

# D-KEFS Validity: an Update of the Research

The Delis-Kaplan Executive Function System (D-KEFS) comprehensively assesses the key components of executive functions. It is the first standardised set of tests to evaluate higher-level cognitive functions in both children and adults from 8 to 89 years of age.

The tests assess vital executive functions such as flexibility of thinking, inhibition, problem solving, planning, impulse control, concept formation, abstract thinking and creativity in both verbal and spatial modalities. Following, for your information, is an update of the research that has been completed with the D-KEFS. This has been written for Pearson Assessment by Dr Matthew Jones-Chesters, University of East London.

## Introduction

The D-KEFS combines 'established' tasks and newer procedures under a common rubric. In addition to achievement scores, and in line with the Kaplan (1988) 'process' approach, norms are provided for D-KEFS subtest error variables, between-task contrasts, and intra-task parameters (e.g. rate of output). The validity of the established procedures (e.g. Stroop task, Trail Making Test) has been demonstrated in numerous studies over the last fifty years. For these reasons, the D-KEFS content validity – its credibility with the test user – is high (Swanson, 2005; Homack et al, 2005).

The original publication of D-KEFS provided clinical profiles for patients with Huntington's disease and patients with dementia Alzheimer's type: these preliminary clinical validity studies intimated that dissociations within the executive functions across different presentations were captured by the D-KEFS tasks (see D-KEFS Technical Manual for further information). However, several reviewers suggested that more clinical validity data was needed (Kelly, 2003; Schmidt, 2003; Shunk et al, 2006) as, without seeing data on the performance of patients from a range of clinical groups, it can be difficult for the user to interpret scores and profiles (Baron, 2005).

Delis et al (2004) responded that much of the test's development and validity data had appeared in the scientific neuropsychology literature, where it was available for peer scrutiny. For example, the development of the Sorting Test (then the California Card Sorting Test; CCST) was documented in patients with Multiple Sclerosis by Beatty et al (1995; Beatty & Monson, 1996), in patients with long-term alcoholism by Beatty et al (1993), in patients with Parkinson's disease and cognitive decline by Beatty and Monson (1990), in patients treated for psychosis by Beatty et al (1994) and in an older adult sample by Beatty (1993). Nevertheless, Delis et al (2004) provided a review of the more recent literature, addressing reliability and validity issues.

They showed that within a few years of publication, D-KEFS tests had been successfully employed in a wide range of neuropsychological and neurological studies. Here, we provide an extension and update to the previous review. We summarise and integrate for the D-KEFS user the large and growing body of literature on D-KEFS tests, focusing on those studies that provide information on criterion (clinical, concurrent and predictive) validity.

## Clinical Validity Studies

### ■ Frontal Lobe Lesions

Failures in the control of cognition and behaviour have been comprehensively described in patients with brain damage. Interest in this area began with the famous case of Phineas Gage, who in 1848 had much of his left-frontal brain destroyed in an accident with an iron tamping rod (Harlow, 1868). Since then, evidence from lesion studies, neuroimaging and clinical reports has accrued to suggest that the frontal lobes of the brain (and their connections to other regions) are intimately associated with executive functions. Frontal lobe lesions are associated with problems in abstraction, set-shifting, planning and organisation, behavioural inhibition and cognitive flexibility (Stuss & Knight, 2002).

Baldo and colleagues have produced a series of papers addressing the

performance of a group of 12 patients with frontal lobe lesions (FLL) on D-KEFS tests. On D-KEFS Design Fluency, Baldo *et al.* (2001) showed that the FLL group generated significantly fewer designs that matched controls on all three conditions (basic, filter and switching) but did not make significantly more errors. There was no difference between patients with left- versus right-hemisphere lesions on these tasks (see below for further discussion).

On D-KEFS Verbal Fluency, the FLL group generated significantly fewer items than controls on all conditions (letter, category, switching). The FLL group were particularly disadvantaged on the *Letter Fluency* condition; and the performance of patients with left-hemisphere lesions was poorer than among patients with right-sided lesions. These results confirm the sensitivity of letter fluency to

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anterior left-hemisphere lesions.

On the D-KEFS Twenty Questions Test, Baldo *et al.* (2004) found that the FLL group asked significantly more questions than matched controls and their performance did not improve over the four task trials (as it did for controls). Qualitatively, the patients tended to rely on series of concrete questions about specific stimulus instances (e.g. 'Do you get milk from it?') rather than abstract questions concerning superordinate categories (e.g. 'Is it an animal?') Again, no difference emerged between patients with left- versus right-hemisphere lesions; however patient performance was strongly correlated with performance on the D-KEFS Sorting Test (*correct sorts* score), which attests to the facility in categorisation demanded by this task.

On the D-KEFS Word Context Test, Keil *et al.* (2005) showed that the FLL group achieved fewer correct identifications than matched controls, and required significantly more guesses to deduce the correct responses they did obtain. Qualitatively, the patients showed less evidence of using information from prior trials to inform their guesses on the next trial. There was a non-significant trend for poorer performance by patients with left-hemisphere lesions; and patient performance was related to scores on a measure of semantic fluency (animal naming) but not to immediate memory, confirming the sensitivity of this test to deficits in verbal abstraction.

On D-KEFS Trail Making, Yochim *et al.* (2007) found that the FLL group were slower than matched controls on all conditions, particularly *Letter Sequencing*, but were significantly disadvantaged on the key condition of *Number-Letter Switching*. Indeed, scores on this condition reliably distinguished the patients from controls, and patients also made significantly more errors. Moreover, poor patient performance was not accounted for by differences in response speed, which confirms the importance of taking component functions into account (e.g. by calculating *contrast* analyses) when interpreting test scores.

During initial development of the Sorting Test, Delis *et al.* (1992) compared small groups of patients with FLL and patients with Wernicke-Korsakoff syndrome (WKS; a condition associated with executive function deficits) to patients with non-WKS amnesia and matched controls. They found that the amnesic group differed from controls only on *describing sorts* (self-generated or used by the examiner). In contrast, the FLL and WKS groups' performance was comparable, and much poorer than controls on most dimensions (except for number of *attempted sorts*). More recently, Dimitrov *et al.* (1999) using larger participant samples found that an FLL group's performance was poorer than controls on all Sorting Test dimensions, including number of *attempted sorts*. Notably, they also found that patients with Parkinson's disease were distinguished from matched controls only on *perseverative sorts*, which confirms the clinical impression that these patients have difficulties in shifting mental set (Hannay *et al.*, 2004a, p.232-233) and suggests that this task is sensitive to that phenomenon.

Kramer *et al.* (2007) examined the relationship between brain lobe volume (on MRI scan) and performance on D-KEFS Design Fluency in a large mixed sample of patients (with a dementia diagnosis) and older-adult controls. Regression analyses were conducted, taking into account Mini-Mental State Examination scores, baseline performance

(basic and filter scores) and reversed digit span (a measure of Working Memory). Only right and left frontal lobe volumes were significantly associated the key condition of *Switching*; and left frontal volume was more strongly correlated with switching than right frontal volume. Parietal and temporal lobe volumes were not associated with switching performance. Taken together with the Baldo *et al.* (2001) study (see above) these results contribute to the emerging consensus that design fluency tasks are not differentially sensitive to focal right-frontal lesions, as had originally been suggested (Jones-Gotman, 1991).

Cato *et al.* (2004) used several D-KEFS tests in their case study of a patient (CD) who had an acquired ventro-medial area FLL. CD's scores on a range of cognitive tests were all in the normal range or above, including many of the D-KEFS tests. However, his performance was poor on several of the D-KEFS error and contrast variables. On the D-KEFS Colour-Word Test, CD was average or better for time-to-completion in all conditions, but he scored in the impaired range for number of *Inhibition/Switching errors*. On the D-KEFS Trail Making Test, CD was high-average for all completion times, but was in the low-average range for *Number-Letter Switching errors*.

On the D-KEFS Design Fluency Test, CD's scores were average for the basic and filter conditions, but he was impaired on the *Switching* condition, and his many *set-loss errors* placed him in the low-average range. On the D-KEFS Verbal Fluency Test, CD showed the profile of better category fluency than letter fluency expected for a FLL patient (see above). On D-KEFS Sorting, CD was average for most dimensions, but he produced many incorrect descriptions on the *Sort Recognition* condition. Qualitatively, CD's performance was characterised by a preference for speed at the expense of accuracy: a phenomenon often observed in patients with ventro-medial FLL (Damasio, 1994, p.52-62).

## ■ Frontal Lobe Epilepsy

Epilepsy is characterised by recurrent, unprovoked seizures, originating from abnormal hypersynchronous discharges of cortical neurons. The clinical presentations, and accordingly the neuropsychological sequelae, of seizures will reflect the location and propagation-extent of the cortical neurons involved (Hannay *et al.* 2004b). There are several means of classifying epilepsy, including: whether seizure onset arises in one or both cerebral hemispheres; whether there is loss of awareness; the extent of motor involvement; presumed or confirmed aetiology; and the cortical lobe implicated. Epilepsy due to seizures originating in the frontal lobes has been reliably associated with executive function deficits (Upton & Thompson, 1996).

In a series of articles, McDonald and colleagues have investigated the performance on D-KEFS tests of groups of around 20 patients with frontal lobe epilepsy (FLE). On D-KEFS Trail Making, McDonald *et al.* (2005a) showed that the FLE group were significantly slower than matched controls and patients with temporal lobe epilepsy (TLE) on the key condition of *Number-Letter Switching*, and made more *set-loss* errors. However, the groups were indistinguishable on the baseline conditions (Visual Scanning, Number Sequencing, Letter

Sequencing and Motor Speed). These results suggest that this task might reliably distinguish patients with FLE from patients with other seizurefoci.

On the D-KEFS Colour-Word Test, McDonald *et al.* (2005b) found that the FLE group were significantly slower than matched controls on the key conditions of *Inhibition* (Stroop effect) and *Inhibition-Switching*, though not on the baseline conditions (colour-naming and word-reading). The FLE group as a whole were only marginally slower than a matched TLE patient group. However, patients with left-hemisphere FLE were the most disadvantaged on these key conditions; the performance of patients with right-hemisphere FLE and TLE were comparable. In the same study, McDonald *et al.* (2005b) report that both FLE and TLE groups were significantly slower than controls on D-KEFS *Letter Fluency* and *Category Fluency* conditions, but were not distinguishable from each other.

On D-KEFS Design Fluency, McDonald *et al.* (2005c) showed that patients with FLE generated significantly fewer designs than patients with TLE and matched controls on the complex *Switching* condition, though not on the basic and filter formats. Patients with left-side FLE were the most disadvantaged. The results suggest that in these samples there may be subtle deficits present that are only detectable using more complex task formats. Notably, in this set of FLE/TLE studies, key seizure variables (e.g. age of onset, frequency, severity) were not consistently associated with task deficits, suggesting that the tests are more sensitive to the epileptogenic process than to its sequelae; a finding that might prove useful for the clinician addressing chronic presentations and/or patients with complex treatment histories.

### ■ Multiple Sclerosis

Multiple Sclerosis (MS) is an idiopathic condition, characterised by the formation of focal areas of demyelination in CNS white matter. The course of MS is highly variable: ranging from single episodes with full recovery; through a *relapsing-remitting* sequence, with potential progression to a *secondary-progressive* condition; and the very disabling *primary-progressive* process.

Neuropsychological deficits are observed in up to 50% of patients with advanced forms, and are typically associated with lesions to the periventricular white matter. MS is not a condition of specific frontal-lobe degeneration; rather, cognitive deficits emerge from damage to subcortical 'pathways' and the isolation/disconnection of cortical regions. Affected patients show particular problems with learning and memory, complex attention, and problem solving. Some authors (e.g. Hannay *et al.*, 2004c, p.253-254) have suggested that executive function deficits may contribute to the difficulties observed in other cognitive domains (e.g. memory retrieval, visuo-spatial construction) as well as to problems in activities of daily living and behavioural flexibility.

Benedict *et al.* (2006) compared the performance of patients with MS and matched controls, on a number of neuropsychological tasks (from the *Minimal Assessment of Cognitive Function in MS* battery) including the D-KEFS Sorting Test. The MS patient group scored significantly lower than controls on the *correct sorts* and *describing sorts* scores. In a Principal Components Analysis for patients with a relapsing-remitting course, the *correct sorts* and *describing sorts*

scores combined to form a unique 'executive function' factor among the tests, which explained 18% of variance in battery performance. Logistic Regression predicting *disability/employment* status showed that *describing sorts* was a significant factor, after self-reported depression and a measure of verbal delayed memory.

Parmenter *et al.* (2007) examined the performance of 111 patients with MS and 46 matched controls on the D-KEFS Sorting Test and the Wisconsin Card Sorting Test (WCST). Patients with MS scored lower than controls on most dimensions of both tests; however, only D-KEFS *correct sorts*, *sort description*, and *sort repetition* discriminated between the groups when self-reported depression was taken into account. Regression analysis showed that both tests discriminated between employed and disabled patients. Moreover, neuroimaging showed that scores on both tests were correlated with the extent of brain atrophy and/or lesion size. The authors suggest that the greater sensitivity and parallel forms provided for the D-KEFS Sorting Test make it a useful alternative (e.g. when re-testing may be required) to the WCST.

### ■ Adult Cerebrovascular Processes

There are a number of cardiovascular processes that affect the cerebral structures. Some may result in stroke (ischaemic or haemorrhagic): focal lesions that are associated with circumscribed cognitive impairments. Others may involve insidious, generalised, subcortical degeneration that (as with MS, see above) show a predilection for the periventricular white matter, and result in associated patterns of cognitive decline. Examples include small vessel disease due to hypercholesterolaemia, and hypoxia in chronic cardiovascular or pulmonary disease.

Jefferson *et al.* (2007) examined the performance of older adults treated for cardiovascular disease on a range of neuropsychological tests addressing attention, executive function and memory. Two *a posteriori* sub-groups were defined as having normal versus low cardiac output (CO; blood exiting the heart, in litres per minute). The low CO group were significantly slower than the normal CO group on the D-KEFS Trail Making key condition of *Number-Letter Switching*; they also achieved lower total scores on the D-KEFS Tower Test. There were no significant differences on the Colour-Word Test, nor on standard measures of verbal fluency, complex attention, verbal or visuo-spatial memory. The results suggest that certain D-KEFS subtasks are more sensitive to subtle cognitive deficits than a range of established measures.

Kramer *et al.* (2002) examined the performance of older adults with one or more subcortical lacunes (detected on MRI scan) on a range of tests addressing language, perception, and memory, and the D-KEFS Colour-Word and Sorting Tests. Compared to matched controls, patients with lacunes were significantly slower on the D-KEFS Colour-Word Test key condition of *Inhibition* (but not on the baseline conditions). On the D-KEFS Sorting Test, patients with lacunes generated fewer *correct sorts*, and scored lower for *initiation*. This group also achieved lower scores on a visuo-spatial memory test, but not on other measures of memory, execution, perception or language. The results suggest that these D-KEFS tests would be a useful addition to clinical or research cardiovascular batteries.

## ■ Prenatal Exposure to Alcohol

Substantial prenatal exposure to alcohol (via mother's alcohol consumption) can result in a range of disabling physical, cognitive and behavioural problems in children, which persist into adulthood (Connor & Streissguth, 1996). These effects are observed in children with significant foetal alcohol exposure (FAE) who nevertheless do not meet diagnostic criteria for Foetal Alcohol Syndrome (FAS), which requires facial dysmorphism to be present. Behavioural and executive function problems are prominent among the deficits observed (Kodituwakku et al, 1995) and children with FAS show particular difficulties in planning, problem-solving, set-shifting, inhibition and perseverative responding.

Mattson and colleagues have examined the performance of a group of 18 children with prenatal exposure to alcohol (aged 8 to 16 years) on four of the D-KEFS tests. On the D-KEFS Trail Making Test, Mattson et al (1999) found that children with FAE and FAS were slower than age-matched controls on the key condition of *Number-Letter Switching* (the FAS group significantly so), but not on the component Scanning, Sequencing and Motor Speed conditions. Regression analysis showed that having an FAS diagnosis accounted for 18% of the variance in this effect, after age and baseline performances were taken into account.

On the D-KEFS Colour-Word Test, Mattson et al (1999) found that the children with FAE/FAS were significantly slower than controls on both key conditions, *Inhibition* (Stroop effect) and *Inhibition-Switching*, though not on the baseline conditions (Colour Naming and Word Reading). The alcohol-exposed children also made more errors, and the FAS group were most disadvantaged on the complex *Switching* trial. On the D-KEFS Tower Test, children with FAE/FAS achieved fewer passes than age-matched controls (5 versus 8 on average, respectively) and committed significantly more *rule violations* (4 versus 0 on average, respectively). On the D-KEFS Word Context Test, children with FAE/FAS required significantly more *guesses* to deduce the correct responses than matched controls. The children with a diagnosis of FAS made significantly more set-loss errors than the FAE and control children.

On D-KEFS Design Fluency, Schonfield et al. (2001) found that children with FAE/FAS generated significantly fewer designs than age-matched controls on all three conditions (basic, filter and switching), and the two alcohol-exposed groups were not distinguished. On D-KEFS Verbal Fluency, children with FAE/FAS generated significantly fewer items than controls on all three conditions (letter, category and switching), and again the two alcohol-exposed groups were not distinguished. For most of these fluency conditions, having the FAE/FAS diagnosis made a contribution to the observed deficits, after age and traditional IQ scores were taken into account.

## ■ Autistic Spectrum Disorders

Autistic disorder and Asperger's syndrome are characterised by deficits in the development of language and communication skills, with limited social interaction and pretend play, and restricted-repetitive behavioural patterns. Intellectual and language functions are more affected in autism than in Asperger's syndrome, but these

two diagnoses are now regarded as points along the autistic spectrum of disorders (ASD). While deficits in *mentalising* ('theory of mind') have been postulated to account for the observed social and imaginative difficulties (Baron-Cohen, 2001), *executive dysfunction theory* has been advanced to explain the restricted-repetitive and stereotyped behaviours (Turner, 1997).

Kleinhans et al. (2005) examined D-KEFS test performance in a group of 12 children and adults with an ASD diagnosis but who were 'high functioning' (mean Full Scale IQ score = 100). Each ASD participant's performance was compared to the normative data so that age-scaled scores and contrasts were derived. Over the four tests studied (Verbal Fluency, Design Fluency, Trail Making and Colour-Word) performance was variable, but the ASD group achieved slightly (but reliably) lower scaled scores overall. Specific deficits emerged only on the Trail Making *Visual Scanning*, Verbal Fluency *Category Switching*, and Colour-Word *Inhibition* conditions.

Lopez et al. (2005) compared a group of 17 patients with ASD to an age-matched control group on six D-KEFS tests: Verbal Fluency, Design Fluency, Trail Making, Colour-Word and Tower Test. Over all conditions, the ASD group's performance was consistently (but not significantly) below the control group. Focal deficits appeared for the ASD group on the D-KEFS Tower Test. On theoretical grounds, the authors combined the D-KEFS *Number-Letter Switching* scores with total WCST scores to form a composite 'cognitive flexibility' index. Regression analyses showed that *cognitive flexibility* was the best predictor of restricted-repetitive symptoms among the scores.

## ■ Psychiatric Disorder

Lysaker et al. (2006) examined the relationship between D-KEFS test performance, symptom-severity ratings and reported insight (illness, illness consequences and treatment need) in a group of 53 patients treated for psychosis (schizophrenia or schizoaffective diagnoses). There were no reliable associations between test performance and *awareness of illness consequences*. However, regression analyses showed that the D-KEFS Tower Test *total* score accounted for 13% of the variance in awareness of illness scores, and for 11% of the variance in *awareness of treatment need* scores. The authors conclude that the ability to plan ahead, and to respond to contextual demands (as addressed by Tower Tests), are related to degree of insight in this population.

Kiang et al. (2007) compared the D-KEFS Proverb Test performance of a group of 18 patients with a diagnosis of schizophrenia and 18 matched controls. The schizophrenia group scored lower than controls on both *abstraction* and *accuracy* dimensions, and this difference was significant for *abstraction* even with years-of-education taken into account. For the patients, *abstraction* scores were not correlated with symptom severity ratings, but were associated with *categories achieved* on the WCST, which suggests that this test might prove useful in addressing executive functions separately to psychotic symptoms.

## ■ Other Studies of Interest

Wetter et al. (2005) examined D-KEFS Colour-Word Test performance in a sample of 22 non-demented individuals who were

positive for Apolipoprotein E ε4 allele (AE4; a genetic risk factor for dementias of the Alzheimer's type) and 29 matched AE4-negative controls. The two groups did not differ on completion times for any of the key conditions. However, within the AE4-positive group there was a subgroup of five participants who made substantially and significantly more errors on the *Inhibition/Switching* condition than the remainder of sample. The authors suggest that the presence of such a distinct subgroup within the AE4 sample intimates the sensitivity of subtle indices such as *Inhibition/Switching* errors in detecting *very early* cognitive change in persons at risk for dementia.

Karp *et al.* (2006) have investigated the potential effects of mood and pain on neuropsychological test performance in older adults. They examined the performance of 56 non-demented older adults with enduring pain on a range of cognitive tests. Among their measures (WAIS-III Digit Symbol Coding *completion*, WAIS-III Digit Symbol Coding *memory*, Mini Mental State Examination, and D-KEFS Trail Making Test) only the D-KEFS key condition of *Number-Letter Switching* was associated with pain severity; and this relationship held even when depression, education and opiate treatment effects were partialled out of the regression. The authors suggest that this test might offer a fair index of the effects of pain on cognitive test performance in older adult patients.

Loken Thornton *et al.* (2007) examined the neuropsychological test performance of 51 adults with chronic kidney disease (CKD). Compared to matched controls, the patients with CKD showed significantly poorer *set-shifting* (on the D-KEFS Trail Making *Letter/Number Sequencing* minus *Motor Speed* contrast). The patients also showed significantly greater Stroop interference (on the D-KEFS *Colour-Word Inhibition* minus *Colour Naming* contrast). These effects were more marked among older patients, and regression analyses suggested that the D-KEFS contrasts were associated with a diagnosis of CKD even after demographic variables, illness severity and depression were taken into account.

## Clinical Validity Studies

### ■ Convergent Validity

The *Woodcock-Johnson III Tests of Cognitive Abilities* (WJ-III COG; Woodcock *et al.*, 2001) incorporates five *clinical clusters* (combinations of subtests) that might be useful in the assessment of learning disabilities or developmental disorders. Of these, three share a conceptual underpinning with the executive functions. Floyd *et al.* (2006) investigated the relationship between the clinical clusters and scores on D-KEFS tests (*Colour-Word*, *Sorting*, *Twenty Questions*, *Word Context* and *Tower Tests*) in a large, non-clinical sample of children and adults. For adults, the WJ-III *executive processes* cluster was reliably correlated with all D-KEFS test scores; the strongest association being with *Word Context total*. WJ-III *cognitive fluency* was correlated with the D-KEFS *Colour-Word* key conditions of *Inhibition* and *Inhibition-Switching*. WJ-III *working memory* was strongly associated with *Word Context total*, and also correlated with *sort-description* scores.

For children, there were significant correlations between all the WJ-III clusters and D-KEFS tests. The WJ-III *executive processes* cluster was most strongly correlated with D-KEFS *Sorting recognition-description* and next with *Word Context total* scores. WJ-III *cognitive fluency* was best correlated with D-KEFS *Colour-Word Inhibition*. WJ-III *working memory* was most strongly associated with *Twenty Questions total* and next with *Word Context total* scores.

### ■ Divergent Validity

Delis *et al.* (2007) investigated the relationship between executive functions and intelligence test performance in a large sample (N = 470) of children and adolescents. Verbal and Performance intelligence scores (VIQ and PIQ) were obtained using the Wechsler Abbreviated Scales of Intelligence (WASI; Wechsler, 1999) and compared to the D-KEFS *Category Fluency*, *Design Fluency*, *Number-Letter Switching*, *Colour-Word Inhibition/Switching* and *Sort Recognition* subtests. As anticipated, there were significant correlations between the D-KEFS subtests and VIQ/PIQ scores across most tasks. However, for the youngest and oldest groups (8-10 years and 17-19 years, respectively) not all associations were significant. Moreover, around 20% of individual participants exhibited a marked discrepancy (greater than one standard deviation) between their overall IQ score and a composite of their executive function scores (EF). Some 13% of participants had EF scores that were significantly *higher* than their IQ, while 7% of participants had EF scores that were significantly *lower* than their IQ. The results suggest that though IQ and EF scores may share common components, they also noticeably diverge in many individuals.

## Predictive Validity Studies

### ■ Instrumental Activities

The *instrumental* activities of daily living (IADL; e.g. shopping, housekeeping, food preparation and use of transportation) differ from the *basic* activities (e.g. dressing, eating, ambulation and hygiene) in that they involve planning, autonomy and self-monitoring, and thus are required for independent living (Lawton & Brody, 1969).

Jefferson *et al.* (2006) examined the relationship between IADL (as rated by an informant) and performance on a range of executive function tests in 72 older adults with stable cardiovascular disease. Logistic regression on overall IADL function was best predicted by the D-KEFS *Colour-Word* key condition of *Inhibition*; and *Inhibition* correlated individually with 4 out of 8 IADL item scores. D-KEFS *Trail Making Number-Letter Switching* was individually associated with *laundry* and *transportation* functions; while the D-KEFS *Tower Test total* was individually associated with *transportation*. MMSE score was individually associated with *shopping* and *food preparation* functions (as was a standard letter fluency task). However, standard format figural fluency and paced-serial addition tasks were not associated with IADL.

## ■ Educational Achievement

Recent research has suggested that while *content-based* measures (achievement and ‘intelligence’ tests) are good indices of an individual’s educational attainment, *process-based* measures may contribute more to our understanding of developmental progression and educational needs (Meltzer *et al.*, 2007). Altemeier *et al.* (2006) examined the relationships between D-KEFS tests (Colour-Word and Verbal Fluency Tests) and core learning skills (note taking and report writing) in large sample of children in school Year 3 (aged around 8 years) and Year 5 (aged around 10 years). Regression models showed that for *note taking*, in both year groups, D-KEFS Colour-Word *Inhibition* contributed significantly to performance, even with basic literacy skills (reading, writing and copying) taken into account. For *report writing*, in both year groups, D-KEFS *Letter Fluency* was a significant contributing factor, after basic literacy skills (writing and reading in Year 3; writing, reading and alphabet writing in Year 5) were taken into account. The results add weight to the emerging consensus that executive functions are important contributors to educational attainment, and suggest that these D-KEFS tasks are sensitive indices of them.

## ■ Ageing

Declining performance with advancing age has consistently been observed on tests of executive functioning. Whether conceptualised as aspects of ‘fluid intelligence’ (*gf*; Cattell & Horn, 1978) or ‘performance intelligence’ (PIQ; Wechsler, 1944) scores on tests requiring problem solving or novel concept formation, particularly under time constraints, decline with age; and these differences are repeatedly attested to in normative data studies. Some authors have argued that these effects are mainly attributable to a general slowing of processing speed with age (e.g. Salthouse, 1993) while others have shown that significant age-related declines remain (on some tasks) even with the effects of latency partialled out (e.g. Lowe & Rabbitt, 1997). Accordingly, the potential to take component functions into account (e.g. processing speed, motor function) is a key strength of the D-KEFS in the assessment of older adults.

Wecker *et al.* (2000) examined the effects of age on the D-KEFS Trail Making and Colour-Word Tests in a normal sample aged 20 to 79 years. For both tasks, increasing age was associated with generally slower performance across all conditions, but not more errors. On the D-KEFS Trail Making Test, regression analyses showed that with performance on the baseline conditions (Scanning, Motor Speed and Sequencing) taken into account, age did not make a unique contribution to performance on the key *Number-Letter Switching* condition, nor to error rates. On the D-KEFS Colour-Word Test, age accounted for some 5% of variance in the key *Inhibition* condition (Stroop effect) after baseline word reading and colour naming were accounted for; but again was not associated with error rates.

Wecker *et al.* (2005) examined the relationships between age, gender, IQ scores, education and D-KEFS *Switching* subtest performance. In a large normal sample aged 20 to 89 years, for the three tests studied (Trail Making, Verbal Fluency and Design Fluency) increasing age was associated with declining performance across all conditions. Regression analyses showed that on the Trail Making Test, with the

demographic and baseline conditions accounted for, age contributed a further 3% of the variance on the key *Number-Letter Switching* condition. On Verbal Fluency, age accounted for 4% of the variance on the key *Category Switching* condition, after baseline and demographic variables; but this represented a non-linear relationship, suggesting that age was associated with better relative performance in middle age (rather than youth). On Design Fluency, age contributed some 9% of the variance to the key *Switching* condition, after accounting for demographic variables and the baseline conditions. The results suggest that age does exert small but reliable effects on cognitive flexibility.

## Conclusion

In summary, there is now a substantial body of literature to support the validity of the D-KEFS<sup>UK</sup> tests as indices of executive function and executive dysfunction. Certainly some tasks appear to have attracted more research attention than others: more work might be needed to establish the utility of the Proverbs Test in populations affected by neurological disorders. However, the utility of the D-KEFS Trail Making, Verbal Fluency, Design Fluency, Colour-Word and Sorting Tests have been established in several clinical and non-clinical populations. The Word Context, Twenty Questions and Tower Tests have proved most useful so far in developmental and predictive validity studies. Preliminary support for the concurrent (convergent and divergent) validity of the system has been found in two large, recent studies. Accordingly, the D-KEFS appears a useful instrument, offering opportunities for a multidimensional approach to assessment (using normative, process and criterion interpretative methods) in a range of clinical and educational settings.

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