The Diverse Central Executive during everyday Multi-Tasking

Abstract

Multi-tasking defined by interleaving numerous tasks in order to achieve many goals in a short amount of time is essential in everyday life and intuitively involves the central executive component of working memory. The link between executive processing and everyday functioning has not been consistently observed in clinical studies with traditional executive tests but has been demonstrated in studies using ecologically valid tests. This may be due to the diverse nature of the central executive. Numerous separable executive processes have been established such as 'shifting' and 'inhibition' and recent evidence suggests that dual task ability is a further separable executive process which may be particularly important in everyday functioning. However this link has never been formally investigated in the healthy population. An ecologically valid test of multi-tasking, the Edinburgh Virtual Errands Test (E-VET) (Logie, Trawley and Law, 2010) and a traditional test of executive processing the Wisconsin Card Sorting Test (WCST) were given to a group of healthy young participants (n=85) along with three domain specific tests of executive functioning, a dual task test and intelligence tests. It was predicted that the results would support the multi-component model of executive processing which includes dual tasking as a separable executive function and that the executive tests would be predictive of the ecologically valid test (E-VET) performance and the traditional executive test performance (WCST). An exploratory factor analysis was used to split E-VET performance into two components - memory and intentionality. A significant proportion of the variance in the intentionality component of multi-tasking was predicted by dual tasking and general intelligence 'g'. Only general intelligence significantly predicted WCST performance and latent memory within multi-tasking. Correlation analysis gave support to the multi-component model of executive processing and dual task ability appeared to be separable to measures of 'shifting' and 'inhibition' however more stringent statistical techniques are recommended. These results strengthen the argument for using more complex, ecologically valid paradigms when studying the diverse central executive and multi-tasking.

Multi-tasking, defined as the interleaving of numerous tasks in order to achieve various goals is essential for independent everyday living. Several cognitive processes are thought to be necessary in order to successfully multi-task including the active maintenance and regulation of task-relevant information from both short and long term memory stores known as working

memory (Miyake and Shah, 1999). An important component of working memory is executive functioning or the process or processes by which internal goals are represented and by which control can be asserted over automatic responses in order to achieve these goals. As such executive functioning is central to goal directed behaviour and this has been represented in numerous working memory theories. For example in Baddeley and Hitch's (1974) model the central executive is necessary for attending to and encoding short term memory traces and a similar mechanism is described in the Supervisory Attention System model by Norman and Shallice (1986). Even those models of working memory which do not propose a separate central executive component emphasise the importance of manipulation and regulation of memory and cognition (Miyake et al, 1999). Having control over automatic cognitive mechanisms is essential in everyday multi-tasking as it allows flexibility and online planning in the face of changing environments and changing goals.

While this association between executive functioning and multi-tasking seems intuitive, there have been numerous cases reported of brain damaged patients with significant problems with everyday functioning but normal performance on tests purporting to measure executive function such as the Wisconsin Card Sorting Test (WCST) and the Tower of Hanoi (ToH) test (see (Eslinger and Damasio, 1985);(Metzler and Parkin, 2000);(Shallice and Burgess, 1991)). This may indicate that there is dissociation between executive tests and multi-tasking, or a difference between the patient's performance within the psychologist's laboratory and the real life environment (Muselam, 1986). However recent evidence suggests that this disparity may be down to a weakness inherent in traditional executive tests (Burgess, Alderman, Volle, Benoit and Gilbert, 2009). Recently developed, ecologically valid tests have been shown to be more sensitive to multi-tasking difficulties or 'strategy application disorder' than traditional executive tests. Shallice and Burgess (1991) showed that brain injured patients who performed within the normal range on traditional executive tests and tests of intelligence performed poorly during the multiple errands test (MET). In this test participants had to perform various errands in a shopping centre which required task interleaving and online planning for optimal performance such as buying a loaf of bread or finding out yesterday's exchange rate (Shallice et al., 1991). While the MET was found to be sensitive to frontal brain injury, it required numerous research assistants to follow the participants around to note the performance as well as permission from the owners of the shops involved. As the test took place in a real life shopping centre, it was also difficult to replicate experimentally as many of the tasks relied on the reaction of shop workers and on the shops being open and not crowded.

Subsequent multi-tasking tests have been developed which can be performed quickly inside a psychologist's office and are therefore more suitable paradigms for experimental and clinical purposes than the MET. For example the six elements test (SET) which assesses the ability to switch between three tasks in an optimal fashion (Shallice et al., 1991) and the Greenwich task (Burgess, Veitch, Costello and Shallice 2000) which measures the ability to monitor performance and remember a diverse set of rules while performing three tasks. Patients with brain injuries who have difficulties with everyday tasks assessed through carer interviews and questionnaires also showed deficits in the SET and Greenwich tasks (Burgess et al., 2000). However, unlike the MET, these assessments involved abstract tasks such as creating models or separating different coloured beads rather than tasks representative of those required in everyday life. Another adaption of the MET which is directly comparable in design to the original MET and therefore more ecologically valid than the SET or Greenwich tasks is the Edinburgh Virtual Errands Task (E-VET) (Logie, Trawley, and Law, 2010). In this test participants are asked to plan and complete a number of errands in a four-storey virtual building. The virtual environment allows automatic calculation of scores and a stable environment which can be recreated for every participant. Therefore the E-VET offers an experimental setting while also retaining important aspects of everyday multi-tasking. This test has been used to extend a previous model of multi-tasking developed in a study of brain injured patients given the Greenwich task (Burgess et al., 2000). Logie and others (2010) used structural equation modelling to analyse various scores related to E-VET performance in order to develop this model to include the healthy population. They found that the same three components found by Burgess and others (2000) were the best fit for the multi-tasking data, namely 'memory', 'intentionality' and 'planning' (Logie et al, 2010).

A possible explanation for the disparity between the results of traditional executive tests such as the WCST, ToH and the verbal fluency test and recently developed, ecologically valid tests is the multi-dimensional nature of executive processing. Although some theories of working memory hold that the executive function system is unitary (see Lovett Reder and Lebiere, 1999) there is evidence that separate capacity limits exist within every individual for different kinds of executive abilities independent of previous memory experience and retrieval strategy (Miyake, Friedman, Emerson, Witzki, Howerter and Wager, 2000). If the central executive is made up of several sub-processes then it is likely that relatively simple laboratory tasks only 'tap' some of these executive processes but not others. This has led to criticism of the

continued use of traditional executive tests in research into executive processes (Burgess, Alderman, Emslie, Evans and Wilson, 1998). The widespread use of the WCST in particular has been heavily criticised (Burgess, Alderman, Forbes et al., 2006). The WCST is a test of set shifting which requires participants to recognise and flexibly switch between three sorting rules (Eling, Derckx and Maes, 2008). The test has been criticised for its lack of generalisability to, or representiveness of tasks required in everyday living and because the evidence supporting the WCST as a valid test of executive dysfunction is severely outdated (Milner, 1963);(see Burgess et al., 2006). Compared to a traditional executive test such as the WCST, more complex and ecologically valid multi-tasking tests are likely to involve more executive processes and therefore be more sensitive to executive dysfunction. There is evidence from clinical and non-clinical studies that several separable executive functions exist (Burgess et al, 1998), and that traditional executive tests only involve some of these executive functions (Miyake et al., 2000). A study by Miyake and colleagues (2000) used confirmatory factor analysis of nine simple executive tests to establish three separable executive sub-processes named shifting, inhibition and updating. While the tests differed in type of stimuli and other idiosyncratic requirements, they were chosen so that they would match in terms of executive operation. For example as 'shifting' is thought to involve the switching of attention or focus between two or more distinct mental sets (Miyake et al., 2000) the letter number sequencing test and the plus minus test (see method section) are both measures of shifting despite involving the manipulation of different information using different sensory modalities. Both tests require shifting between two distinct mental processes – addition to subtraction in plus minus test and number ordering to letter ordering in the letter number sequencing test – and in both a cognitive cost occurs because of the shifting of mental sets (Rogers and Monsell, 1995). The other separable executive processes established in this study were 'inhibition' which is assessed by tasks which involve the overriding of automatic responses to stimuli and 'updating' which can be measured by tasks which involve the monitoring and manipulation of information during working memory (Miyake et al., 2000). Having established these three separable executive abilities, Miyake and colleagues then used structural equation modelling to investigate the extent to which these latent executive functions predicted traditional complex executive tasks such as the WCST, ToH, verbal fluency and dual tasking. None of the complex executive tasks were found to involve all three latent executive functions supporting the hypothesis that the disparity between traditional executive tests and recently developed, ecologically valid executive paradigms is due to the diverse nature of the central executive (Miyake et al., 2000). While these three separable

executive processes have received a great deal of attention, other executive processes which may also be separable have been neglected such as the ability to activate long term memory representations and the ability to perform two tasks at the same time (Baddeley, 1996). According to Baddeley and Logie's multiple-component model of working memory, dual task ability – the process of simultaneously attending to and performing two tasks from different sensory modalities which require the same cognitive resources – is an essential component of the central executive (Baddeley et al., 1999).

Dual task ability was one of the complex executive tasks included by Miyake and colleagues (2000). It was found that none of the three latent executive functions were related to dual tasking. This suggests that dual tasking may itself be a separable executive function (Friedman, Miyake, Young, DeFries, Corley and Hewett, 2008). This possibility has also been supported by evidence that those with damage to the frontal lobes (which is often associated with dysexecutive syndrome) showed marked performance impairments during dual task conditions compared to non-frontal brain injury patients (Baddeley, Della Salla, Papagno and Spinnler, 1997). This finding also suggests that dual tasking may be particularly important for successful multi-tasking and independent living as frontal lobe damage impacts negatively on the ability to perform everyday tasks such as cooking a meal or buying goods from a supermarket (Baddeley, 1986). This association between dual tasking and everyday functioning has been re-enforced by other evidence from studies with dysexecutive patients and other patient groups. For example dual task ability was a good predictor for rehabilitation success in patients with dysexecutive behavioural difficulties who received operant conditioning rehabilitation. Those who responded to the treatment had significantly better dual task ability than those who did not (Alderman, 1996). Another group who show dual task deficits are those with Alzheimer's disease (Baddeley et al., 1991). Of the many devastating effects of Alzhiemer's disease is the decline of everyday independence due to deterioration of working memory abilities (Baddeley, Logie, Bressi, Della Salla and Spinnler, 1986). In a recent study, patients with Alzeimer's disease showed a specific deficit in dual task ability, even once baseline task ability is controlled for, which does not exist in normally ageing people or those with mild cognitive impairment (Foley, Kaschel, Logie and Della Salla, 2011). Another study of dual task ability in those with traumatic brain injury (TBI) found that while only a quarter of the TBI patients had dual task deficits, poor dual task performance in this group was associated with deficits in psychosocial functioning as measured by the Functional Assessment and Functional Independence measures (Foley, Cantagallo, Della

Salla and Logie, 2010). While there is accumulating evidence from patient studies that dual task ability is predictive of everyday functioning, this has not been formally investigated in the healthy population.

Under the framework set out by Burgess and colleagues (2006), multi-tasking ability measured in the MET or the E-VET would be a measurable cognitive function which, amongst other things, involves executive processes (Burgess, Alderman, Forbes et al., 2006). The separable executive processes are cognitive operations all of which contribute to the higher cognitive construct of working memory. It is widely accepted that working memory is a component of fluid intelligence (which involves reasoning and other higher mental abilities) and that general intelligence ('g') is a combination of fluid intelligence and acquired knowledge (crystallised intelligence) (Duncan, Burgess and Emslie, 1995). In the Wechsler Adult Intelligence Scale III (WAIS III) working memory is a sub-component of fluid intelligence (Weschler, 1997). While working memory is thought to be a measure of fluid intelligence, crystallised intelligence depends upon fluid intelligence to develop (Carroll, 1993). For this reason it is suggested that all executive operations and tests involving executive abilities should positively correlate with 'g' - a combination of fluid and crystallised intelligence measures. This hypothesis has received support from numerous clinical and individual differences studies which found a positive relationship between both fluid and crystallised intelligence and executive functioning (Friedman, Miyake, Corley, Young, DeFries and Hewitt, 2006).

There were three aims of the current study. The first aim was to demonstrate that there are several domain specific executive operations such as shifting and inhibition and that dual tasking is one such separable executive function. The second was to investigate which executive processes predicted a traditional executive test (WCST) in the healthy population. The final aim of the study was to investigate the relationship between separable executive functions, dual tasking and multi-tasking in the healthy young population using an ecologically valid measure of multi-tasking (E-VET). To achieve these aims, the WCST, an adapted version of the E-VET, a dual task test, three domain specific tests of executive function and two intelligence tests measuring reasoning and vocabulary (fluid and crystallised intelligence, combined to represent general intelligence 'g') were used. The domain specific executive tests included were all tests used or similar to tests used by Miyake and others

(2000) and included two tests of latent 'shifting' - the plus minus test and the letter number sequencing test - and the colour word interference test (CWIT), a measure of latent 'inhibition'. The WCST was used to represent traditional executive tests as it is one of the most widely used executive tests in clinical practice (Bulter, Retzlaff and Vanderploeg, 1991).

It was predicted that while the different separable executive processes and dual task ability would positively correlate with 'g', they would not correlate with each other (see hypothesis one). Secondly, it was predicted that 'g', the measures of executive shifting, dual task ability and inhibition would predict the WCST (see hypothesis two). Finally it was anticipated that dual tasking, 'g' and the domain specific executive functions would be predictive of multi-tasking ability in a regression analysis (hypothesis three). However, given the multi-dimensional nature of multi-tasking detailed by Burgess and others (2000) and by Logie and others (2010), the current study left open the possibility that executive processing may feed into different facets of multi-task ability differently. In Logie, Trawley and Law (2010) for example, structural equation modelling found that multi-tasking contained planning and intentionality aspects both of which were driven by memory. For this reason, numerous E-VET scores of different elements of planning and performance were gathered to allow an exploratory factor analysis to be performed with the intention to repeat the regression analysis with any separable factors which were derived.

Hypothesis 1

Executive functioning is not unitary and is made up of several separable constructs and dual tasking is one such separable executive construct.

Prediction 1 – Dual tasking should positively correlate with 'g' but not the other separable executive functions.

Prediction 2 – At least one measure of 'shifting' and the CWIT will positively correlate with 'g' but they will not correlate with each other.

Hypothesis 2

The WCST is a test of higher order executive function which is predicted by domain specific tests of shifting as well as intelligence and other executive functions such as dual tasking and inhibition.

Prediction 3 – The combined WASI scores representing 'g' and measures of switching, inhibition and dual tasking will explain a significant proportion of the variance in WCST responses.

Hypothesis 3

Executive processing, intelligence and dual tasking are necessary for successful multi-tasking

Prediction 4 - A significant proportion of the variance in E-VET performance will be explained by dual task, 'g' and domain specific measures of executive functioning.

Method

Participants

In total, 86 people participated in this study. All participants were healthy young adults between the ages of 19 and 30 (mean = 22.5 years, SD = 2.195). They were recruited using the graduate employment website 'SAGE' (Student and Graduate Employment) and so they were all either recent graduates, undergraduate or postgraduate students from Edinburgh University. They had a mean of 15 years of formal education (range = 12-20; SD = 2.345). Inclusion criteria required participants to be between 18 and 35 and speak fluent English.

Procedure

Participants were paid £6 an hour and signed a consent form after being informed they could leave the experiment at any time and that their results would be anonymous. The experiment lasted between and hour and an hour and a half and the tests were administered in the order in which they are described below.

E-VET

The Edinburgh Virtual Errands Test (E-VET) (Logie, Trawley and Law 2010) is a computerised measure assessing the ability to plan and perform various errands in a virtual office and shopping centre environment. Participants were given five minutes to plan the order in which they would perform 11 errands and then eight minutes to complete as many of the errands as possible within the virtual environment. An overall E-VET score was computed automatically (see table 1) and various other performance scores were also calculated by the computer or recorded manually by the experimenter during test performance. The E-VET was viewed on a 42-cm colour monitor, on a Dell XPS PC with Intel Core Quad 2.33 GHz processor and 1 GB ATI Graphics Card. The virtual environment was created using Hammer editing software within the game Half Life 2. It consists of four storeys with 10 rooms on each floor (five on each side), two sets of stairs and a central (non-functional) lift. This virtual environment was the same as that used by Logie et al. (2010), as were the keyboard control system and set of errands which the participants had to perform.

Introduction stage

Before beginning the E-VET, participants were informed of the building structure, where in the building they would begin the test and the rules. The stair rule stipulated that they should only go up the stairs on the right and down the stairs on the left and the object and room rules established that objects and rooms not on the plan should not be picked up or entered. Participants were then shown how to control the avatar and how to pick up and drop objects and push buttons and enter codes. They were then given as long as they liked to get used to navigating the virtual environment.

Planning stage

During the planning stage a large board was presented to the participants. The plan board was situated opposite the computer desk, facing the computer. The 11 errands (see table 1) were arranged in a random order and were written on squares of cardboard and attached to the board using Velcro. The subjects were given a map of the building and asked to re-arrange tasks into an optimal order bearing in mind that some of the tasks would have to be completed before others. To prevent confusion during E-VET performance, the participants were also informed that one of the tasks (task number 11, see table 1) was an open ended task with no clear end point. Finally, subjects were informed that they could turn around if they needed to during the test to check their plan. Five minutes were given for planning and if any subjects completed the plan before five minutes they were asked to attempt to memorise the plan for the remaining time. Participants were given access to the building map during the planning stage. As the planning board was placed directly behind the participants chair as they performed the E-VET on the computer, the number of times they turned around to look at the board to be easily noted by the experimenter and recorded as number of 'participant pivots'.

Table 1 – Errands in optimal order

Optimal task order	Errand
1	Get Stair Code from notice board in G8
2	Turn off Lift G Floor
3	Pick up Newspaper in G3
4	Drop Newspaper on desk in S4
5	Meet Person S10 before 3:00 min
6	Pick up Brown Package in T4
7	Turn on Cinema S7 at 5:30 min
8	Get Key Card in F9
9	Use Key Card to unlock G6 (via G5)

10	Drop Package in G6
11	Sort red and blue Binders in room S2.

Performance stage

Participants were given eight minutes to perform as many of the errands as possible in the virtual environment. During performance, the building map was also available to participants. While the participants attempted the test, the order in which they performed the errands and the order in which they planned the errands were recorded by the experimenter. These scores were later used to create three variables; 'plan optimality' – the extent to which the participants plan is similar to the optimal plan, 'performance optimality' – the extent to which the participants performance is similar to the optimal plan and 'plan following' – the extent to which the participant followed up on their intended actions (see scoring details in Table 2). The optimal plan used was the same as that validated by Logie et al. (2010).

While there are many similarities between the E-VET used in the present study and the test used in Logie, Trawley and Law (2010) and Trawley, Logie and Law (2011), there are also a few differences. Previous research using the E-VET has focussed on working memory and memory capacity while this study wished to investigate the link between executive abilities and everyday multi-tasking. The alterations were designed to create a multitasking test which would rely less on memory capacity (e.g. memorising plan and recalling of tasks without access to the plan during performance) and more on executive processes such as reasoning involved in optimal planning and performance and online monitoring during performance. For this reason the plan was always made available to participants during E-VET performance.

Table 2 - Manual Scoring

	Plan optimality	*Performance optimality*	*Plan following*
Scoring	● For each task in right position = 2 points; ● For each task one place off right position = 1 point; ● Binders task at 6,7 or 8 = 1 point (providing it is planned or performed before cinema task);	● For each task in right position = 2 points; ● For each task one place off right position = 1 point; ● Binders task at 6,7 or 8 = 1 point (providing it is planned or performed before cinema task)	● Task performed in same position as plan = 1 point; ● Three consecutive tasks performed in same order as plan (even if not in the same position) = 1 point + 1 extra point for every subsequent task in the same order as the plan

	● Dropping of package or newspaper before picking them up or trying to use keycard before picking it up = -2 points		after the first consecutive three.
Possible Range	● Minimum = -6 (no task in correct or one place away from correct order + keycard used and objects planned to be dropped before they were picked up) ● Maximum = 22 (all tasks planned in optimal order)	● Minimum = 0 (none of the tasks performed in correct place or one place away from optimal order) ● Maximum = 22 (all of the tasks performed in optimal order)	● Minimum = 0 (no tasks performed in same place and no more than two tasks performed consecutively in the same order as the plan) ● Maximum = 11 (all of the tasks performed in the same order as the plan)

As the E-VET takes place in a virtual environment, it is also possible to record aspects of the performance which it is not possible to record with the naked eye. Therefore other variables include the distance walked during the task and the time spent on the floors between rooms which are useful measures of navigation efficiency and memory failure. An overall E-VET score validated by Logie, Trawley and Law (2010) can also be calculated. This score takes into account the number of tasks completed, rewards the participants for sorting many folders, making the meeting on time and turning on the cinema at the right time and also punishes rule breaks such as picking up objects or entering rooms not in the plan and breaking the stair rule (see Table 3).

Table 3* E-VET score calculation

Bonus points added	**+4**	**+3**	**+2**	**+1**	**0**
Number of folders sorted	30+	23–29	15–22	8–14	1–7
Cinema (absolute time discrepancy, in seconds from 5:30 min)	0–2	3–5	6–7	8–10	11+
Meeting (time discrepancy, in seconds over 3:00 min)	≤3 min	1–12	13–25	26–37	38±
Penalty points deducted	**−4**	**−3**	**−2**	**−1**	**0**
Number of objects picked up that were not on the errand list	4+	3	2	1	0
Number of rooms entered that were not on the errand list	4+	3	2	1	0
Number of times stair rule broken	5+	4	3	2	1

*From Logie, Trawley and Law, 2010

Dual Task

The dual task test (Logie et al., 2004) assesses the ability to perform two tasks simultaneously while controlling for ability on each individual task. It consists of a digit recall and a tracking test element both of which are configured to each individual's level of ability. The dual tasking score is then calculated as the average of the proportional performance changes in both tasks between the single and dual task conditions. This test was performed using the same computer as the E-VET. The dual task test used is a computerised version of the test described in Logie et al. (2004) and Della Salla et al (2011).

Establishing Digit Span

Firstly the digit span of each participant was established. Starting with three digits and then increasing over eight levels to ten digits, random combinations of pre-recorded numbers were presented aurally through the computer loudspeaker. The participant's responses were recorded by the examiner on the keyboard. Four number combinations were given for each digit set. As soon as a subject responded incorrectly for two or more of the four responses, the digit span test ended and the digit span was established as the maximum number of digits with three or more correct responses.

Establishing Tracking Span

The next section involved the tracking element. This task required participants to use the mouse to keep the cursor over a circular icon or 'ladybird' which randomly moved around the screen. To establish baseline tracking ability the speed of the ladybird increased by 1 cm/s if participants kept the cursor on the icon 60% of the time for 5 seconds. The speed was gradually reduced when the participant maintained contact for less than 40 % of the time for 5 seconds. Tracking span was established as the maximum speed at which the participant could keep the cursor on the icon for 40 – 60% of the time over a three 5 second periods.

Independent Digit Recall and Tracking

To establish digit recall and tracking ability on their own the participants performed a digit recall test for 90 seconds set to their own maximum digit span and then the tracking task for

ninety seconds set to their speed adjusted level. The first 10 seconds of the tracking test and first set of digits test were considered practice and so were not used in the final score.

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Dual Task Test

The final section consisted of simultaneous performance of digit recall and tracking both set to individual levels of ability. Once again, first 10 seconds of tracking and the first set of digits were considered practice and unused in the final calculations. The dual task score was calculated as the average of the change in digit recall (percentage of numbers correctly recalled) and tracking performance (percentage of time spent with the cursor over the icon) between the single and dual task conditions (see equations below).

$$P\text{m} = 100 - \frac{[(^{\text{m}}\text{single} - {}^{\text{m}}\text{dual}) \times 100]}{^{\text{m}}\text{single}}$$

Proportional performance of digit recall = Pm
Percentage of digits recalled accurately = m

$$P\text{t} = 100 - \frac{[(^{\text{t}}\text{single} - {}^{\text{t}}\text{dual}) \times 100]}{^{\text{t}}\text{single}}$$

Proportional performance of tracking ability = Pt
Percentage of time with cursor over icon = t

$$\mu = \frac{P\text{m} + P\text{t}}{2}$$

Proportional performance of both tasks (dual task score) = μ

Executive tests

Plus Minus Test

The plus minus test (Spector and Biederman, 1976) has been used as a measure of latent shifting (Miyake et al., 2000) and it assesses participant's ability to quickly alternate between simple addition and subtraction when baseline adding and subtracting speed is controlled for.

Firstly, the time it took participants in seconds and milliseconds to two decimal places to add three to a list of 30 numbers and then subtract three from a list of 30 different numbers were recorded separately. The participants then had to alternate between adding and subtracting from a third list of 30 numbers and the time taken in this alternating condition was also calculated. The score used (μ) was the time from the alternating condition minus the average of the times in the plus and minus conditions;

$$\mu \; = \; \text{time} \, (+/-) \quad - \quad \frac{\text{time}(+) + \text{time}(-)}{2}$$

Colour Word Interference Test

The Colour Word Interference Test (CWIT) from the Delis-Kaplan Executive Functioning System (Delis, Kaplan and Kramer, 2001) was used to assess inhibition of a pre-potent response. This test consisted of a congruent trial in which participants read aloud a list of words as quickly as possible and an incongruent trial in which the participants were asked to read the colours of the ink instead of the words. The words were 'red', 'tan', 'green', or 'blue'. Each was coloured one of the other three colours (e.g. the ink of each 'red' was either blue, green or tan) and there were 112 randomly ordered items. Two stimuli sheets were used, one for the congruent trial and one for the incongruent trial. Both the congruent and incongruent trial stimuli sheets contained the same stimuli but in different random orders. The CWIT score (μ) was calculated by subtracting each participants time (seconds and milliseconds to two decimal places) to complete the incongruent trial by the time they took to complete the congruent trial.

$$\mu \; = \; \text{time(incongruent trial)} - \text{time(congruent trial)}$$

Letter Number Sequencing

The letter Number Sequencing task is an optional subset within the working memory component of the Wechsler Adults Intelligence Scale III (Wechsler, 1997). This test assesses the ability to maintain and manipulate information and importantly also involves switching between two mental representations, namely numbers and letters. Participants were given a randomly ordered list of letters and numbers and were required to repeat these, stating the

numbers in numerical order first and then the letters in alphabetical order afterwards. There were thirty items in total consisting of 10 sets of three. The test ended before the last item if a participant responded incorrectly for all three items in a set. The Letter Number Sequencing score was the number of items out of 30 performed correctly.

WCST

The Wisconsin Card Sorting Test (WCST) is purported to assess executive functioning and specifically the ability to shift from one mental set to another (Fray, Robbins and Sahakian, 1996). In this study, the 128 card manual version (Grant, Berg and Nyman, 1996) was used. This test consisted of placing four category cards (see Figure 1) in front of the participant. They were asked to match cards one at a time from the pile of 128 to one of the four category cards. Each card contained one to four red, yellow, blue or green triangles, circles, stars or crosses. As the participant matched the cards the only feedback given from the experimenter was 'correct' or 'incorrect'. The participants were told to attempt to get as many correct responses as possible. Each time the participant made 10 correct responses in a row, the matching rule was changed by the experimenter. The first matching rule was colour of the symbols. After 10 correct responses the rule changed to form (shape of symbols) and then number of symbols after which the pattern was repeated again creating six matching sets. The test was ended after all the cards had been sorted or after all six matching sets had been completed, whichever came first. The score used in the analysis was the perseverated responses (both correct and incorrect). Perseverative responses or errors are the most commonly used score from the WCST (e.g. Miyake et al., 2000); (Rusconi, Maravita, Bottini & Vallar, 2002). Participants are said to have perseverated when they carry on sorting by one matching rule after they get negative feedback for that rule. While the perseverative error and perseverative response scores are very similar, the perseverative response score also includes those responses which are assumed to be perseverative but which were spuriously correct. For example, if the matching set was colour and the participant perseverated by continually matching via number, an error would not occur if one of the cards matched both number and colour. This response would be recorded as perseverative provided there were unambiguous perseverative errors either side of this response. Given the possibility of ceiling effects in a young, healthy and intelligent sample, the score which offers more variation, namely perseverative responses was selected as the dependent variable for the WCST.
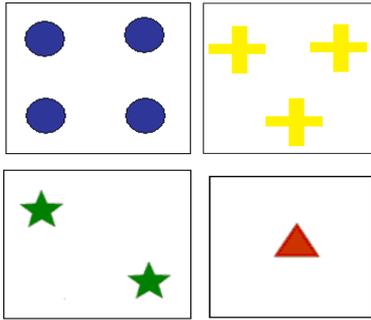
Figure 1 - Category cards in WCST test with four blue circles, three yellow crosses, two green stars and one red triangle.

WASI

Two items from the Wechsler Abbreviated Scale of Intelligence (WASI) were used in order to estimate general intelligence or 'g'. The Matrix Reasoning section was used to measure fluid intelligence and the Vocabulary section was used to measure crystallised intelligence (Wecshler, 1999). Both these subtests have been shown to be reliable and valid, and the appropriate items were used for the age of the participants to achieve a normal spread of results (Wechsler, 1999). In the case of Matrix Reasoning this meant starting at item seven out of thirty-five, (assuming that 1-6 were correct if they got 7-11 correct) and continuing until all the items were completed unless they responded incorrectly to four in a row, or four out of the their last five items. This was a similar case for the Vocabulary subtest as the test was started at item nine and carried on all the way to item forty-two unless the participant was given a score of zero for four items in a row or four out of the last five items. General intelligence or 'g' was calculated by establishing the average of the two WASI scores;

'g' = $\underline{\text{WASI matrices} + \text{WASI vocabulary}}$
$\qquad\qquad$ 2

Analysis/Results

Descriptive Statistics

The data were screened for any outliers and checked for bimodal or skewed distribution. Observation of the standardised residuals of all the variables used in analysis revealed that the colour word interference test and plus minus task scores both contained two scores which were more than three standard deviations higher than the mean. The combined WASI matrices and WASI vocabulary 'g' score also contained two results more than three standard deviations below the mean. One of these low 'g' scores which resulted from the combination of an average WASI matrices score and an extremely low WASI vocabulary score lead to the data from the participant in question being removed from the data set. This score was established as unreliable because of the participant's relative ability on the WASI matrix reasoning task and because English was not their first language. As there was no obvious reason for any of the other outliers in the data, the analysis was run with and without these outliers. There was no substantive difference between the results with and without these outliers so the analysis with the original data set (n=85) was reported.

The variables to be used in correlation analysis were also checked for normal distribution using a Shapiro-Wilk test of normality. Only the dual task scores were found to be normally distributed. None of the data was bimodal, however the WCST perseverative responses and the plus minus test were positively skewed suggesting a possible ceiling effect and therefore a logarithm transformation was performed on all the variables. However, even after transformation the Shapiro-Wilk test showed that the distribution did not achieve normality for any of these variables and so the untransformed data was used. While regression and factor analysis techniques are robust to data that is not normally distributed, correlation analysis is not and so a non-parametric correlation technique (Spearman rank correlation) was used when testing hypotheses one (Tabachnick and Fidell, 2007). Table 4 shows the mean, median, maximum and minimum and standard deviation scores for each variable used to analyse the data involved in hypotheses one and two.

Table 4 – Descriptive statistics of all variables other than E-VET score

Variable	Mean	Median	Min	Max	Standard deviation
'g' (average of WASI vocab and WASI matrices)	47.25	47.5	35	53.5	3.612
WCST perseverations (% of responses)	11.23	9.64	2.78	32.03	6.448
Dual task (100 - average proportional change in tasks)	95.12	95.5	76.6	113.1	6.712
Plus Minus (seconds)	15.65	12.45	-7.30	76.35	15.197
Colour Word Interference Task (seconds)	28.55	29.20	-12.00	73.00	12.679
Letter Number (score out of 30)	22.19	22.00	17.00	28.00	2.697

Relationship between dual tasking, executive tests and general intelligence

Table 5 shows the Spearman's rank correlation scores for each of the six variables in hypotheses one to four. As a non parametric statistic was used, all of the variables were analysed using their original untransformed scores. The accepted level of probability was set at the standard level of 0.05.

Table 5 - Spearman's rank correlation scores for each of the six variables in hypotheses one and two.

	'g'	WCST perseverations	Dual task	Plus minus	Colour word interference task	Letter-number sequencing
'g'	1					
WCST Perseverations	-0.16	1				
Dual task	0.22*	-0.077	1			
Plus minus	-0.08	-0.089	-0.05	1		
Colour word interference task	-0.32**	-0.064	-0.21	0.22*	1	
Letter number sequencing	0.3**	-0.21	0.006	-0.15	-0.15	1

Key: *= p<.05; **=p<.01

Correlations key in prediction 1   Correlations key in prediction 2

As seen in Table 5, dual tasking was not significantly correlated with performance on any of the other executive tests (all $p > .05$). However, dual task performance was significantly positively associated with performance on the combined WASI scores representing 'g' ($p < .05$)

Performance on the Colour Word Interference Test was significantly negatively associated with 'g' ($p < .01$). Letter Number Sequencing was significantly positively associated with 'g' ($p < .01$) but not with the colour word interference test performance ($p > .05$). Performance on the Plus-Minus Task was significantly positively associated with performance on the Colour Word Interference Test ($p < .05$), but not with Letter Number Sequencing or 'g' (all $p > .05$).

WCST performance

The WCST performance was analysed using a hierarchical regression. General intelligence 'g' was added to the model first followed by the two tests of latent 'switching', namely the plus minus test and letter number sequencing. The colour word interference and dual task scores were the last to be added to the model. General intelligence alone accounted for 4.5 % of the variance in WCST percentage perseverative responses ($p < .05$) (Figure 2). The only predictor to increase the variance explained by this model was the plus minus task. Together 'g' and the plus minus task accounted for 5.8% of the variance in WCST percentage perseverative responses ($p < .05$). However an analysis of variance (ANOVA) comparison of the two models established that the plus minus test did not significantly improve the fit of the model ($F (1,82) = 2.16$, $p > .05$) and so the model with 'g' alone predicting WCST perseverations was endorsed.

	Coefficients	Standard error	Standardised β
Intercept	31.3	9.02	.000***
'g'	-0.42	0.19	.029*
P< 0.05			
Adjusted R2 = 0.045			

Figure 2; best fitting regression model for WCST perseverative responses
(* = *p*<0.05; ** = *p*<0.01; *** = *p*<0.001)

Assumptions

The even spread in the plot of residuals versus predicted values for the endorsed model (figure 3) indicates that the assumptions of linearity and homoscedasticity have been met. There were no influential points with Cook's distances above one. Observation of the QQ plot of the standardised residuals vs a theoretical normal distribution (figure 4) revealed that there was one outlier with a standardised residual score above three. The distribution of standardised residuals showed that the normality assumption was violated especially at the extremes.
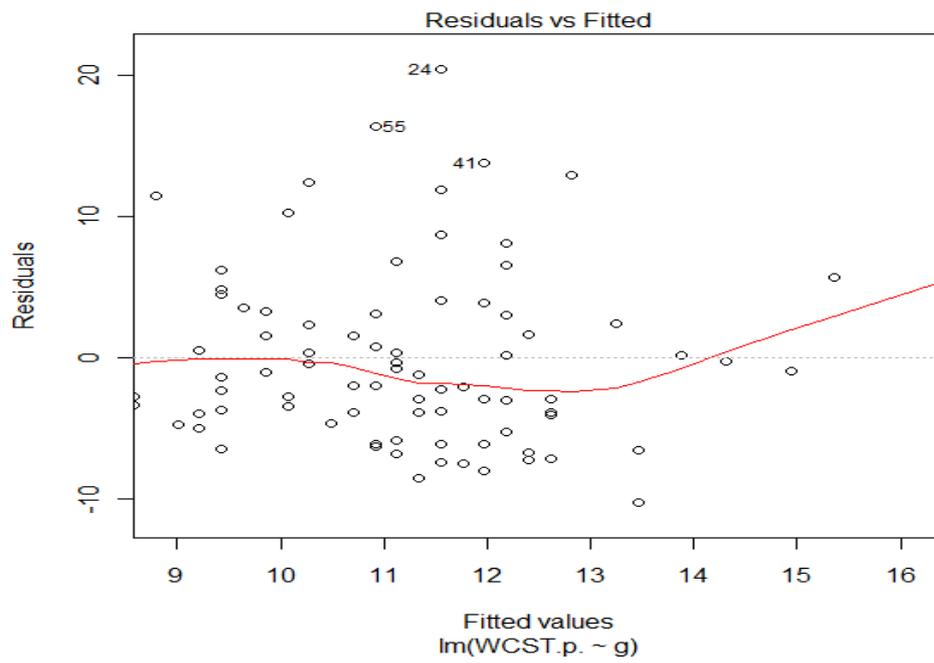
Figure 3 – Plot of the residuals in the endorsed model predicting WCST perseverations.
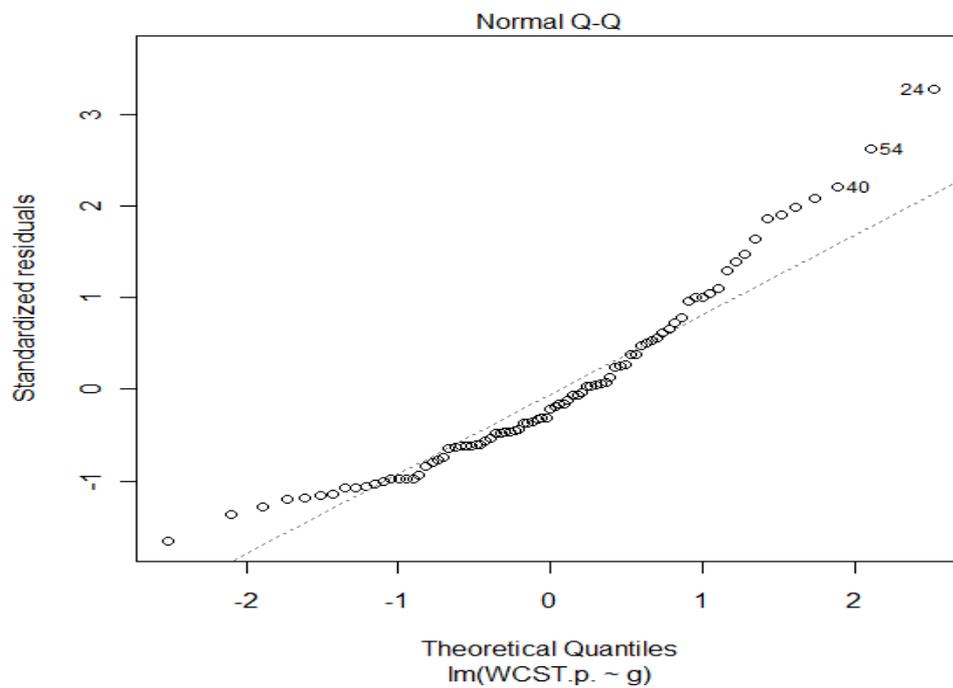

Figure 4 – Normal QQ plot of the standardised residuals vs a theoretical normal distribution for the endorsed model.

E-VET performance

The E-VET score was generated by taking the number of tasks completed, rewarding participants for good time keeping and folder sorting and punishing them for breaking rules (see table 3)(Logie et al, 2010). The participants in this study attained a mean score of 3.635 with a median of 4, a range of 15 (from -3 to 12) and a standard deviation of 2.36. Table 6 shows the Spearman's rank correlations between the E-VET score and the other test scores. There were no significant correlations between the E-VET and other test scores (all $p > .05$).

Table 6 – Correlations between E-VET score and other variables

	WCST perseverative responses	Dual Task test	Plus Minus test	Colour Word Interference Test	Letter Number Sequencing	General Intelligence 'g'
E-VET score	0.04	0.16	-0.21	-0.04	0.12	-0.05

Regression analysis

A hierarchical regression was performed to predict E-VET score. Based on the evidence provided by working memory, executive function and multi-tasking literature, the order the predictors were entered into the model in the following order - the dual task test, 'g' and finally the tests of separable executive function. Dual task alone was found to account for only 1.4% of the variance in the E-VET score however this model was not significant ($p > .05$). The only predictor to increase the variance accounted for by this model was the plus minus test. Dual task and plus minus score accounted for 4.3% of the variance in E-VET score however this was also not significant ($p > .05$) (see Figure 5). As models 1 and 2 were both non significant, neither was endorsed. As stated earlier, multi-tasking has been shown to be multi-faceted and so although working memory and executive functioning may be related to multi-tasking, they may be related to one facet of multi-tasking and not others. For this reason an exploratory factor analysis of all of the measures of multitasking was performed to attempt to establish two or more separable factors and explore how these relate to the executive tests.

	Coefficients	Standard error	Standardised β
Intercept	-0.66	3.62	.86
Dual task	0.05	0.04	.19
Plus Minus	-0.03	0.02	.07
p = 0.063			
Adjusted R2 = 0.043			

Figure 5; best fitting regression model for E-VET score

Exploratory Factor Analysis

Table 7 shows the descriptive statistics of the E-VET variable raw scores and the inter-correlations (Spearman rho) between the E-VET variables used in the factor analysis.

Table 7 : E-VET variable intercorrelations

Variables	mean	median	standard deviation	1	2	3	4	5	6	7	8	9
1 Time on floors	25910	23576	62.46	1	0.85**	0.23*	0.26*	0.008	0.006	-0.06	-0.11	0.03
2 Total distance travelled	3.64	4.00	9477.8		1	0.25*	0.32**	-0.02	0.14	0.11	0.05	0.21*
3 Participant pivots	5.47	5.00	3.198			1	0.05	0.05	-0.29**	0.01	-0.19^	0.07
4 Stair rule breaks	0.518	0.00	0.8397				1	0.17	-0.12	-0.15	-0.17	-0.24*
5 Object and room lure (combined score)	0.718	0.00	1.08685					1	-0.15	-0.16	-0.3**	-0.34**
6 Plan optimality	2.73	2.00	5.404						1	0.68**	0.55**	0.46**
7 Performance optimality	4.95	5.00	4.295							1	0.64**	0.74**
8 Plan following	9.28	10.00	3.067								1	0.66*
9 Tasks completed	8.78	9.00	2.259									1

($*$ = $p<0.05$; $**$ = $p<0.01$)

Examination of the principle components analysis of the data matrix confirmed its suitability for factor analysis – the KMO statistic was 0.67 (>0.6). The scree-plot (shown in figure 6)

shows that the data consisted of two meaningful factors and this was confirmed using a Horn's parallel analysis.
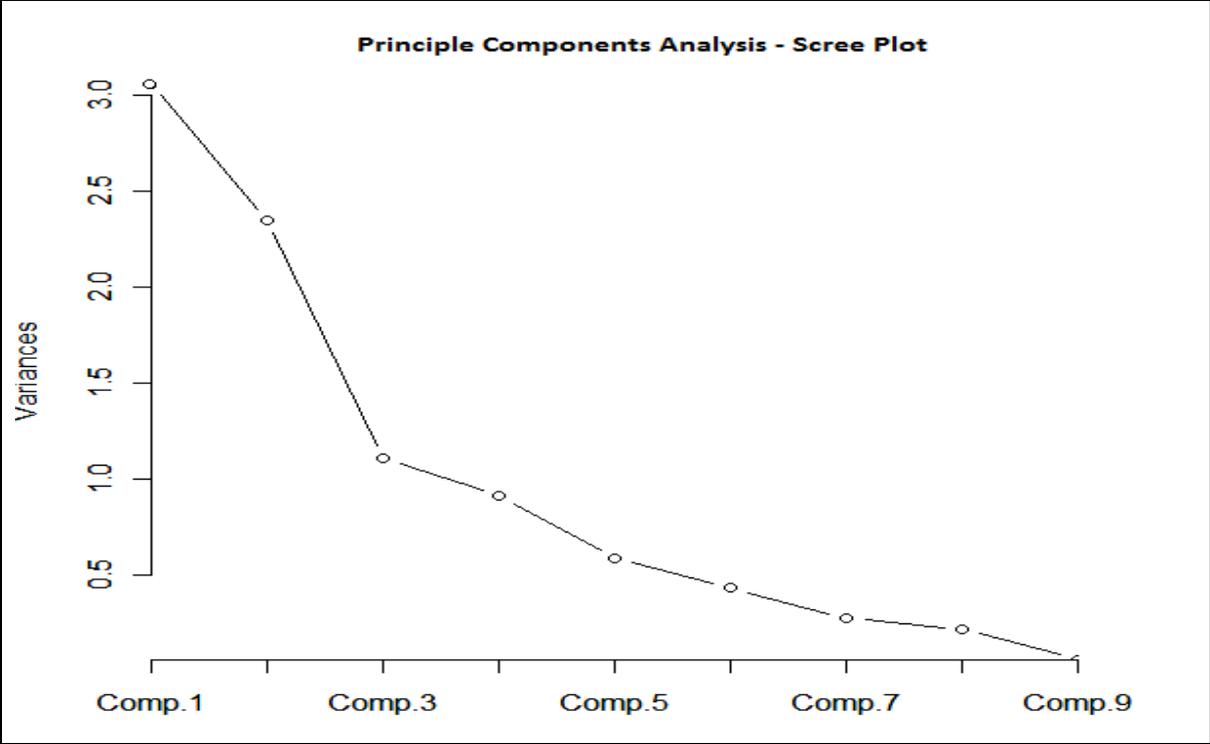

Figure 6 - The scree-plot of the principal components analysis for the E-VET data matrix.

For the factor analysis, oblique and orthogonal (varimax) rotations were compared and since the same factor structure was observed in both, the simpler orthogonal rotation was chosen. The percentage of explained variance and cumulative variance of the two factors is shown in Table 8.

Table 8: Proportional and cumulative variance explained by the two factors

	Factor 1	Factor 2
Proportional variance	0.29	0.25
Cumulative variance	0.29	0.54

Based on the combination of variables in each factor, the latent variables were labelled 'intentionality' and 'memory'. The loadings for the two factors are shown in Figure 7. The first factor consisted of planning and performance optimality, plan following, and number of tasks completed. The second factor consisted of the time spent on the floor, the total distance

25

travelled during the E-VET as well as the participant pivot score measuring the number of times subjects turned around to view their plan during the performance stage. The number of times the stair rule was broken also contributed to this factor. The combined score of object and room lure did not significantly contribute to either factor. Based on previous multi-tasking literature (Burgess et al., 2000);(Logie et al., 2010) factor one was labelled 'intentionality' as it measured participants ability to plan an intended set of actions and perform the plan in an optimal manner (Logie et al., 2010) and factor two was labelled 'memory' as it consisted of four different indicators of memory failure.
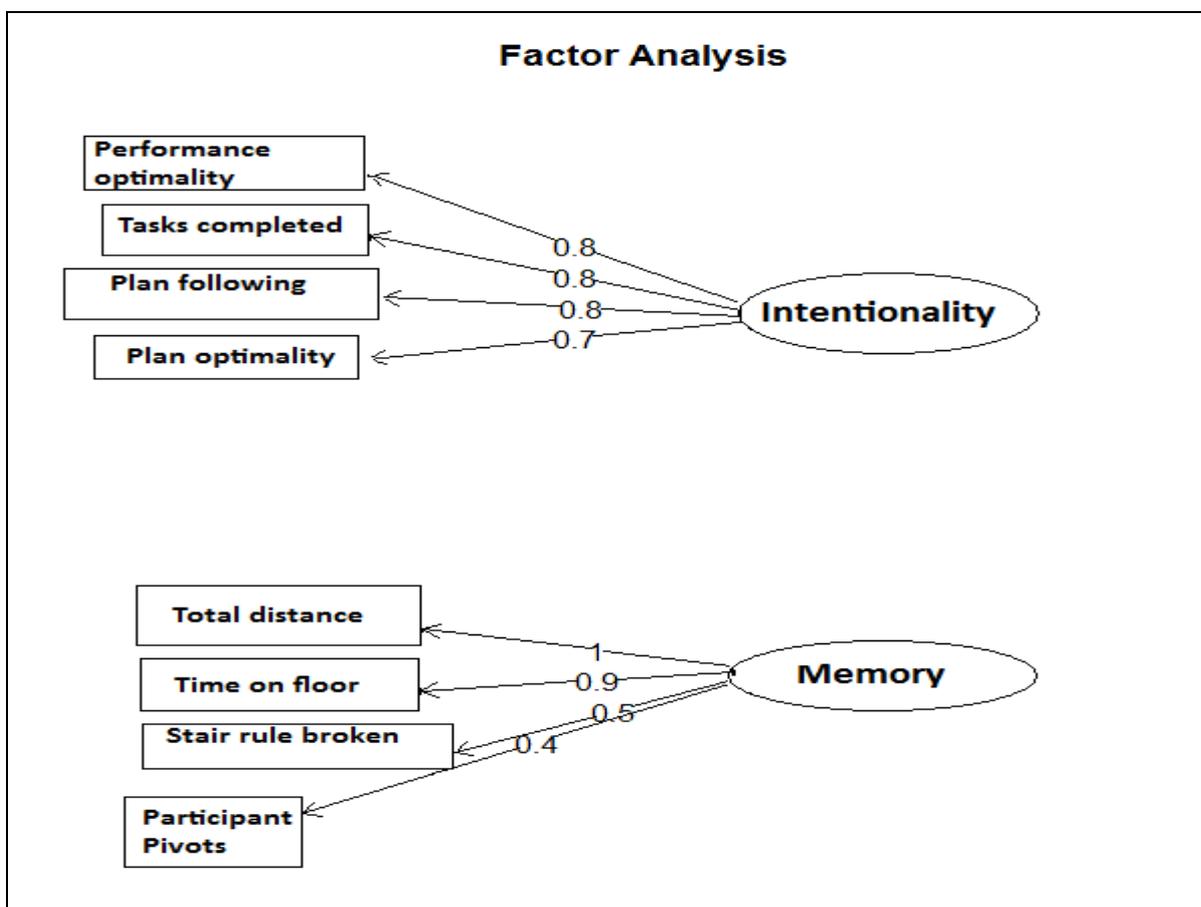

Figure 7 – loadings for latent 'intentionality' and 'memory'

Regression analysis with latent variables

The previous hierarchical regression analyses were performed again to investigate the extent to which dual tasking, 'g', and the domain specific executive tasks predicted multi-tasking. The regression method was used to calculate factor scores for latent intentionality and memory.

Intentionality

Dual task test score alone accounted for 5.85% of the variance in the intentionality component of E-VET performance ($p < .05$). When 'g' was added to this model the amount of explained variance increased to 10.1% ($p < .05$) (see figure 8). An ANOVA comparison of these two models confirmed that 'g' significantly improved the fit of the model ($F (1,81) = 4.92$, $p <$ .05). Of the three domain specific tests of executive function only letter number sequencing improved on the amount of variance explained by this model. Dual task score, 'g' and letter number sequencing explained 11.7% of the variance in latent intentionality ($p < .05$). However an ANOVA comparison showed that adding letter number sequencing to the model with dual task ability and 'g' did not significantly improve the fit of the model ($F (1,82) =$ 2.45, $p > .05$). The endorsed model for latent intentionality is displayed in figure 8 below.

	Coefficients	Standard error	Standardised β
Intercept	-5.90	1.75	.001***
Dual task	0.03	0.02	.034*
'g'	0.06	0.03	.029*
p = 0.005			
Adjusted R2 = 0.101			

Figure 8; best fitting regression model for latent intentionality within the E-VET
(* = *p*<0.05; ** = *p*<0.01; *** = *p*<0.001)

Assumptions

The graph of residuals versus predicted values shows that the assumptions of linearity and homoscedasticity have been met for the endorsed model (figure 9). While there were a few outliers, no residuals had a Cook's distance of more than 1. However, observation of plot of the standardised residuals vs a theoretical normal distribution showed that the assumption of normality was violated for the endorsed model especially at the extremes (figure 10).
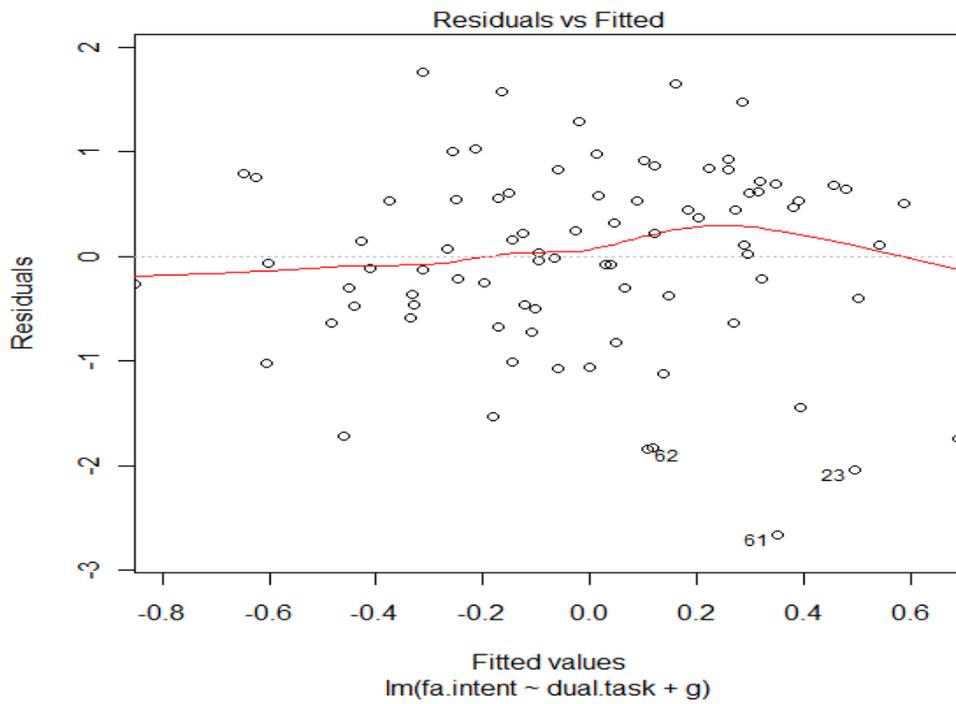
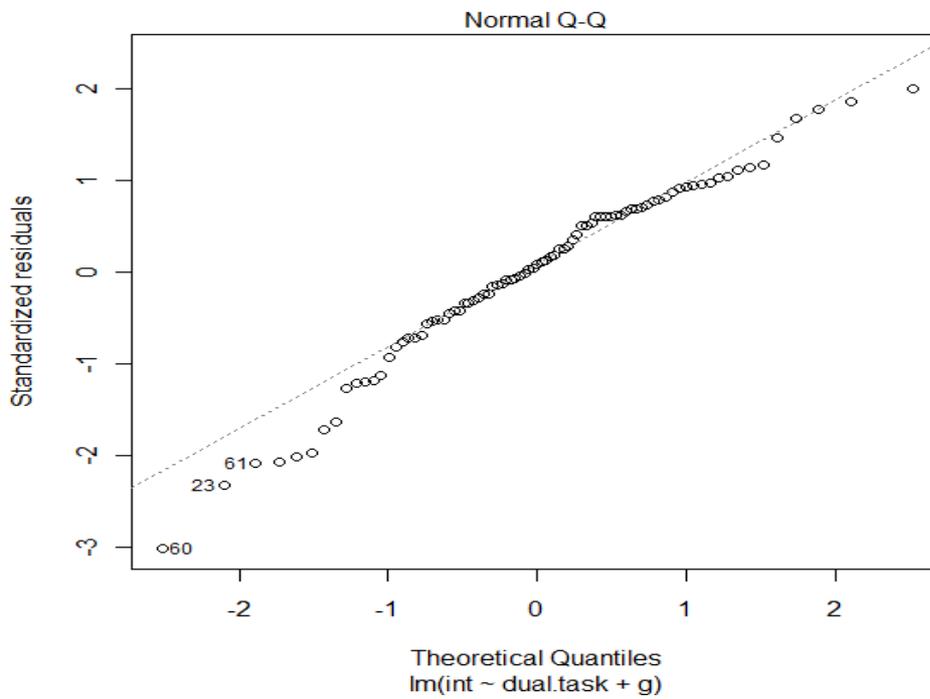Figure 9 – Plot of the residuals in the endorsed model predicting latent intentionality.

Figure 10 – Plot of the standardised residuals vs a theoretical normal distribution for the endorsed model for intentionality.

Memory

Dual task score predicted 1.72% of the variance in the memory component of E-VET performance however this was not significant ($p > .05$). As dual task ability alone was a poor predictor of latent memory in multitasking and did not significantly predict latent memory, it was removed and models with 'g' alone and with other predictors were tested. General intelligence 'g' accounted for 5.54% of latent memory within E-VET performance ($p < .05$) (see figure 11). The only additional predictor to improve the model was the plus minus test. General intelligence and plus minus test score explained 7.07% of latent memory ($p < .05$). However, an ANOVA comparison between the two models showed that adding the plus minus test did not significantly improve the fit of the model ($F(1,82) = 2.36, p > .05$). The endorsed model with 'g' alone predicting latent memory is displayed in figure 9 below.

	Coefficients	Standard error	Standardised β
Intercept	3.37	1.39	.017*
'g'	-0.07	0.03	.017*
p = 0.017			
Adjusted R2 = 0.0554			

Figure 11; best fitting regression model for latent memory within E-VET

Assumptions

Figure 12 shows a plot of residuals versus predicted values for the endorsed model. The residuals are evenly spread throughout the plot indicating that the assumptions of linearity and homoscedasticity have been met. There were no outliers and no cases had a Cook's distance of more than 1. The plot of the standardised residuals vs a theoretical normal distribution shows that the assumption of normality was not met as there was large amounts of deviation from the theorestical normal values at the extremes (figure 13).
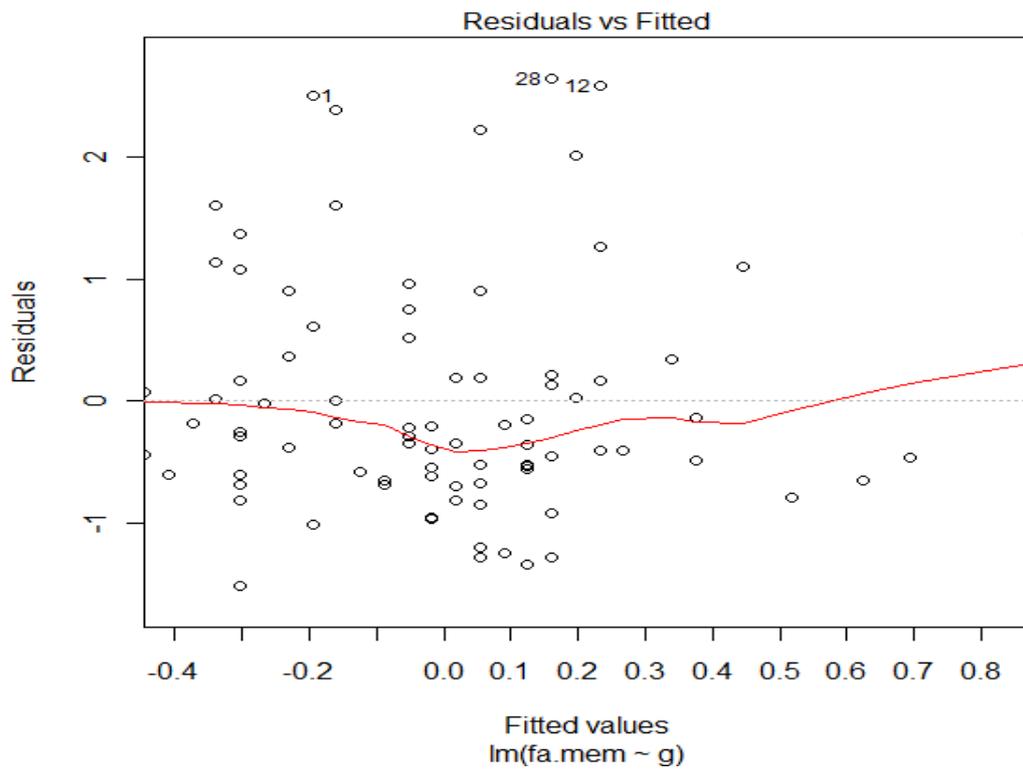
Figure 12 – Plot of the residuals in the endorsed model predicting latent memory.
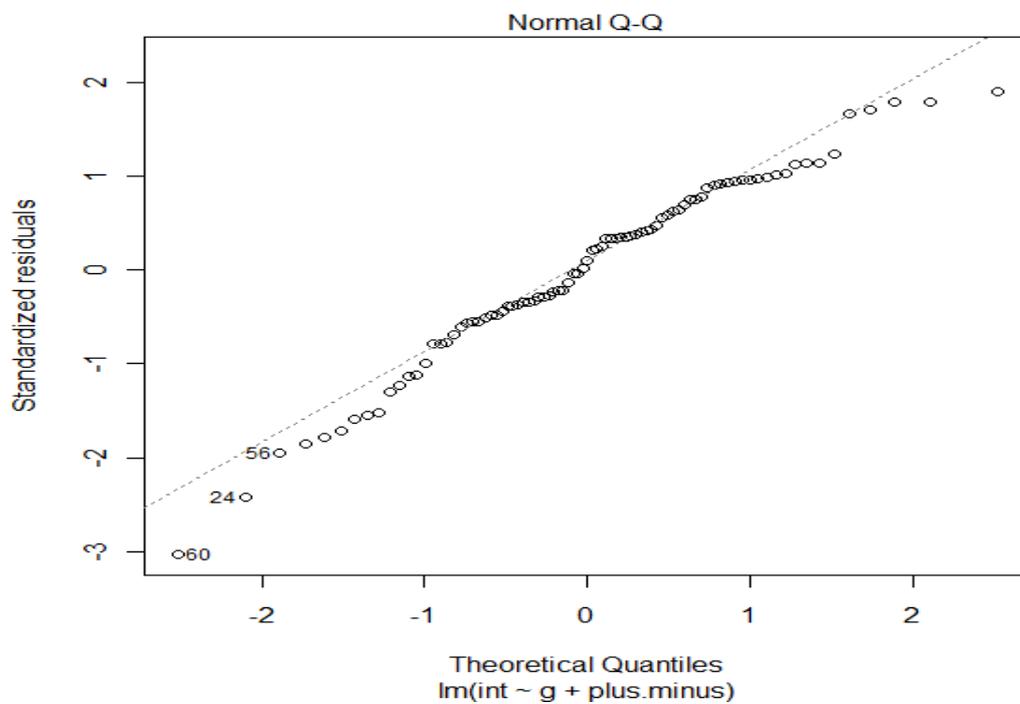

Figure 13 - Plot of the standardised residuals vs a theoretical normal distribution for the endorsed model for memory.

Discussion

The first aim was to investigate the existence of separable executive functions and the possibility that dual tasking is also a separable executive function. It was predicted that if the colour word interference task (CWIT) – a measure of latent inhibition - and measures of latent shifting (the letter number sequencing and the plus minus task) were separable processes then the CWIT and at least one of the 'shifting' measures would correlate with 'g' but not with each other. This prediction was supported as both the CWIT and the letter number sequencing scores were correlated with 'g' while no significant relationship between the letter number sequencing and the CWIT was found. With regards to dual task ability it was predicted that dual task score would correlate with 'g' but not with the plus minus test, CWIT or the letter number sequencing test. Dual tasking ability was found to be significantly positively correlated with 'g' but no significant relationship was found between dual task score and the other tests of executive function. These results can be taken as evidence that there are distinct executive processes because while successful performance of both the CWIT and letter number sequencing represents intelligent behaviour within the domain of working memory, different capacity limits were observed within individuals for these two tasks. The results also provide evidence dual task ability is an executive function which is separate from both 'shifting' and 'inhibition'.

While hypothesis one was supported there were also conflicting findings and methodological weaknesses which require the interpretation of the results to be approached with caution. If both the plus minus test and the letter number sequencing test are measures of latent 'shifting' then they should be related and should both be separable from the CWIT. However while the plus minus test and letter number sequencing task scores were not related, the CWIT and plus minus test were positively correlated. This result indicates that processes other than executive shifting and inhibition were necessary for successful completion of these tasks and that this affected the relationships between the tasks. For example, the significant correlation between the CWIT and the plus minus test may be due to the fact that both relied heavily on processing speed. The CWIT required hasty processing of the ink colour as well as the inhibition of the pre-potent word reading response and the plus minus task required rapid switching between addition and subtraction during the alternating condition. Therefore, it is possible that while the CWIT and plus minus task differed in their executive requirements, the

observed relationship was due to their similar processing speed requirements. Furthermore, the letter number sequencing task, while also a measure of shifting, was not timed and therefore required accurate rather than hasty processing. This task also relied heavily on memory capacity as the numbers and letters had to be held in memory while re-ordering took place. This may explain why it was not related to any of the other executive tests as unlike the other executive tasks, the letter number sequencing task was not configured to individual ability either by subtraction of the experimental trial from a control trial (plus minus and CWIT) or by establishing individual ability before the test performance (dual task). For this reason it is difficult to interpret the letter number sequencing score as a reliable indication of shifting ability because memory capacity within individuals was not controlled for.

While the prediction that dual tasking ability would be related to 'g' but none of the other executive tests proved correct, the extent to which this finding can be used as evidence that dual task ability is a separable executive function is questionable. This is because an important part of the prediction rested upon proving the null hypothesis – that dual tasking ability would not be correlated with the other executive functions. Additionally, the power of this experiment was low given the relatively small sample size of 85 and small effect sizes found in hypothesis one. When the power is low there is an increased chance that a small, 'real' correlation would be found to be non significant. In such circumstances, attempting to prove the null hypothesis to support predictions becomes a very suspect practice as the hypothesis is likely to be accepted even if it is not true. While the type one error level of 0.05 is frequently used as the cut off when deciding the significance of a result, it is less useful and can be misleading in cases such as this where acceptance of the null hypothesis is the goal. When the individual effect sizes, low power and relatively high probability of type two error are taken into account it is difficult to maintain that there is substantial evidence from this study that dual task ability is both separable from 'inhibition' as measured by the CWIT but also related to 'g' as measured using the WASI. It is also likely that in an experiment with sufficient power, the dual task and CWIT scores would be significantly correlated and prediction two would not have been accepted.

The second aim was to investigate the relationship between the Wisconsin Card Sorting Test (WCST) and domain specific tests of executive function and intelligence. It was found that 'g' alone was the best predictor of WCST performance. Dual task ability, inhibition

represented by the CWIT and the plus minus test and letter number sequencing all failed to account for a significant proportion of WCST perseverations. The WCST requires insight and reasoning for successful performance and so it is no surprise that it is related to general intelligence. It is, however, surprising that neither letter number sequencing nor the plus minus test significantly improved this model predicting the perseverative responses in the WCST. This is surprising because perseveration during this test has been implicated as a sign of difficulty in shifting mental set or switching between matching by colour, form or number (Fray et al., 1996). A possible explanation for this result could be that the measures of executive shifting are not measuring the same type of shifting as the WCST. For example the plus minus task requires hasty and entirely predictable switching between addition and subtraction which is very different from the set shifting and reasoning abilities required during the WCST which necessitates insight in order to figure out the rules and continuous monitoring of the experimenters feedback. As discussed above, the letter number sequencing task may be a test of memory capacity as well as shifting and this may explain why it did not predict WCST score as the WCST requires online processing rather than the maintenance of many pieces of information. While the WCST has previously been proposed as the 'gold standard' test of executive processing (Eling et al., 2008), recently there has been substantial criticism directed towards the continued use of the WCST in executive function research (Burgess et al., 2006). This is the result of evidence suggesting that successful performance the WCST does not require some executive processes such as inhibition or updating (Miyake et al., 2000). The hierarchical regression analysis supported the suggestion that the WCST does not tap many important aspects of executive functioning.

The final aim was to investigate the relationship between multi-task performance, intelligence and the domain specific executive functions including dual tasking. The executive tasks, 'g' and dual tasking did not predict a significant proportion of the variance in the overall E-VET score measure which was calculated using the scoring system from previous studies using the E-VET (Logie et al., 2010);(Trawley et al., 2011). One reason for this result could be that the scoring system used to create the E-VET score was taken from studies which used a different version of the E-VET than the current study. As the scoring method remained the same, the differences in E-VET scores are likely to have resulted from the differences in the design of the tests in each of the experiments. The mean percentage E-VET score in the current study was far lower than in Logie, Trawley and Law, 2010) (18.18% compared to 49.30%) and

there was far less deviation in the scores in the current paper (standard deviations; 11.8% in the current study compared to 28.46% in Logie, Trawley and Law, 2010). As participants found the E-VET in the current experiment more challenging, the scoring method may have been both overly harsh when rewarding very good performances and also too lenient when punishing poor performances as indicated by the lower variation of scores.

Another possible reason for this result which was considered before analysis was the multi-faceted nature of multi-tasking. For this reason several measures of different aspects of the E-VET performance other than the overall E-VET score were taken and analysed in an exploratory factor analysis. Two meaningful factors were derived from the factor analysis and named memory and intentionality. Intentionality during multi-tasking refers to the ability to create and successfully carry out a plan involving the interleaving of tasks to achieve various goals in an optimal fashion. Memory within multi-tasking refers to the ability to remember any task rules as well as what tasks have been, and still need to be, performed. The 'time spend on the floors' and 'total distance travelled' variables which load into this factor also indicate that spatial awareness or the participant's ability to monitor their position in a three-dimensional environment may be related to memory during E-VET performance. This two factor model differs from the previous model of multi-tasking established in patients with frontal brain injury by Burgess and colleagues (2000) which has recently been extended to the healthy population by Logie and others (2010) because planning was not a found to be a separate factor. Instead the planning optimality score loaded into the intentionality factor. The alterations of the E-VET design from that used by Logie and others (2010) may explain this finding. As less planning time was made available, the plans made by participants in the current study were poorer than the plans made by the participants in Logie, Trawley and Law (2010). The plan optimality percentage was 40.9% in the current study compared to 46.36% in previous study. As the plan was available to participants at any point during the E-VET, the quality of the plan directly affected the task performance. Good plans could be followed directly from the planning board while bad plans would require alteration during performance which adversely affected performance. Another possible reason for this finding is that there were two measures of planning in Logie and others (2010) – one for the set of errands participants eventually performed and another taken at the end of the E-VET procedure for a different set of errands. There was only one measure of planning in the current study and so while planning may be a separable component of multi-tasking there were not enough measures in the current experiment for this factor to be observed. The model also differed

from the previous models in that the memory factor is made up of E-VET variables rather than independent measures of working memory span such as the verbal and spatial working memory task. This difference may have occurred because only one of the four variables which loaded into latent memory in the current study ('travel time') was included in the factor analysis performed by Logie, Trawley and Law (2010).

When the regression analysis was repeated, it was found that latent memory within multi-tasking was only significantly predicted by 'g'. It is unsurprising that 'g' was related to latent memory given that the variables which load into this factor appear to be indirect measures of working memory capacity as well as spatial awareness both of which have been established as components of general intelligence (Wechsler, 1999). Dual task ability and the tests of executive function did not account for a significant proportion of the variance in latent memory. This is likely to be because none of these tests assessed memory capacity. Dual task ability and 'g' predicted a significant proportion (10.1%) of latent intentionality Once again it is not surprising that 'g' should predict a task which requires reasoning during planning, spatial awareness and continual monitoring of performance. Dual task ability (without 'g') also explained a significant proportion (5.85%) of the variance in the intentionality aspect of E-VET performance. This result adds to evidence from clinical studies that dual tasking is vital during the performance of everyday tasks. It suggests that within the healthy population, dual task ability predicts a significant proportion of the intentionality aspect of multi-tasking. In other words the ability to plan and perform a number of tasks in an optimal fashion relies as heavily on dual task ability as it does general intelligence. None of the three tests of executive functioning predicted latent intentionality or memory within multi-tasking. This may be because shifting and inhibition are not necessary during this aspect of multi-tasking. Alternatively, it may be the case that while these executive abilities contribute to multi-tasking performance, they may do so within their capacity limits. For example while inhibition is probably required in order override the temptation to go down the 'up' stairs during the E-VET, the level of inhibition necessary is probably too low for any relationship to be established in the healthy population.

Future research

The correlation analysis used in hypothesis one cannot realistically be used to ascertain that dual tasking is a separable executive ability or that there are separable executive processes. The conflicting nature of the results illustrates the difficulties with using correlation analysis

in order to investigate a complex construct such as executive processing. Inter-correlations are predicted between the various executive processes within the central executive in multi-component theory of working memory (Baddeley et al., 1999) and such correlations were observed by Miyake and colleagues (2000) between latent shifting, updating and inhibition. For this reason the only way to get a conclusive result when investigating whether an executive ability such dual tasking is separable from other executive abilities is to give several different measures of each and use confirmatory factor analysis (CFA) to establish their independence. The use of CFA would prevent predictions which rely on proving the null hypothesis as the fit of the predicted factor structure could be directly tested. A future study could do this by giving several tests of dual tasking which require different sensory modalities. For example dual tasks involving walking and talking and digit recall and tracking could be given as well as several tests of inhibition, updating and shifting and confirmatory factor analysis could verify whether or not dual tasking was separable. Another possible dual task test which may be interesting to perform in such a study would be a combination of two tests which have been established as measures of other executive functions. For example the tone monitoring task (a measure of updating) and the anti-saccade task (a measure of inhibition) were both measures used by Miyake and others (2000) which could feasibly be performed simultaneously. If the dual task of inhibition and updating was found to be unrelated to either of the inhibition of updating tasks separately, it would indicate that dual tasking is an executive ability which is separable from those two established executive functions.

The results of the hierarchical regression analysis of executive functions predicting the WCST supports the claim that future studies should look to use more complex and ecologically valid paradigms in order to increase the understanding of the diverse central executive and to develop executive tests for clinical practice. This is because none of the tests of executive functioning predicted the WCST performance. Given the diverse nature of the central executive, it is likely that more complex paradigms will involve more of the executive processes and so will be more informative to the working memory literature than simple tests such as the WCST which allegedly assess executive functioning (Chan, Shum, Toulopoulou and Chen, 2008). This is especially true if the complex paradigms are representative of functioning required in everyday life. The E-VET is both a complex and ecologically valid paradigm. In this study the E-VET was used to demonstrate a link between dual tasking and everyday multi-tasking. Considering the E-VET is a computerised test, it is easily adaptable

and could be used to test other theories. For example, Trawley and others (2011) used the E-VET to investigate prospective memory failures in an ecologically valid setting. The E-VET could also be used to investigate the effects of normal and abnormal ageing or frontal brain injury on multi-task performance. The results of any clinical study which used the E-VET would have the advantage of being inherently generalisable to everyday functioning.

While the tests of inhibition and shifting did not predict multi-tasking, it is possible that updating, another executive function established by Miyake and colleagues (2000) may be related to E-VET performance. Updating refers to the processes by which memory representations are monitored and manipulated. Multi-tasking requires the constant updating of working memory representations during task performance and so it is likely that established measures of latent updating would predict E-VET performance. A future study could investigate this link by using confirmatory factor analysis to establish separable executive processes and then using structural equation modelling to investigate the relationship between these executive processes and E-VET performance.

In this study it was found that dual task ability is predictive of the intentionality component of multi-tasking. This evidence from the healthy population adds to the growing evidence from clinical studies that dual task ability is essential to everyday functioning. Much of this evidence has been gathered from studies with Alzheimer's patients. For example those with Alzheimer's disease (AD) find it difficult to keep track of a conversation with more than one person or walk and talk at the same time (Cocchini, Della Salla, Logie, Pagini, Sacci and Spinnler (2004). Additionally this dual task deficit has not been found in healthily ageing participants (Foley et al., 2011). For this reason the dual task test is a very promising clinical test for the early detection of AD. It is claimed that the dual task test is ideal for use in a clinical setting as it is both ecologically valid and experimentally sound (Della Salla et al., 2011) and the fact that dual tasking is predictive of multi-tasking measured within an ecologically valid paradigm supports this claim.

Conclusion

The central executive and multi-tasking ability are both diverse constructs which makes them difficult to investigate experimentally. This study used correlation analysis, exploratory factor analysis and hierarchical regression analysis in order to investigate the relationships between these constructs. It was found that dual task ability along with general intelligence are

significant predictors of the intentionality aspect of multi-tasking performance. The results also supported the continued use of ecologically valid paradigms in both executive functioning and multi-tasking research. With regards to future research it is recommended that confirmatory factor analysis and structural equation modelling techniques are used to confirm the separable nature of executive functions and also investigate the relationship between these executive functions and multi-tasking ability.

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