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ASSESSING THE EFFICACY OF NUTRACEUTICAL INTERVENTIONS ON COGNITIVE FUNCTIONING IN THE ELDERLY

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ABSTRACT: ***With many nutraceutical interventions designed to slow cognitive aging, there is a need for computerised tests that can detect small cognitive changes that may occur in response to these interventions. A battery of 13 computerised cognitive tasks was developed to capture the range of cognitive functions that decline with age. One hundred and twenty adults aged 21 to 86 years, with a MMSE score ≥27 completed the test battery. Accuracy and response time were measured. Regression analysis revealed age-related decrements in cognitive performance for all tasks. Performance accuracy for the Spatial Working Memory task and speed of response for Spatial Working Memory, Contextual Memory and Immediate Recognition tasks showed the greatest age-related decline. The tasks showed good test-retest reliability and correlated with other commonly used neuropsychological tests in aging research. With the sensitivity of this cognitive test battery to aging, it may be useful in future studies investigating cognitive improvements in response to nutraceutical interventions in older adults.***

KEY WORDS: Age-Related Cognitive Decline, Cognitive Aging, Computerised Testing, Nutraceutical Intervention

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INTRODUCTION

With the population aging at a rapid rate, there is increasing interest in slowing the cognitive decline associated with increasing age. Both pharmacological interventions (e.g. cholinesterase inhibitors) and nutraceutical interventions (e.g. Ginkgo biloba) are purported to improve or stabilise cognitive functions that decline with age. In order to test the efficacy of these interventions, tasks must be used which target the cognitive functions most susceptible to cognitive decline and which are sensitive enough to capture very small changes that may occur in response to these interventions. The current study assesses the reliability and validity of a newly developed set of computerised tasks that have millisecond sensitivity and capture a range of cognitive functions that decline with age.

Cognitive changes that occur with age affect multiple areas of function including memory, executive function and cognitive speed (Christensen, 2001). With increasing age comes a decrease in the speed of information processing. This is identified by decreases in the speed of motor movements and slower response times in tasks such as Digit Symbol Substitution (Joy et al., 2000). Speed of processing has been proposed to be an underlying factor in age-associated decline in many areas of cognitive function (Salthouse, 1996). However, other research indicates that specific cognitive functions decline with age, and this cannot be solely explained by a general cognitive slowing hypothesis. For example, impairments in the Trail Making Test, a measure of executive functions such as inhibition and set switching, remain significantly related to age once processing speed measures are taken into account (Alfonso et al., 2005; Hester et al., 2005; Salthouse and Babcock, 1991; Wecker et al., 2005).

There is a general consensus that crystallised abilities (e.g. vocabulary and general knowledge) can remain stable until very late in life whereas fluid abilities (e.g. attention, executive function and memory) decline from middle adulthood until late old age (Gunstad et al., 2006). Memory functions are disproportionately affected with age (Nilsson, 2003). This is particularly evident for episodic memory, the memory for ones own personal life events and experiences (Tulving, 2002). Episodic memory decline is the most prominent deficit found in normal aging (Braver et al., 2001; Haaland et al., 2003). This has been observed in the Logical Memory subtest of the Weschler Memory Scale (WMS), which requires subjects to recall a story under different conditions at different intervals (Ritchie et al., 1993). Aging effects have also been proposed for attention (Mani et al., 2005), working memory (Salthouse and Babcock, 1991) and visuospatial abilities (Briggs et al., 1999; Reynolds et al., 2002). Typical results show that executive non-verbal tasks are affected by aging whereas language and basic attention tasks are more resilient (Jenkins et al., 2000). For more processingintensive tasks, this decline begins as early as in the twenties (Park et al., 2002). Evidence from brain imaging studies indicates that spatial abilities are susceptible to decline (Cabeza et al., 2005). Additionally, Merrick et al. (2004) found significant age effects mainly with visuospatial tasks compared to verbal tasks.

Despite reports of general cognitive decline with age, older individuals can sometimes perform with the same level of accuracy as younger people if given enough time to complete a task (Brebion, 2001). However, when timing is restricted, accuracy might be impaired if there is insufficient time to complete all of the mental processes required for the task (Salthouse, 1996). Thus, there is a trade-off: speed is forfeited for greater accuracy, or vice-versa. Accordingly it is important when investigating age-related cognitive decline to measure both variables in order to obtain a more complete representation of an individual's cognitive functioning.

Computerised tasks are expedient because they offer both speed and accuracy measures. They can also provide millisecond sensitivity, which enables the detection of very small changes that may occur early in the course of cognitive decline or in response to a therapy or intervention. Moreover, computerised tasks can score performances quickly and accurately, can provide multiple formats for longitudinal studies or multiple testing sessions, and provide a consistent approach for presentation of stimuli and delivery of task instructions. This opportunity is not afforded by the more traditional neuropsychological tests such as the Mini Mental State Examination (MMSE) (Folstein et al., 1975) and the Wechsler Adult Intelligence Scales (WAIS) (Wechsler, 1981).

There are numerous computerised test batteries that have been used to measure cognitive processes. Some of these have focussed on the measurement of the effects of pharmacological and nutraceutical compounds (Ferguson et al., 2003; Wesnes et al., 2000) and others have been used as a diagnostic tool for early detection of dementia and Alzheimer's disease (Egerhazi et al., 2007). Some batteries that are currently in use in elderly populations were not designed specifically for an elderly population or are biased toward the identification of overt dementia (Anderson et al., 2006) and do not attempt to capture the range of cognitive functions that decline in normal aging. A number of these task batteries are commercial products and so accessibility is limited. Moreover, very few cognitive batteries have been developed to specifically target cognitive decline. Normative data is also limited.

There are numerous new nutraceutical interventions currently being used and tested in elderly patients which claim to target the cognitive processes that decline with age (Fotuhi et al., 2009; Fusco et al., 2007; Jia et al., 2008). When researching such interventions, it is important that the test battery has millisecond sensitivity in order to measure the subtle changes that may occur in response to the intervention. Also, it is important that the test battery include fluid measures of intelligence that have been shown to decline with age and thus have potential to improve or stabilise with such interventions.

The present study used 13 moderately demanding computerised tasks that assessed speed and accuracy of cognitive functions in adults of various ages with the aim of determining which tasks are sensitive to the effects of aging. It was hypothesised that the tasks would be reliable over time with little or no practice effects. High correlations ($r>.6$) were considered adequate test-retest reliability. It was hypothesised that all tasks would demonstrate some decline in performance with increasing age, particularly the tasks more sensitive to aging such as Spatial Working Memory and Contextual Memory (episodic memory). Furthermore, it was hypothesised that age effects would remain apparent after controlling for the underlying effects of processing speed.

MATERIALS AND METHODS

Subjects

One hundred and twenty participants (57 female, 63 male) were recruited via advertisements in local newspapers and university bulletin boards. Ages ranged from 21 to 86 years (M=53.1, SD=16.0). The mean level of education for the sample was 15.3 years (SD=3.2). Participants were screened for cognitive impairment using the MMSE and all participants had a score of 27 or higher. Participants were non-smokers, had no history of head injury or neurological disorder and were not suffering any clinically diagnosed depressive disorder. No participant was excluded based on initial screening. Thirty-five participants (22 female, 13 male) additionally completed the validation tasks and 34 subjects (23 female, 11 male) returned to complete a follow-up session (test-retest) approximately one to four weeks after the initial session. When possible, testing took place at the same time of the day as the first session and participants completed an alternate version of the battery. The study had approval from the Swinburne University Human Research Ethics Committee and all participants gave written informed consent.

Equipment and materials

The tasks consisted of thirteen screen-based cognitive tasks that were developed based on the cognitive and neuroimaging literature focussing on processes that are most likely to decline with age. Simple and Choice Reaction Time tasks (explained below) were included in the battery to control for motor effects and decision time being a component of other tasks. These tasks have been used in previous studies investigating nutraceutical effects on cognition (Pipingas et al., 2008).

Testing was conducted on a 17-inch colour monitor using a DOS-based computer software package and took approximately 50 minutes to complete. Stimulus timing and participant response were accurate to one millisecond, with stimulus presentation synchronised to the screen refresh rate (Paredes et al., 1990). Participants responded using a 4-button box, with each button a different colour and arranged in the positions of compass poles (top = yellow etc). The investigator read the task instructions from a manual to ensure consistent explanation of the tasks. Each task was preceded by a short practice trial and participants were given an opportunity to ask questions. Except where otherwise indicated, tasks are described here in the order presented to participants. A selection of participants returned for a second visit and completed an alternate form of the tasks.

Immediate/Delayed Word Recall

Participants were presented with a list of 12 words that were presented one at a time in the centre of the screen. Each word was presented for 2-seconds, with an inter-stimulus interval (ISI) of 1-second. Participants were then given two minutes to record with pen and paper as many words as they could remember (Immediate condition). At the end of the testing session, typically 45 minutes later, they were again given two minutes to record remembered words from the original studied list (Delayed condition).

Simple Reaction Time

Participants responded with a right button press to the appearance of a single white square at the centre of the screen. Thirty targets were presented with a randomised inter-stimulus interval (ISI) to avoid anticipation effects.

Choice Reaction Time

Participants responded with a left (blue) or right (red) button press to the appearance of a blue triangle or red square respectively. Presentation order and ISI were randomised to avoid anticipation effects. This task was used as a measure of visual perceptual decision time.

Immediate/Delayed Recognition

Participants were asked to study a series of 40 abstract images presented serially in the centre of the screen for 3-seconds each with no ISI. On completion, another series of images was presented, half of which were from the studied series and half were new (Immediate condition). Participants indicated with a right (yes) or left (no) button press whether or not they recognised the image from the studied series. This task was repeated at the end of the testing session with the remaining 20 images from the studied series and another 20 new images (Delayed condition). Because abstract patterns are difficult to verbalise, the task can be described as a measure of non-verbal recognition memory.

Visual Vigilance

Participants were required to initially memorise a single digit target number appearing in the centre of the screen for 2-seconds. A series of numbers was then presented one at a time in the centre of the screen for 0.6-seconds each, with no ISI. Each time the target number appeared in the series, participants were required to respond as quickly as possible with a right button press. The appearance of the target was randomised and the probability was set at 20%, resulting in 30 possible targets from a total of 150 stimuli presented. The time taken to respond was used as a measure of visual vigilance or sustained attention.

N-Back Working Memory

In each of these tasks a series of letters were presented one at time in the centre of the screen for 1.3-seconds, with an ISI of 0.2-seconds. Participants responded with a right button press each time a letter was the same as the previous letter (1-Back condition), or the same as the letter two letters before (2-Back condition). A target probability of 20% was set, resulting in 15 possible targets from a total of 75 stimuli presented Due to the requirement to hold changing information in the short term memory store, this task was used as a measure of working memory.

Stroop Colour-Word

The test consisted of two congruent and two incongruent trials, presented alternately. Stimulus words were randomly presented (RED, BLUE, GREEN, YELLOW) in either congruent or incongruent colours for 1.7-seconds, with an ISI of 0.5-seconds. Participants responded by pressing one of four buttons corresponding to the colour of the word, irrespective of what the word read. This task was used as a measure of executive function and more specifically inhibition; participants had to inhibit the automatic reading response.

Spatial Working Memory

In each trial participants were presented with a 4 x 4 white grid on a black background, with six grid positions containing white squares. Participants were given 3 seconds to remember where the white squares were located. The grid became blank and a series of four white squares were sequentially displayed in various grid positions for 2-seconds each. Participants responded with a yes/no response to indicate whether each square matched a position that was originally filled. In total, participants completed 14 trials, each of which was separated by a blank screen displayed for 2-seconds. Each trial was set such that two out of the four locations in the response series corresponded to the original grid locations, and two did not. The task required participants to hold spatial information in a store that has previously been described as working memory (Baddeley, 2003).

Contextual Memory

A series of 20 everyday images were presented at the top/bottom/left/right of the screen for 3-seconds each with no ISI. On completion of the series the same images were displayed again in randomised order in the centre of the screen for 2-seconds each with no ISI. Participants responded with a top/bottom/left /right button press to indicate the original location of each image. This task required participants to recall the spatial context of the original presentation and was used as a measure of episodic memory. Upon completion of the SUCCAB computerised tasks, a subset of participants completed the validation tasks, described below in the order of presentation.

Logical Memory I (From the Weschler Memory Scale)

In each of the three parts of this test, participants listened to a paragraph and immediately after were instructed to repeat as much of the story as they could remember. The first paragraph was about a woman named Anna and the second and third paragraphs were the same and about a man named Joe. Participants were scored on the number of correct ideas they remembered. This task has been described as the purest measure of episodic memory (Ritchie et al., 1993)

Logical Memory II (From the Weschler Memory Scale)

During the first two parts, participants repeated back as much of the stories that they were read in Logical Memory I. During the third part, participants were presented with 15 statements on each story and they had to indicate whether the statement was true or false.

Trail Making Test (TMT) - Part A

Part A Participants were given a piece of paper with the numbers 1-25 surrounded by circles written randomly on the page. Participants were instructed to follow the numbers as quickly as possible in ascending order starting at one and finishing at 25 by drawing straight lines between each number, without lifting the pen from the paper. If a participant missed a number/letter, they were instructed to go back and correct the order. Participants were scored on the time taken to complete the task.

Digit Symbol-Coding (from the WAIS III)

Participants were presented with an A4 piece of paper with a key on the top consisting of numbers 1-9 with a corresponding symbol under each number. Below were rows of random numbers with blank squares below each number, and participants were given two minutes to fill in the blank squares with the corresponding symbol. Participants were not allowed to skip any numbers or rows.

Statistical Analyses

For the Immediate and Delayed Word Recall tasks, only accuracy was analysed. For Simple and Choice Reaction Time, Visual Vigilance, 1-Back and Stroop tasks, ceiling effects were anticipated for accuracy data and thus only response time was analysed. Both accuracy and speed of response were analysed for the remaining computerised tasks. Test-retest reliability was assessed using Pearson's Product-Moment correlations (r) between Time 1 (T1) and Time 2 (T2). Practice effects were analysed by testing the significance of the difference between the mean of T1 and the mean of T2 with paired t-test comparisons. Accuracy and response time for the tasks were correlated with some of the widely used neuropsychological tests in aging research. Sequential multiple regression analyses were performed using SPSS software version 13 (SPSS Inc. Chicago) for all cognitive measures. Number of years of education was included in all regression models because education often correlates with cognitive performance (Anstey and Christensen, 2000) and education levels may differ between older and younger adults. For accuracy measures, education and age were entered sequentially into each model as the predictor variables. For the response time measures, education and age were each entered sequentially for the Simple and Choice Reaction Time tasks only. For the remaining response time tasks, education, Choice Reaction Time and age were entered sequentially into each model. The Choice Reaction Time task was chosen as a baseline measure of processing speed to control for the effects of motor response and simple decision time that might be evident in all tasks susceptible to global cognitive slowing. For the Stroop tasks, an additional variable was created by subtracting each score on the Congruent task from the score on the Incongruent task. The extra time taken to respond to the Incongruent task is thought to represent the inhibition of automatic word reading known as the Stroop interference effect (Wecker et al., 2000).

RESULTS

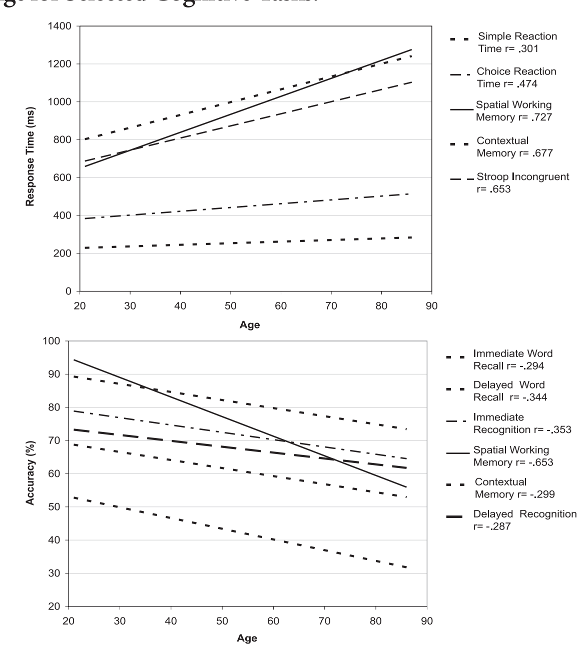
Preliminary analysis confirmed that age was correlated with education, with older participants generally having fewer years of education than younger participants (r = -.29, p=.002). Minimum and maximum scores, means, standard deviations, and correlation between age and each accuracy and response time measure are presented in Table 1. Age was significantly correlated with accuracy and response time on all tasks. Figure 1 illustrates the relationship between age and performance for selected cognitive tasks.

The results from the test-retest reliability and practice effects are shown in Table 2. All performance accuracy measures showed moderate to high correlations, and all except one were significant at p<.001. The only significant practice effect was found for the Spatial Working Memory task. The majority of the response time measures showed high and significant correlations at p<.001. Only the Immediate Recognition, Stroop tasks and Contextual Memory task showed

TABLE 1. Minimum and Maximum Scores, Means, Standard Deviations and Correlation with Age for Cognitive Measures. *p<.01, **p<.001, †= not analysed, *N*=120

	Min	Max	Mean (±SD)	Correlation with Age r
Accuracy (%)				
Immediate Word Recall	25	91	60.1 (13.3)	-.294*
Delayed Word Recall	0	83	42.5 (16.6)	-.344**
Simple Reaction Time	83	100	99.3 (2.4)	†
Choice Reaction Time	77	100	96.0 (4.9)	†
Immediate Recognition	38	95	71.8 (10.0)	-.353**
Visual Vigilance	67	100	98.6 (4.6)	†
1-Back Working Memory	67	100	98.9 (4.4)	†
2-Back Working Memory	60	100	90.4 (9.0)	†
Stroop Congruent	69	100	95.9 (6.2)	†
Stroop Incongruent	69	100	96.2 (5.8)	†
Spatial Working Memory	34	100	76.0 (14.4)	-.653**
Contextual Memory	50	100	81.5 (13.1)	-.299*
Delayed Recognition	38	88	67.6 (9.9)	-.287*
Speed (ms)				
Simple Reaction Time	169	438	256 (45)	.301*
Choice Reaction Time	240	648	448 (68)	.474**
Immediate Recognition	734	1445	1064 (134)	-.582**
Visual Vigilance	304	551	397 (45)	.544**
1-Back Working Memory	285	586	399 (63)	.283*
2-Back Working Memory	341	916	581 (122)	.251*
Stroop Congruent	553	1313	888 (186)	.595**
Stroop Incongruent	528	1429	894 (184)	.653**
Stroop Interference Effect	-62	496	128 (115)	.310*
Spatial Working Memory	525	1635	963 (211)	.727**
Contextual Memory	654	1424	1017 (160)	.677**
Delayed Recognition	777	1319	1028 (122)	.435**

FIGURE 1. Relationship between Cognitive Performance and Age for Selected Cognitive Tasks.



significant practice effects.

The validity of the tasks was explored using correlations between the computerised tasks and the validation tests, shown in Table 3. The Logical Memory Tests correlated with the memory tasks (word and picture recall and recognition tasks) and not with the attention/executive function-type tasks (N-Back, Stroop and Spatial Working Memory). Both the Trail making Test and Digit Symbol Coding task showed strong correlations with the computerised tasks.

Results of regression models for accuracy measures are presented in Table 4. After controlling for education, age significantly predicted performance accuracy for all analysed tasks. Change in R^2 was largest for Spatial Working Memory, reflecting the greatest decline in this cognitive measure with increasing age.

Results of regression models for response time measures are presented in Table 4. For Simple and Choice Reaction Time, age significantly predicted performance after controlling for education, with change in R^2 values reflecting slower response time with increasing age. After controlling for education and Choice Reaction Time, age significantly predicted performance on all tasks except 1-Back and 2-Back Working Memory. Change in R^2 values for age were highest in the Spatial Working Memory, Stroop Incongruent and Contextual Memory tasks, indicating that age had a greater impact on response time for these tasks.

Results of regression models also confirmed the importance of taking into account education and processing speed when investigating cognitive

TABLE 2. Means, Standard Deviations, Test-retest Correlations and Practice Effects for T1 and T2. * p< .05, **p< .001, *N*=34

	Mean T1 (±SD)	Mean T2 (±SD)	Correlation	df	t	Eta^2
Accuracy (%)						
Immediate word recall	76.3 (16.7)	77.2 (15.2)	.42*	29	-.265	.002
Delayed word recall	57 (20.9)	57.7 (23.6)	.52**	29	-.083	.000
Immediate recognition	71.2 (13.0)	72.7 (13.4)	.58**	33	-.703	.015
2-back	90.1 (11.1)	91.6 (8.3)	.54**	31	-.863	.024
Incongruent stroop	94.7 (8.1)	96.6 (4.3)	.50**	32	-1.590	.073
Spatial working memory	77.3 (14.6)	80.2 (14.1)	.84**	32	-2.140*	.125
Contextual memory	81.8 (12.1)	80.4 (15.9)	.63**	33	.617	.011
Delayed recognition	67.4 (12.4)	70.3 (10.6)	.51**	33	-1.441	.059
Speed (ms)						
Simple reaction time	247.03 (46.96)	251.70 (36.07)	.74**	33	-.868	.022
Complex reaction time	428.77 (71.52)	430.13 (75.16)	.81**	33	-.176	.001
Immediate recognition	1020.19 (139.18)	979.61 (142.96)	.73**	33	2.281*	.136
Visual vigilance	386.84 (51.11)	387.82 (45.14)	.81**	31	-.185	.001
1 back	377.27 (76.74)	369.64 (66.36)	.74**	32	.834	.021
2 back	567.01 (117.67)	527.17 (104.17)	.48**	32	2.012	.112
Congruent stroop	794.82 (201.70)	757.97 (158.34)	.91**	33	2.484*	.158
Incongruent stroop	880.69 (231.97)	815.84 (186.83)	.93**	32	4.192**	.355
Spatial working memory	929.33 (234.43)	903.61 (244.52)	.93**	32	1.625	.074
Contextual memory	996.16 (217.14)	939.06 (149.95)	.71**	33	2.16*	.124
Delayed recognition	1012.55 (176.44)	991.44 (156.36)	.67**	33	.908	.024

TABLE 3. Correlations Between SUCCAB Tasks and Validation Tasks. * p< .05, **p< .001, *N*=35

	Logical memory 1 total score	Logical memory 2 total score	Trailmaking A	Digit Symbol Coding
Accuracy				
Imm word recall	.421**	.423**	- .497**	.572**
Del word recall	.431**	.511**	- .384*	.422*
Imm recognition	.372**	.464**	- .584**	.669**
2-back	0.215	0.196	- .232	.510**
Incongruent stroop	0.21	0.23	- .556**	.637**
Spatial WM	0.179	0.18	- .569**	.757**.
Contextual memory	.259*	.338**	- .498**	.603**
Del recognition	.410**	.389**	- .465**	.453**
Response Time				
Simple RT			.767**	-.79**
Choice RT			.555**	-.761**
Imm recognition			.657**	- .811**
Visual vigilance			.604**	- .816**
1-back			.676**	- .696**
2-back			.665**	- .624**
Congruent stroop			.702**	- .862**
Incongruent stroop			.739**	-.747**
Spatial WM			.698**	- .8**
Contextual memory			.66**	- .831**
Del recognition			.627**	- .745**

TABLE 4. Sequential Regression Models for Cognitive Measures. *p<.05, **p<.01, ***p<.001, *N*=120

	Adjusted R^2 (whole model)	R^2 Change	F Change
Accuracy			
Immediate Word Recall			
Education		.017	1.85
Age	.066	.067	7.70**
Delayed Word Recall			
Education		.025	2.65
Age	.102	.094	11.1**
Spatial Working Memory			
Education		.043	5.07*
Age	.432	.399	80.9***
Contextual Memory			
Education		.013	1.53
Age	.076	.079	9.75**
Immediate Recognition			
Education		.073	8.96**
Age	.138	.081	10.8**
Delayed Recognition			
Education		.028	3.24
Age	.071	.059	7.37**
Response Time			
Simple Reaction Time			
Education		.048	5.68*
Age	.088	.056	6.93**
Choice Reaction Time			
Education		.006	.646
Age	.203	.211	30.5***
Visual Vigilance			
Education		.019	2.18
CRT		.308	51.2***
Age	.409	.097	18.8***
Spatial Working Memory			
Education		.055	6.56*
CRT		.250	39.9***
Age	.561	.268	68.8***
Contextual Memory			
Education		.078	9.30**
CRT		.144	20.2***
Age	.460	.253	52.0***
Immediate Recognition			
Education		.031	3.57
CRT		.055	6.74*
Age	.313	.244	40.2***
Delayed Recognition			
Education		.000	.013
CRT		.063	7.43**
Age	.185	.144	19.8***
1-Back Working Memory			
Education		.000	.023
CRT		.201	28.2***
Age	.191	.011	1.53
2-Back Working Memory			
Education		.002	.235
CRT		.123	15.7***
Age	.114	.013	1.60
Stroop Congruent			
Education		.088	10.6**
CRT		.243	39.6***
Age	.440	.124	24.5***
Stroop Incongruent			
Education		.114	13.2***
CRT		.231	36.0***
Age	.515	.184	39.4***
Stroop Interference Effect			
Education		.029	3.10
Age	.094	.082	9.45**

aging. Significant results were demonstrated for the control variables, education and Choice Reaction Time. For the accuracy measures, education was significant in the Spatial Working Memory and Immediate Recognition tasks, with borderline significance in the Delayed Recognition task. For response time measures, education was a significant predictor in Simple Reaction Time, Spatial Working Memory, Contextual Memory, Immediate Recognition and both Stroop tasks, with borderline significance in the Stroop Interference variable. As expected, the Choice Reaction Time task significantly contributed to performance on all response time measures, indicating that performance in these tasks was partly mediated by processing speed and simple decision making.

DISCUSSION

The current study examined age-related cognitive changes using a battery of computerised tests. The reliability hypotheses were supported in that there were good test-retest coefficients (ranging from .42-.93) and practice effects were only observed for a few of the measures. As anticipated, age significantly predicted performance for all tasks in the battery, with the strongest effects demonstrated in performance accuracy for Spatial Working Memory, and in response time for Spatial Working Memory, Contextual Memory and Stroop Incongruent tasks. Once potentially confounding effects of education and processing speed were taken into account, age significantly predicted performance for all tasks with the exception of the 1-Back and 2-Back Working Memory tasks.

The practice effects were observed for reaction time measures of the more complex tasks (Immediate Recognition, Stroop, and Contextual Memory). Therefore it is recommended that an additional practice version (or longer initial practice) be given to participants for these tasks so that performance can stabilise more rapidly, eliminating (or reducing) the practice effects. The Spatial Working Memory task was the only task that showed practice effects for the performance accuracy measure but not for the reaction time measure. In all tasks there is a trade off between accuracy and reaction time (Salthouse, 1996). It seems that in the case of the Spatial Working Memory task, participants may appear to concentrate more on accuracy, and less on speed, resulting in the observed practice effect for accuracy.

The computerised tasks were validated against established pencil-and-paper neuropsychological tests that have demonstrated sensitivity to individual differences in performance and cognitive decline (Golski et al., 1998). They have also previously been used as validation tests for measures of cognitive functions that decline with age (Salthouse et al., 2003; Wilson et al., 2002). Results revealed strong correlations with the validation tests. The computerized tasks measuring recall and recognition correlated with the Logical Memory tests, measures of episodic memory that have been previously shown to decline with age (Haaland et al., 2003). Both the accuracy and reaction time measures of the computerised tasks correlated with the Trail making Test and the Digit Symbol Coding Test, measures of executive function, attention and processing speed (Wecker et al., 2000). These strong correlations reveal that the computerised tasks capture a combination of cognitive functions also captured in these widely used tests and are a valid measure of the cognitive functions that decline with age.

Spatial Working Memory appeared to show the most robust aging effects, with age-related impairment evident for both response time and accuracy measures. Age related impairment has previously been demonstrated in tasks that measure other spatial abilities, for example mental rotation and navigation (Driscoll et al., 2005) and memory for object arrangements (Cherry and Park, 1993). The spatial recognition task in the Cambridge Automated Neuropsychological Test Battery (CANTAB) similarly demonstrated impaired performance with age (Rabbitt and Lowe, 2000). However, there is little cognitive research investigating spatial working memory. The present task suggests that with increasing age it becomes increasingly difficult to hold spatial information in working memory. Given the strong sensitivity of this task to cognitive aging it could be a useful tool in future aging research to measure the degree of cognitive decline and to examine the efficacy of interventions.

Robust aging effects were evident in speed of response for the Contextual Memory task, with significant effects also demonstrated for accuracy. This is consistent with previous research that demonstrates a decline in episodic memory with increasing age using a similar task (Anderson et al, 2006; Nilsson, 2003). Poorer performance on episodic memory tasks may also predict future cognitive impairment or dementia (Albert et al., 2007; Collie and Maruff, 2000), therefore this type of task is an important measure in cognitive aging research.

The Immediate and Delayed Recognition tasks similarly demonstrated age effects for accuracy, with stronger effects evident for response time on these tasks. Generally, previous research has demonstrated that older individuals perform better on recognition tasks than in free recall (Davis et al., 2003) and this was also demonstrated here, with greater accuracy on the recognition tasks than word recall in the group overall. Accuracy in the Delayed Word Recall task demonstrated a stronger age effect than Immediate Word Recall. This finding is consistent with research investigating free recall of word lists that suggests that the short-term memory store is less affected by aging than longer-term memory (Ward and Maylor, 2005).

The current study demonstrated that performance on the Stroop tasks were both correlated with age, an effect that has been demonstrated in several studies in the past (Cohn et al., 1984; Van der Elst et al., 2006; Wecker et al., 2000; West, 2004). However, there has been some discussion as to whether such decrements in inhibitory function are merely due to the effects of age on processing speed (Salthouse and Meinz, 1995). The present study indicated that processing speed accounted for a large proportion of variance in the Stroop Incongruent task. The Interference Effect variable was also significantly related to age, however the relationship was much smaller, as indicated by a small significant effect after accounting for education. In a previous study, researchers argued that the Stroop 'interference effect' becomes more pronounced with age and reflects a decline in executive function (Van der Elst et al, 2006). Moreover, the authors suggested that the degree of decline is influenced by the individual's level of education. This notion is not inconsistent with the findings of the present study, with education having a borderline significant relationship with the Interference variable, and a significant relationship with the Stroop Incongruent task.

Examining the results of the computerised battery as a whole, most of the tasks showed age-related decline. The N-Back tasks showed no age-related decline and were not reliable measures and should therefore be excluded from future studies using this test battery. Overall, the tasks appear to be robust measures of the cognitive functions that decline with age, as apparent from the strong correlations with widely used validation tests and the strong age effects. This advocates the use of the test battery in studies investigating the efficacy of intervention designed to improve or preserve cognition in elderly people. The response time measures were more sensitive to age than accuracy measures, with the exception of Spatial Working Memory. This could be due to the instructions for this task that asked participants to prioritise accuracy over speed. However the present study demonstrates the need to use tests that are sensitive to response time as well as accuracy; if only accuracy measures were recorded then important information regarding age-related cognitive decline would have been overlooked. Speed of response is thus a critical measure for aging research; not just as a measure of general cognitive slowing but also as a measure that can be used to investigate decline in specific cognitive functions. The significant results for education as a control variable also highlight the need to consider education when examining the effects of aging on cognitive tasks. Future studies examining the test battery should gather normative data for different age groups and for patient populations such as dementia, schizophrenia and frontal lobe patients.

The present study has demonstrated the sensitivity of a series of computerised cognitive tasks to age-related cognitive decline. The tasks are easy-to-use and provide a comprehensive assessment of cognitive functions using both performance accuracy and response time measures. This study has also emphasized the importance of examining spatial working memory and contextual memory when assessing age-related decline. The sensitivity of the cognitive battery advocates its use in research that investigates cognitive interventions in older people; it may have capacity to detect the subtle changes that are found in response to pharmaceutical or other interventions.

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