement does not tend to generalise to the untrained or benchmark tests. To enable generalisation of learning, the training tasks themselves may have to be of a more general and multidimensional nature. The research base is, however, very limited, with a wide variety of training methods and outcomes used, making it difficult to combine studies to address these hypotheses. Given the ease of access to these programmes and the potential gains, more research would be warranted.

Overall, though, there is little evidence at present to recommend this type of intervention to those looking to improve their cognitive function. One intervention that has repeatedly been shown to improve cognitive function is physical exercise – when discussing these issues with patients, the decision to advise them to engage in such an intervention with an already firmly established evidence base would seem a no-brainer.

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