RESEARCH ARTICLE

International Journal of Geriatric Psychiatry

Associations between cognitively stimulating leisure activities, cognitive function and age-related cognitive decline

Nicola Ferreira[1], Adrian Owen[2], Anita Mohan[3], Anne Corbett[1] and Clive Ballard[1]

[1]Wolfson Centre for Age-Related Diseases, King's College London, London, UK
[2]Medical Research Council Cognition and Brain Sciences Unit, Cambridge, UK
[3]University College London, London, UK
Correspondence to: C. Ballard, E-mail: clive.ballard@kcl.ac.uk

Objectives: Emerging literature suggests that lifestyle factors may play an important role in reducing age-related cognitive decline. There have, however, been few studies investigating the role of cognitively stimulating leisure activities in maintaining cognitive health. This study sought to identify changes in cognitive performance with age and to investigate associations of cognitive performance with several key cognitively stimulating leisure activities.

Method: Over 65,000 participants provided demographic and lifestyle information and completed tests of grammatical reasoning, spatial working memory, verbal working memory and episodic memory.

Results: Regression analyses suggested that frequency of engaging in Sudoku or similar puzzles was significantly positively associated with grammatical reasoning, spatial working memory and episodic memory scores. Furthermore, for participants aged under 65 years, frequency of playing non-cognitive training computer games was also positively associated with performance in the same cognitive domains. The results also suggest that grammatical reasoning and episodic memory are particularly vulnerable to age-related decline. Further investigation to determine the potential benefits of participating in Sudoku puzzles and non-cognitive computer games is indicated, particularly as they are associated with grammatical reasoning and episodic memory, cognitive domains found to be strongly associated with age-related cognitive decline.

Conclusions: Results of this study have implications for developing improved guidance for the public regarding the potential value of cognitively stimulating leisure activities. The results also suggest that grammatical reasoning and episodic memory should be targeted in developing appropriate outcome measures to assess efficacy of future interventions, and in developing cognitive training programmes to prevent or delay cognitive decline. Copyright © 2014 John Wiley & Sons, Ltd.

Key words: cognition; activities; function; age; decline
History: Received 08 November 2013; Accepted 16 May 2014; Published online in Wiley Online Library (wileyonlinelibrary.com)
DOI: 10.1002/gps.4155

Introduction

Subtle alterations of cognition are common and well established in older adults, even in the absence of dementia or significant cognitive impairment. People frequently report increasing difficulties with memory and speed of thought, and research has shown that cognitive domains such as memory, processing speed, reasoning and executive functioning decline with age (Deary *et al*., 2009; Singh-Manoux *et al*., 2011). Whilst these changes are not in themselves clinically significant, they may represent the very earliest stages of decline and are potentially important targets for public health interventions. There is a growing body of literature indicating the potential role of lifestyle factors in preventing or delaying cognitive decline, but as yet, evidence remains inconsistent, and it is unclear which factors may be directly linked to cognitive health in ageing. The existing evidence base also does not provide a clear answer as to the reasons behind the differences in cognitive decline experienced by different individuals.

Emerging evidence strongly indicates a role for cognitive reserve, defined as the combined effect of education, occupation and regular completion of cognitive leisure activities, in reducing the likelihood of developing dementia and cognitive decline over the full life course (Valenzuela and Sachdev, 2006a). One systematic review reported a 46% reduction in incident dementia in people rated within a high cognitive reserve demographic (Valenzuela and Sachdev, 2006b). A large recent longitudinal epidemiological study including over 13,000 adults over 65 years also reported a more favourable cognitive trajectory for people with a higher cognitive reserve score, with a lower risk of developing cognitive impairment (Marioni *et al.*, 2012). It is difficult to distinguish the distinct influences of education, occupation and cognitive activity as they are closely linked as lifestyle factors within the umbrella of cognitive reserve. There is some evidence to support a weak link between level of education and cognitive ability in older age from a cross-sectional study (Murayama *et al.*, 2013), although further cross-sectional studies indicate that a higher level of education leads to improved performance in specific cognitive domains but does not impact on the overall rate of cognitive decline (Martins *et al.*, 2012).

A key unanswered question is whether activities that are thought to stimulate the brain may contribute to maintaining cognitive function or reducing cognitive decline. There is some evidence to support the value of 'cognitive training', although the best studies focus on intense interventions in older individuals that include strategy training (Willis *et al.*, 2006). A recent systematic review identified 10 published randomised controlled trials (RCTs) of cognitive training in healthy older adults and reported no impact on cognition (Cohen's *d* effect size 0.16). The review highlighted the limited quality and number of existing studies examining this question and the need for larger RCTs with more robust design to be conducted over longer periods (Papp *et al.*, 2009). A number of commercial cognitive training products are marketed to older adults as a means of maintaining cognitive ability and activities such as completing crosswords and Sudoku have been widely advocated in the public domain by commercial enterprises. However, there is very little direct evidence to support the value of these activities in the absence of strategy training. A large trial of an online cognitive training programme in young and mid-life adults reported no benefit to cognition (*Owen et al.*, 2010). More recently, however, a study in 46 older adults demonstrated improvements in multi-tasking ability as well as generalised improvement to attention and working memory over 6 months following training in multi-tasking delivered through a video game (Anguera *et al.*, 2013). Although this is a small study, this is a promising indicator that targeted cognitive training may be beneficial in older adults.

There remains a great deal of uncertainty regarding the specific contribution of many common cognitively stimulating leisure activities to overall cognitive health during ageing. A better understanding of this relationship would provide valuable insight into the relative risk profiles of individuals. It would also enable better guidance to support people in understanding and reducing their risk, as well as informing future research into potential cognitive training approaches. This paper describes the outcomes from the analysis of baseline data from over 65,000 adults who participated in a large clinical trial. The analysis primarily aimed to examine the association between cognitive function and self-reported level of engagement with cognitively stimulating leisure activities such as computer games, crosswords and Sudoku to establish whether this lifestyle factor plays a role in overall cognitive health. The secondary aim was to explore trends in age-related cognitive decline over the lifespan.

Methods

Study design

Baseline data collected as part of an online RCT was analysed. This included demographics, engagement in specific cognitively stimulating activities and performance on cognitive tasks.

Participants

As part of a partnership between the British Broadcasting Corporation (BBC), Alzheimer's Society (UK) and the Medical Research Council, the BBC invited all adults (over 18 years old) in the UK and inter-wnationally to take part. Participation required a basic level of computer literacy and access to a computer with a connection to the Internet. A total of 65,431 adults were recruited and completed baseline assessments through an online platform. Participants completed a short questionnaire and a series of cognitive tasks.

Demographics and lifestyle questionnaire

Participants provided demographic information including age, gender, ethnicity and highest level of education. Level of education was recorded within seven categories from 'none' to 'postgraduate or professional qualification' (see Table 1 for full list of categories). Frequency of participation in four activities, crosswords, Sudoku or similar puzzles, cognitive training computer games and non-cognitive training computer games, were recorded as 'more than once a day', 'once a day', 'once a week', 'once a month', 'occasionally' or 'never'.

Cognitive tasks

The cognitive domains assessed within this study were grammatical reasoning, spatial working memory, verbal working memory and episodic memory as described in our previous publication (Owen *et al.*, 2010) and elsewhere (http://www.cambridgebrainsciences.com).

Table 1 Participant demographics

Variable	Age 18–64 years	Over 65 years
Age (years)		
18–29	28,955	n/a
30–39	16,788	n/a
40–49	13,521	n/a
50–64	14,718	n/a
65–74	n/a	2896
75–84	n/a	578
85–90	n/a	41
Gender		
Male	25,707 (41%)	1156 (41.3%)
Female	36,928 (59%)	1640 (58.7%)
Undisclosed	11,347	719
Ethnicity		
Asian/Asian British	4532	38
Black/Black British	777	3
Mixed race	1493	14
White	54,505	2725
Other	1328	16
Undisclosed	11,347	719
Level of education		
None	771	101
Primary school (to age 11 years/ American 5th grade)	428	36
Secondary school, e.g. GCSEs (to age 16 years/ American 10th grade)	8288	579
Further education: A levels (to age 18 years/ American 12th grade)	11,224	192
Further education: technical/vocational, e.g. HNVQ	9956	648
University degree	19,945	660
Postgraduate or professional qualification, e.g. PhD	12,023	580
Undisclosed	11,347	719

In the grammatical reasoning task, participants had to determine, as quickly as possible, whether grammatical statements about presented pictures were correct or incorrect. For example, a picture of a large square and a smaller circle with the statement 'the circle is not smaller than the square' would be correctly answered 'false'. Participants completed as many trials as possible within 90 s. The outcome measure was the total number of trials answered correctly minus the number answered incorrectly.

To assess spatial working memory, participants completed a 'spatial search' task in which they had to search through a series of boxes presented on the screen to find a hidden star. Participants had to remember that a star would never be hidden in the same box twice. The subsequent star was hidden, and participants had to begin a new search for a hidden star. To perform well in this task, participants had to remember previous searches made and develop a strategy for finding the stars. Participants were allowed to make three errors before the test was terminated. The main outcome measure was the average number of boxes opened in the successfully completed trials.

The verbal working memory task used was a computerised version of the 'digit span' task, which assesses how many digits a participant can remember in sequence. The version used here was based on the 'ratchet-style' approach in which each successful trial is followed by a new sequence that is one digit longer than the last, and each unsuccessful trial is followed by a new sequence that is one digit shorter than the last. Participants were allowed to make three errors before the test was terminated. The main outcome measure was the average number of digits remembered in all successfully completed trials.

The episodic memory task was a 'paired-associate-learning' task in which a sequence of 'window shutters' opened up on the screen to reveal a picture of a different object in each window (for example, a ball or a hat). At the end of each sequence, the participants were shown a series of objects, one at a time, and had to select the correct window for each object. The version used here employed a ratchet-style approach in which each completely successful trial was followed by a new trial involving one more window than the last, and each unsuccessful trial was followed by a new trial involving one less window than the last. Participants were allowed to make three errors before the test was terminated. The main outcome measure was the average number of correct object-place associations ('paired associates') in the trials that were successfully completed.

Statistical methods

Initial Spearman's correlation analyses were conducted to determine which cognitively stimulating activities would be entered into the regression model for each cognitive domain. Dependent variables were scores on the cognitive tasks: grammatical reasoning, spatial working memory, verbal working memory and episodic memory. To account for the increased chance of reaching statistical significance due to the large sample size, only variables with a correlation coefficient of at least 0.1 for each cognitive domain were entered into a regression analysis focussing on that cognitive modality (see Supporting Information Tables 1–3). This coefficient was selected on the basis of standard statistical texts that consider 0.1 to be a small but significant effect size (Cohen, 1988). This was therefore considered to be the minimum level of correlation for inclusion in the regression analysis. This was repeated for each of the areas of cognition examined. Outliers outside two standard deviations were removed before data were entered into the linear regression model using the forward stepwise method. In addition to analysis of the overall cohort, data from participants aged 18–64 years were analysed separately to data from participants aged 65 years and over on the basis of exploratory data analyses (Figure 1). All statistical evaluations were completed with the use of SPSS statistical analysis package (version 19.0.0, released August 2010).

Results

Cohort characteristics

Of 77,497 participants aged 18–90 years who initially registered and completed at least one baseline task, 65,431 also provided lifestyle information and were included in this analysis. In the overall cohort, the most frequent age range was 18–29 years (37.4%). Of those who disclosed their gender, ethnicity and level of education, participants were predominantly female (58.9%), Caucasian (86.7%) and educated beyond the age of 18 years (67%). Detailed demographic data are presented for both groups in Table 1.

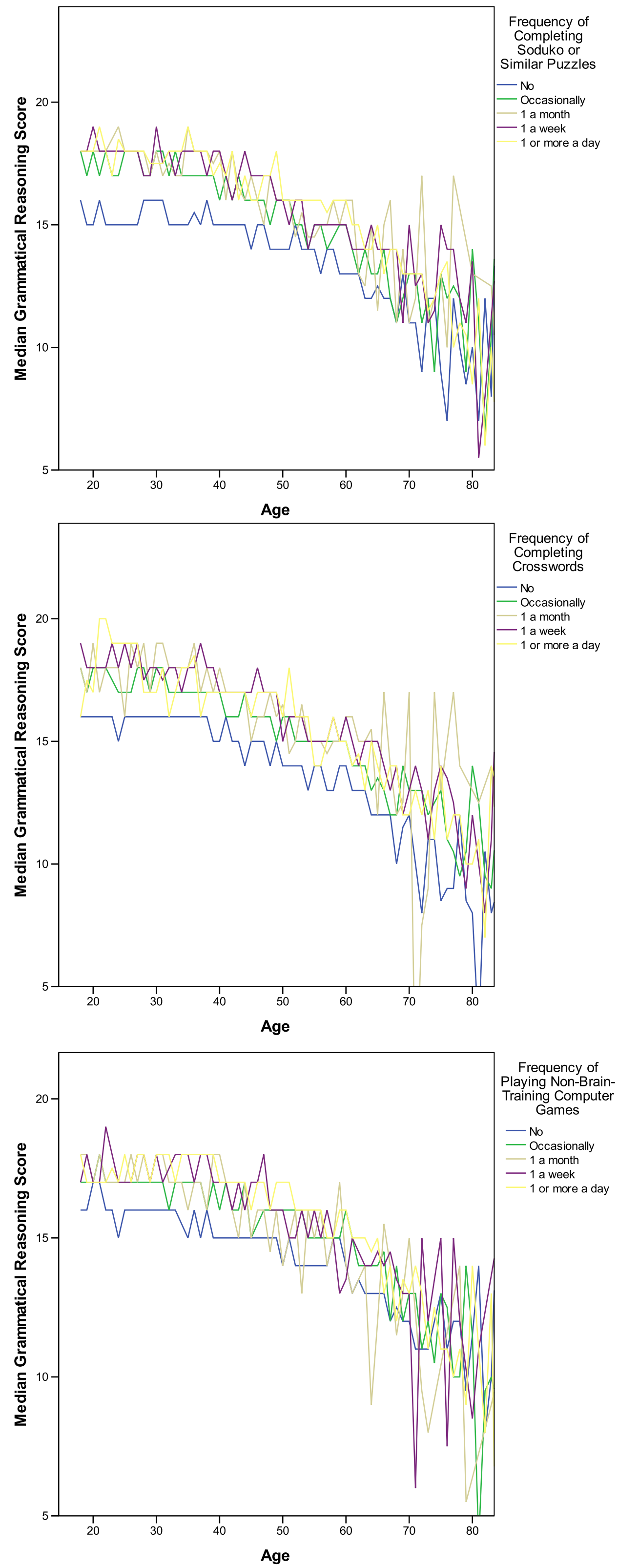

Figure 1 Median grammatical reasoning scores by age and frequency of completing Sudoku or similar puzzles, crosswords and non-cognitive-training computer games.

Grammatical reasoning

Spearman's correlations showed that age was inversely associated with grammatical reasoning ability ($r_s = -0.148$, $p < 0.0005$) in the full cohort (score range: −16 to 41). Variables positively associated with grammatical reasoning were education ($r_s = 0.103$, $p < 0.0005$), frequency of completing Sudoku or similar puzzles ($r_s = 0.124$, $p < 0.0005$) and completing non-cognitive training computer games ($r_s = 0.128$, $p < 0.0005$). Separate analyses of the 18–64 and over 65 groups indicated that although level of education was positively associated with grammatical reasoning in the over 65 age group ($r_s = 0.151$, $p < 0.0005$), it fell short of reaching the stipulated coefficient of 0.1 for the 18–64 age group ($r_s = 0.099$, $p < 0.0005$). Frequency of completing non-cognitive training computer games was positively associated with grammatical reasoning in the 18–64 age group ($r_s = 0.127$, $p < 0.0005$), although this also did not reach 0.1 in the over 65 group ($r_s = 0.085$, $p < 0.0005$). In addition to the associations identified in the full cohort, frequency of completing crosswords was positively associated with grammatical reasoning in the 18–64 age group ($r_s = 0.101$, $p < 0.0005$), but again, the correlation coefficient did not reach 0.1 in the over 65 group ($r_s = 0.088$, $p < 0.0005$). No other associations with grammatical reasoning reached a correlation coefficient of 0.1 (Supplementary Tables 1–3).

On the basis of the results of the Spearman correlation analyses, three regression analyses were performed for grammatical reasoning: one analysis per age group with predictor variables, which reached the correlation coefficient of 0.1 for that age group. Predictor variables entered into each model are highlighted in Supporting Information Tables 1–3. Significant models emerged from the regression analyses, which accounted for variation in the 18–65 and over 65 age groups and the overall cohort. The overall model ($F(4,\ 62{,}327) = 1710.01$, $p < 0.0005$) accounted for 9.9% of the variance in grammatical reasoning (adjusted $R^2 = 0.099$). The 18–65 and over 65 groups models ($F(4,\ 59{,}678) = 1043.25$, $p < 0.0005$; $F(3,\ 2663) = 84.24$, $p < 0.0005$) accounted for 6.5% (adjusted $R^2 = 0.065$) and 8.6% (adjusted $R^2 = 0.086$) of the variance in grammatical reasoning, respectively. All variables entered into these models significantly predicted grammatical reasoning scores (Table 2).

Spatial working memory

Spearman's correlations showed that frequency of completing Sudoku or similar puzzles was positively associated with spatial working memory ($r_s = 0.124$, $p < 0.0005$) in the full cohort (score range: 2.00 to 11.47). Playing non-cognitive training computer games was also positively correlated ($r_s = 0.104$, $p < 0.0005$). Further analyses showed that this association reached a coefficient of 0.1 in the 18–64 group ($r_s = 0.105$, $p < 0.0005$) but not in the over 65 group ($r_s = 0.054$, $p < 0.0005$).

On the basis of the results of the Spearman correlation analyses, two regression analyses were performed for spatial working memory: one analysis for the full cohort and one analysis for the 18–64 age group. Predictor variables entered into each model are highlighted in Supporting Information Tables 1 and 2. The regression analysis for the full cohort identified a model ($F(2,\ 58{,}260) = 625.71$, $p < 0.0005$), which accounted for 2.1% of the variance in spatial working memory (adjusted $R^2 = 0.021$). Frequency of completing Sudoku or similar puzzles and non-cognitive training computer games significantly predicted spatial working memory scores in the overall cohort. For the 18–64 age group, a significant model also emerged ($F(2,\ 55{,}743) = 649.00$, $p < 0.0005$), which accounted for 2.3% of the variance in spatial working memory (adjusted $R^2 = 0.023$). Frequency of Sudoku or similar puzzles and non-cognitive training computer games significantly predicted spatial working memory scores in the 18–64 age group.

Verbal working memory

With the full cohort, Spearman's correlations show that highest level of education was positively associated with verbal working memory ($r_s = 0.100$, $p < 0.0005$; score range: 1.00 to 11.84). However, this positive correlation fell short of reaching a coefficient of 0.1 for both the 18–64 age group ($r_s = 0.098$, $p < 0.0005$) and the over 65 age group ($r_s = 0.097$, $p < 0.0005$). No other variables reached a correlation coefficient of 0.1.

Episodic memory

Spearman's correlations showed that age was inversely associated with episodic memory ($r_s = -0.267$, $p < 0.0005$) in the full cohort (score range: 1.00 to 7.91). Frequency of playing non-cognitive training computer games was positively associated ($r_s = 0.113$, $p < 0.0005$) in the full cohort. However, this correlation only reached a correlation coefficient of 0.1 in the 18–64 age group ($r_s = 0.113$, $p < 0.0005$) and not the 65 plus group ($r_s = 0.052$, $p < 0.0005$). The only variable found to be positively associated with episodic memory in

Table 2 Regression coefficients

	Grammatical reasoning			Spatial working memory			Episodic memory		
	Full cohort	18–64	65+	Full cohort	18–64	65+	Full cohort	18–64	65+
Age	$\beta = -0.236$, t (62,326) = −60.456, $p < 0.001$	$\beta = -0.194$, t (59,677) = −47.032, $p < 0.001$	$\beta = -0.179$, t (2662) = −9.651, $p < 0.001$	N/A	N/A	N/A	$\beta = -0.328$, t (62,363) = −86.506, $p < 0.001$	$\beta = -0.298$, t (59719) = −75.135, $p < 0.001$	$\beta = -0.185$, t (2651) = −9.800, $p < 0.001$
Highest level of education	$\beta = 0.151$, t (62,326) = 39.417, $p < 0.001$	N/A	$\beta = 0.188$, t (2662) = −10.149, $p < 0.001$	N/A	N/A	N/A	N/A	N/A	N/A
Crosswords	N/A	$\beta = 0.078$, t (59,677) = 17.086, $p < 0.001$.	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Sudoku/ similar puzzles	$\beta = 0.125$, t (62,326) = −31.876, $p < 0.001$	$\beta = 0.101$, t (59,677) = 22.413, $p < 0.001$	$\beta = 0.120$, t (2662) = 6.488, $p < 0.001$	$\beta = 0.099$, t (58,259) = 23.849, $p < 0.001$	$\beta = 0.106$, t (55,742) = 25.054, $p < 0.001$	N/A	N/A	$\beta = 0.116$, t (59,719) = 29.227, $p < 0.001$	$\beta = 0.130$, t (2651) = 6.884, $p < 0.001$.
Brain-training computer games	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Non-cognitive training computer games	$\beta = 0.105$, t (62,326) = 26.826, $p < 0.001$	$\beta = 0.089$, t (59,677) = 21.81, $p < 0.001$	N/A	$\beta = 0.094$, t (58,259) = 22.649, $p < 0.001$	$\beta = 0.094$, t (55,742) = 22.142, $p < 0.001$	N/A	$\beta = 0.068$, t (62,363) = 17.984, $p < 0.001$	$\beta = 0.056$, t (59,719) = 14.001, $p < 0.001$.	N/A

Note: Verbal working memory is not included in this table as no regression analysis was necessary on the basis of the results of Spearman's correlations.

the separate analyses of both age groups was frequency of completing Sudoku or similar puzzles (18–64: $r_s = 0.102$, $p < 0.0005$; 65 and over: $r_s = 0.113$, $p < 0.0005$).

Three regression analyses were performed for episodic memory: one analysis per age group with predictor variables, which reached the correlation coefficient of 0.1 for that age group. Predictor variables entered into each model are highlighted in Supporting Information Tables 1–3. A significant model emerged from the regression analysis ($F(2, 62{,}364) = 4170.25$, $p < 0.0005$), which accounted for 11.8% of variance in episodic memory in the overall cohort (adjusted $R^2 = 0.118$). Models for the 18–64 age group ($F(3, 59{,}720) = 2268.28$, $p < 0.0005$) and over 65 group ($F(2, 2652) = 75.23$, $p < 0.0005$) accounted for 10.2% and 5.3% of variance, respectively (adjusted $R^2 = 0.102$, 0.053, respectively). All variables entered into these models significantly predicted episodic memory in all age groups.

Discussion

This study investigated associations between cognitive performance and participation in specific cognitively stimulating leisure activities in more than 65,000 individuals between the ages of 18 and 90 years. The findings have indicated potentially important associations between specific activities and the functioning of individual cognitive domains. Increasing age was significantly associated with both grammatical reasoning and episodic memory ability, with younger participants scoring better in these cognitive domains. Age was not, however, found to be associated with performance on spatial working memory or verbal working memory tasks. The finding that age is associated with change in cognitive domains is in keeping with the current literature on healthy ageing, which highlights a gradual decline in key cognitive domains including memory, learning, language and processing speed (Roldán-Tapia *et al.*, 2012; Vance *et al.*, 2012; De Beni *et al.*, 2013; Gluhm *et al.*, 2013). In particular, episodic memory is established as a key domain affected by age (Shing *et al.*, 2010). Interestingly, the study also identified a strong link between age and grammatical reasoning, a component of executive function, which is less well established in the literature. The specific association of both episodic memory and grammatical reasoning with age indicates that ability in these two domains would be key targets for the design of cognitive training programmes for older people.

In both age groups in the study, increased participation in Sudoku or similar puzzles was associated with better performance on grammatical reasoning, spatial working memory and episodic memory tasks. Sudoku is a logic-based puzzle that has many variations. In the most common form, the puzzle requires players to place the numbers one to nine in boxes within a partially completed 9×9 grid where each number can only appear once within a row, column and each of the nine 3×3 sub-grids. Sudoku puzzles commonly have a unique solution. Completing the puzzle requires the individual to develop strategies to infer which number fits in which box to ensure that no number placement is in conflict to the rules of the puzzle. Few studies have examined the cognitive demands associated with completing Sudoku puzzles or its potential protective factor as a cognitively stimulating activity for delaying cognitive decline. A comparable study did, however, report an association between accuracy on Sudoku puzzles and working memory, as measured by the Wisconsin Card Sorting Test and Backwards Digit Span Task (Chang and Gibson, 2011). Authors of a further study suggest that deactivation in the posterior cingulate cortex and precuneus found during Sudoku completion is likely due to reallocation of cognitive resources required during the task including for working memory, preparatory attention, target detection and monitoring of response accuracy (Jin *et al.*, 2012). It remains to be explored whether cognitive domains including working memory, reasoning and episodic memory are trained by completing Sudoku puzzles and confer a benefit to protection from developing cognitive impairment, although previous studies have indicated a reduced risk of impairment following use of similar cognitively stimulating activities (Wilson *et al.*, 2002; Sattler *et al.*, 2012). A similar association was also seen in people aged 18 to 64 years, where increased time spent playing non-cognitive training computer games was associated with better performance in the same cognitive domains. This is consistent with previous literature (Green and Bavelier, 2003) indicating significantly enhanced visual attention and task-switching abilities amongst individuals who frequently play video games. However, this association did not extend to individuals aged 65 years or over.

The findings from the current study are also consistent with evidence from longitudinal studies that have suggested that composite scores of cognitive activity may be associated with a reduced risk of incident mild cognitive impairment or Alzheimer's disease (Wilson *et al.*, 2002; Sattler *et al.*, 2012). Whilst further follow-up would be required to confirm a significant long-term effect, this study adds weight to the possibility that cognitively stimulating activities such as Sudoku and computer games may, each in isolation, have a role in maintaining cognitive faculties. In the context of the existing evidence base, the significant levels of variance explained by these activities indicate a likely impact on risk of future cognitive decline and dementia. It will be important for future studies to build on these findings in order to elucidate the potential link between specific activities and the likelihood of future cognitive decline and dementia.

One theory that sheds light on how cognitively stimulating activities may provide neuroprotection to cognitive decline is the scaffolding theory of cognitive ageing (STAC) (Park and Reuter-Lorenz, 2009). The STAC model, derived from behavioural, structural and functional imaging data, suggests that cognitive ageing can be understood within the framework of a compensatory scaffolding model. 'Scaffolding' is described as the recruitment of additional circuitry that compensates for declining brain structures. For example, there is a large body of evidence that demonstrates that older adults employ bilateral activation of frontal sites of the brain during tasks that younger adults would only employ the left or right frontal areas (Cabeza *et al.*, 1997; Logan *et al.*, 2002). Evidence supports that this hemispheric asymmetry reduction in older adults facilitates task performance (Cabeza, 2002), which may play a key role in explaining individual differences in rates of cognitive decline. This neuroplasticity of the older adult brain, more widely evidenced by neural reorganisation following rehabilitation after brain damage, may allow for the capacity to train cognition by engagement in puzzles and games. This in turn may serve to strengthen dendritic connections in brain areas able to compensate for declining structures. This process of cognitive training may therefore work to preserve cognitive functioning and potentially delay age-related cognitive decline. Further experimental studies will be important in further understanding the mechanistic relationship between cognitively stimulating activities and cognition, and whether there is a differential impact of different activities.

Interestingly, frequency of completing cognitive training computer games was not found to be associated with any of the four cognitive domains in either age group. Given the current popularity of commercially available products and the aggressive marketing approaches employed to promote these, this is an important finding. This is also supported by our recent RCT of an online cognitive training package that showed no benefit in people under 60 years (Owen *et al.*, 2010). Crosswords were also only associated with one domain – grammatical reasoning – and then only in the 18–64 age group, indicating that crosswords alone are not strongly linked to overall cognitive function.

This study has utilised an extremely large database of robust demographic data, which has provided key insights into the specific roles of cognitive lifestyle factors and age on cognitive health in over 65,000 adults under and over 65 years. We believe that these findings will be valuable in informing the future direction of this type of research. However, certain limitations within the study should be acknowledged. The most important of these is that owing to the cross-sectional design of the study, it is not possible to analyse the change in performance of participants in each measure. In addition, the self-report measures of rating frequency of cognitively stimulating activities were not formally validated, and although age and education were included, where appropriate, in the regression modelling, it is also possible that they could have been confounding factors. The results of this study should be interpreted with caution given the limitation of multiple comparisons, which cause an increase in the likelihood of significant results due to chance. Analysis of the data revealed no effect of age on spatial working memory or verbal working memory. This was unexpected because an effect has been reported in some previous studies, although the evidence is not clear. This finding may be due to the challenge of developing tasks in these domains for repeated online implementation, and this would be a key consideration for future studies. Our sample was also biased towards Caucasian individuals with higher levels of education, and therefore, the findings may have limited generalisability to the larger population. This may also go some way towards explaining the surprising lack of impact of education in the findings. This is particularly true of the older adults who reported playing computer games, and as such, this group represents a self-selected sample that may not be representative. Furthermore, the study did not differentiate between types of non-'cognitive training' computer games, and clearly, there may be potential confounders explaining the apparent associations with cognitive function that were not explored as a result. These limitations all need to be considered when interpreting the data.

Conclusion

Further investigation is clearly required to determine the potential benefits of engaging in Sudoku puzzles and non-cognitive training computer games for preventing or delaying cognitive decline, and potentially reducing the risk of developing mild cognitive impairment and dementia. This is particularly indicated as these activities are associated with grammatical reasoning and episodic memory, cognitive domains that have been found to be associated with age-related decline. High-quality long-term RCTs to determine the causal relationship between these activities, cognitive function and cognitive reserve are required to inform improved guidance for the public regarding the potential value of different 'brain training' approaches. In contrast to extensive training programmes, these activities are easily accessible and therefore have the scope to be of benefit to the wider population in preventing or delaying the debilitating effects of age-related decline. The potential impact within the increasingly ageing population would potentially be clear on both individual and society levels. Furthermore, it will be important to consider the differential impacts of age on specific cognitive domains to develop outcome measures on the basis of detection of change in episodic memory and grammatical reasoning as the most sensitive items.

Conflict of interest

None declared.

Key points

- Grammatical reasoning and episodic memory ability are particularly associated with age.
- Regular completion of Sudoku and similar puzzles is associated with better performance in reasoning and memory regardless of age, whereas non-cognitive training computer games are associated with better cognition in people over 65 years.
- Use of cognitive training computer games is not associated with improved cognitive health, with implications for existing commercially available products.
- This study highlights the need for large-scale RCTs of cognitive training and leisure activities to understand their potential role in preventing or delaying cognitive decline.

Acknowledgements

The authors would like to thank the National Institute for Health Research (NIHR) Mental Health Biomedical Research Centre and Dementia Unit at South London and Maudsley NHS Foundation Trust and Institute of Psychiatry, King's College London for supporting their time on this work.

References

Anguera JA, Boccanfuso J, Rintoul JL, *et al.* 2013. Video game training enhances cognitive control in older adults. *Nature* **501**(7465): 97–101.

Cabeza R. 2002. Hemispheric asymmetry reduction in older adults: the HAROLD model. *Psychol Aging* **17**(1): 85–100.

Cabeza R, McIntosh AR, Tulving E, *et al.* 1997. Age-related differences in effective neural connectivity during encoding and recall. *Neuroreport* **8**(16): 3479–3483.

Chang HS, Gibson JM. 2011. The odd-even effect in Sudoku puzzles: effects of working memory, aging, and experience. *Am J Psychol* **124**(3): 313–324.

Cohen J. 1988. *Statistical Power Analysis for the Behavioral Sciences* (2nd edn). Lawrence Erlbaum Associates: Mahwah, New Jersey.

De Beni R, Borella E, Carretti B, *et al.* 2013. Remembering the past and imagining the future: age-related differences between young, young-old and old-old. *Aging Clin Exp Res* **25**(1): 89–97.

Deary IJ, Corley J, Gow AJ, *et al.* 2009. Age-associated cognitive decline. *Br Med Bull* **92**: 135–152.

Gluhm S, Goldstein J, Loc K, *et al.* 2013. Cognitive performance on the mini-mental state examination and the Montreal cognitive assessment across the healthy adult lifespan. *Cogn Behav Neurol* **26**(1): 1–5.

Green CS, Bavelier D. 2003. Action video game modifies visual selective attention. *Nature* **423**(6939): 534–537.

Jin G, Li K, Qin Y, *et al.* 2012. fMRI study in posterior cingulate and adjacent precuneus cortex in healthy elderly adults using problem solving task. *J Neurol Sci* **318**(1–2): 135–139.

Logan JM, Sanders AL, Snyder AZ, *et al.* 2002. Under-recruitment and nonselective recruitment: dissociable neural mechanisms associated with aging. *Neuron* **33**(5): 827–840.

Marioni RE, van den Hout A, Valenzuela MJ, *et al.* 2012. Active cognitive lifestyle associates with cognitive recovery and a reduced risk of cognitive decline. *J Alzheimers Dis* **28**(1): 223–230.

Martins IP, Maruta C, Silva C, *et al.* 2012. The effect of education on age-related changes in three cognitive domains: a cross-sectional study in primary care. *Appl Neuropsychol Adult* **19**(4): 287–298.

Murayama N, Iseki E, Tagaya H, *et al.* 2013. Intelligence or years of education: which is better correlated with memory function in normal elderly Japanese subjects? *Psychogeriatrics* **13**(1): 9–16.

Owen AM, Hampshire A, Grahn JA, *et al.* 2010. Putting brain training to the test. *Nature* **465**(7299): 775–778.

Papp KV, Walsh SJ, Snyder PJ. 2009. Immediate and delayed effects of cognitive interventions in healthy elderly: a review of current literature and future directions. *Alzheimers Dement* **5**(1): 50–60.

Park DC, Reuter-Lorenz P. 2009. The adaptive brain: aging and neurocognitive scaffolding. *Annu Rev Psychol* **60**: 173–196.

Roldán-Tapia L, García J, Cánovas R, León I. 2012. Cognitive reserve, age, and their relation to attentional and executive functions. *Appl Neuropsychol Adult* **19**(1): 2–8.

Sattler C, Toro P, Schönknecht P, Schröder J. 2012. Cognitive activity, education and socioeconomic status as preventative factors for mild cognitive impairment and Alzheimer's disease. *Psychiatry Res* **196**(1): 90–95.

Shing YL, Werkle-Bergner M, Brehmer Y, *et al.* 2010. Episodic memory across the lifespan: the contributions of associative and strategic components. *Neurosci Biobehav Rev* **34**(7): 1080–1091.

Singh-Manoux A, Marmot MG, Glymour M, *et al.* 2011. Does cognitive reserve shape cognitive decline. *Ann Neurol* **70**(2): 296–304.

Valenzuela MJ, Sachdev P. 2006a. Brain reserve and cognitive decline: a non-parametric systematic review. *Psychol Med* **36**: 1065–1073.

Valenzuela MJ, Sachdev P. 2006b. Brain reserve and dementia: a systematic review. *Psychol Med* **36**: 441–454.

Vance DE, Fazeli PL, Kaur J, *et al.* 2012. Neuropsychology and cognitive health in healthy older adults: a brief overview for psychiatric nurses. *J Psychosoc Nurs Ment Health Serv* **50**(6): 30–37.

Willis SL, Tennstedt SL, Marsiske M, *et al.* 2006. Long-term effects of cognitive training on everyday functional outcomes in older adults. *JAMA* **296**(23): 2805–2814.

Wilson RS, Bennett DA, Bienias JL, *et al.* 2002. Cognitive activity and incident AS in population-based sample of older persons. *Neurology* **59**(12): 1910–1914.

Supporting Information

Additional supporting information may be found in the online version of this article at the publisher's web site.

