Executive Functioning in Treatment-Naïve Adolescents with Alcohol Use Disorders


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**Abstract**

Heavy alcohol use during adolescence confers significant risks for neurocognitive impairment. Executive functioning (EF), a poorly-defined construct that refers broadly to the higher-order cognitive processes subserving goal-directed behaviour, may be particularly adversely affected during the neuro-developmentally vulnerable adolescent period. Previous research in this field has, however, been sparse, inconsistent, and fraught with methodological limitations. Hence, the present study aimed to address such limitations and to isolate the impact of alcohol on adolescent executive abilities. Following Anderson et al. (2001), EF was conceptualised according to a domain-specific model as comprising three discrete, interrelated components: Attentional Control, Cognitive Flexibility, and Goal Setting. A sample of 81 treatment-naïve adolescents (12-15 years) with alcohol use disorders (AUDs) and no comorbid psychopathology or other substance use disorders were compared to 81 demographically matched controls on a comprehensive range of EF measures. Results indicated significant alcohol-related deficits only in the domain of Cognitive Flexibility, and, within that domain, specifically with regards to inhibition skills. Attentional and goal setting abilities were relatively preserved. These findings suggest that 'pure' AUDs in adolescence are particularly associated with a reduced capacity for cognitive control, self-regulation, and flexible, adaptive thought and behaviour. Such impairment may have important implications for long-term social, educational, and occupational functioning.

Executive Functioning in Treatment-Naïve Adolescents with Alcohol Use Disorders

Previous research has firmly established that chronic alcohol use has profoundly negative physiological, cognitive, interpersonal, and social sequelae (Schuckit, 2009). Although such adverse consequences are prevalent at all life stages, the presence of alcohol use disorders (AUDs) in the developmentally vulnerable period of adolescence confers particular risks for functional impairment. Heavy alcohol use amongst youth has been linked to increased risk for accidents, injury or death, delinquent and risk-taking behaviour, academic problems and the development of serious alcohol-related disorders in adulthood (Parry et al., 2004; Zeigler et al., 2005). With specific regard to cognitive functioning, alcohol abuse or dependence during adolescence has particularly harmful effects on complex decision-making and goal attainment (Monti et al., 2005; Zeigler et al., 2005). Consequently, as adolescence represents an important transitional period into adulthood responsibilities, excessive alcohol consumption during this time can have far-reaching adverse social, educational, occupational, and legal implications (Brown & Tapert, 2004; Parry et al., 2004; Schuckit, 2009).

**Neurological and Neurocognitive Consequences of Alcohol Use**

The neurological effects of heavy alcohol use have also been well documented in the literature. Alcohol has significant neurotoxic effects: Adult AUD has been associated with widened sulci, enlarged ventricles, white and gray matter reduction, decreased metabolic rate, reduced cerebral blood flow, and volume deficits and degeneration in a number of brain structures, particularly the frontal lobes, cerebellum, pons, thalamus, and limbic system including the hippocampus (Gilman et al., 1990; Grant, 1987; Lezak, Howieson, & Loring, 2004; Nicolas et al., 2000; Sullivan, Rosenbloom, Serventi, Deshmukh, & Pfefferbaum, 2003). Although alcohol-related brain insult is widespread, cortical atrophy and hypometabolism appear particularly prevalent in the frontal and prefrontal brain regions, areas that subserve higher-order executive functions (Oscar-Berman & Marinkovic, 2007; Pfefferbaum, Sullivan, Mathalon, & Lim, 1997).

Less is known about the specific neurological impact of alcohol during adolescence. However, as the adolescent brain is still undergoing critical neural maturation, it may be particularly susceptible to the neurotoxic effects of alcohol (Brown & Tapert, 2004; Monti et al., 2005; Zeigler et al., 2005). Recent magnetic resonance imaging (MRI) studies have indicated that the adolescent period is characterized by white matter increases (e.g., in the corpus callosum) and gray matter volume decreases, possibly reflecting continuing processes of myelination and synaptic pruning (Blakemore & Choudhury, 2006; Paus, 2005). Such maturational processes, which afford greater cognitive efficiency, occur particularly in the parietal cortex and in the prefrontal cortex (PFC), which has been found to be one of the final brain regions to mature (Gogtay et al., 2004). Hence, alcohol use during this vulnerable period may disrupt development in such brain regions (Monti et al., 2005). Indeed, De Bellis et al. (2005), conducting one of the few studies of its kind, found significantly reduced PFC and PFC white matter volumes in adolescents and young adults with AUDs as compared to matched controls. Importantly, adolescent vulnerability to such alcohol-related brain insults may confer particular, significant neuropsychological disadvantages during this developmental period (Brown, Tapert, Granholm, & Delis, 2000).

The adolescent literature regarding the long-term impact of AUDs on neuropsychological functioning has been somewhat limited, however (Brown & Tapert, 2004). Nevertheless, in general, the extant research indicates that heavy alcohol use is typically associated with subtle but significant functional impairments in several cognitive domains, including visuospatial ability, general intellectual functioning, attention, psychomotor skills, information processing speed, visual and verbal memory, learning, and, in particular, aspects of executive functioning (Brown & Tapert, 2004; Brown et al., 2000; Ferrett, Carey, Thomas, Tapert, & Fein, 2010; Lezak et al., 2004; Tapert & Brown, 1999; Tapert, Granholm, Leedy, & Brown, 2002; Tarter, Mezzich, Hsieh, & Parks, 1995; Zeigler et al., 2005).

**Adolescent AUDs and Executive Functioning**

The selective vulnerability of the PFC to the neurotoxic effects of alcohol, especially during adolescence, suggests that functions subserved by this region may be particularly adversely affected (Oscar-Berman & Marinkovic, 2007). Hence, although alcohol manifests in impairments in multiple cognitive domains during this developmental period, deficits may be expected to be particularly salient with regards to executive functioning, which relies on the integrity of the prefrontal region.

Executive functioning (EF) is a poorly-defined, broad construct that refers generally to the multiple, inter-related higher-order cognitive processes involved in adaptive, purposeful thought and behaviour (Anderson, 2002; Zelazo & Müller, 2002). Intact EF is thus crucial for effective, adaptive everyday functioning and for the execution of day-to-day cognitive, behavioural, emotional, and social tasks (Anderson, Anderson, Northam, Jacobs, & Catroppa, 2001). Disruption by alcohol may therefore have important implications for functional impairment.

The relevant adult literature suggests that chronic alcohol use may have deleterious effects on various aspects of EF, including mental flexibility, attentional control, processing speed, abstract reasoning, planning ability, and inhibition of habitual response tendencies (e.g., Ratti, Bo, Giardini, & Soragna, 2002; see Thomas & Ferrett, in press, for a review). For instance, Ihara, Berrios, and London (2000) compared 17 adults with AUDs to 17 age-matched controls on a comprehensive range of executive functions and found significant alcohol-related deficits in problem-solving, planning, inhibition of competing behavioural impulses and the ability to shift between mental sets, in the absence of memory or intellectual impairments. The authors concluded that 'dysexecutive syndrome' is a prominent feature of heavy, long-term alcohol use.

Investigations regarding alcohol's impact on EF during adolescence have, however, been far more scarce. Most adolescent studies are broad, focussing on general neuropsychological functioning, and failing to specifically address EF. However, those that have addressed aspects of EF have highlighted modest decrements in certain executive skills. In particular, they have found that adolescents with AUDs demonstrate relatively poor abilities in the areas of attentional functioning (including perceptual speed and sustained attention), working memory, self-monitoring, behavioural inhibition, impulsivity, and semantic clustering (Brown & Tapert, 2004; Brown et al., 2000; Ferrett et al., 2010; Tarter et al., 1995; Zeigler et al., 2005).

For instance, Tapert and Brown (1999) and Tapert et al. (2002) conducted seminal longitudinal studies following a sample of adolescents with substance use disorders (SUDs) recruited from inpatient treatment programs. They compared their neuro-cognitive functioning, using a comprehensive test battery, to demographically matched nonabusing controls and to their initial baseline levels at 4- and 8-year follow-ups. Long-term adolescent substance abuse was associated with poorer functioning in the areas of attention and working memory. In particular, chronic alcohol use was associated with deficits in the ability to mentally manipulate information. The total composite domain of EF, and, in particular, planning and problem-solving skills, however, were not found to be significantly impaired by adolescent substance abuse.

Similarly, Brown et al. (2000) compared the overall neuropsychological performance of 33 alcohol-dependent (AD) adolescents, aged 15 to 16 years, who had exceeded 100 lifetime episodes of alcohol use and who were recruited from treatment facilities, to that of 24 healthy matched controls. Results showed significant alcohol-related deficits on tests of processing speed. Interestingly, however, AD participants did not show significant impairments, relative to controls, on standard measures of attention and cognitive flexibility.

In a cross-sectional study, Tarter et al. (1995) compared 106 female adolescents with SUDs to 74 normal community-dwelling controls on a wide-ranging neuropsychological battery and found significantly reduced performance associated with substance abuse on aspects of sustained attention and perceptual speed. That is, adolescent participants with SUDs were found to be highly distractible and slow to respond on visual search and response inhibition tasks. The authors attributed such subtle but significant deficits to impulsive behaviour and impaired ability to inhibit habitual responses to irrelevant, non-target stimuli.

Although offering some insightful preliminary findings, the above studies have limited value due to their highly atheoretical approach with regards to EF. That is, relevant studies in this field tend to use a variety of different, isolated measures specializing in discrete aspects of EF within a general neuropsychological framework and with no clear definitional or theoretical base. Results are hence sparse, inconsistent and difficult to integrate, and the impact of alcohol on adolescent EF remains unclear. The lack of a hitherto specific, systematic focus on EF or an organised theoretical model for its study possibly results from the conceptual and measurement difficulties associated with this complex construct.

**Conceptualization and Measurement Difficulties**

A significant area of contention hindering contemporary EF research pertains to the lack of consensus regarding conceptual understandings of the construct (Senn, Epsy, & Kaufmann, 2004). Early models conceptualized EF as a singular module, emphasizing unitary processes such as inhibition or working memory. Therefore, one of the first conceptualisations saw EF simply as the ability to suppress prepotent responses (Luria, 1966). The merit of such a model lies in the clinical observation that PFC damage often results in perseverative tendencies.  Such a model proved too simplistic to capture the multitude of diverse abilities subsumed under the construct of EF, however (Zelazo & Müller, 2002). Furthermore, the finding that no single ‘dysexecutive syndrome’ exists but that executive dysfunction varies with PFC lesion site challenges the notion of a domain-general executive system (Stuss & Alexander, 2007).

More recent models have acknowledged the complexity of the construct, conceptualizing EF as a system of several inter-related yet distinct processes underlying goal-directed action. Zelazo, Carter, Reznick, and Frye (1997, as cited in Zelazo, Müller, Frye, & Marcovitch, 2003), for example, proposed a functional model, conceiving of diverse EF abilities within the context of a four-stage problem-solving framework moving through (a) problem representation and goal formation, (b) planning, (c) executing the plan, and (d) monitoring, evaluating and adapting progress towards achieving goals. Such a functional theory, while having descriptive value, fails to specifically include particular fundamental aspects of EF, such as attention, although it does implicitly assume such abilities to be intact.

As such, there is still no consensus regarding the nature of EF components or how such processes operate together functionally. A lack of definitional consensus translates into measurement problems, particularly in research, as choice of specific test measures is typically not grounded in clear, broad conceptual theory (Zelazo et al., 2003). Between-study discrepancies in approach and test batteries therefore often exist, which makes integrating findings difficult.

In an attempt to identify the domains of EF, factor analyses, such as confirmatory latent variable analysis, are often conducted on EF test batteries (see e.g., Miyake et al., 2000). Results of such analyses generally identify three or four factors as characterizing EF, supporting a domain-specific model and acknowledging the simultaneous unity and diversity of this construct. However, Zelazo et al. (2003) warn that identification of common factors does not equate with conceptual understanding of processes. Furthermore, factor analyses typically reveal different domains across studies and across age intervals (Zelazo & Müller, 2002). Age-specific EF models therefore may emerge, reflecting the developmental trajectory of these abilities, rather than their underlying structure. Therefore, for example, Senn et al. (2004, p. 460) found different "best fitting model[s]" across age groups, with, for example, inhibition predicting problem-solving abilities in younger children and working memory a more significant determinant in older children. Consequently, with no current standard, uniform EF model, the most practical framework to be used in research appears to be that which has been substantiated by past research as applicable to a relevant age group.

## Anderson's EF Model Applied to Present Research

Bearing in mind such conceptual difficulties limiting prior research and the age-specificity of current models, the present study conceptualized EF according to the domain-specific model proposed by Anderson et al. (2001). This model has been validated for study with adolescent populations.

This conceptual framework identifies three discrete, interrelated domains of EF: (a) Attentional Control; (b) Cognitive Flexibility; and (c) Goal Setting.

*Attentional control* refers to the processes involved in selectively maintaining attention on a specific task for a prolonged time period, as well as one's attentional capacity or span and efficiency of information-processing (Anderson et al., 2001). Another construct falling within this domain is that of complex working memory, which refers to the ability to mentally hold and manipulate information.

*Cognitive flexibility* refers to the ability for adaptive, flexible responding to multiple complex situational demands (Anderson, 2002). Specifically, this component includes the ability to monitor one's behaviour and adjust it accordingly to new demands. The capacity for inhibiting incorrect, salient responses and avoiding perseveration is an important aspect of this domain. Also falling under this category is the construct of word generativity, the capacity for spontaneous word production, as well as the ability to shift flexibly between alternate categories (i.e., cognitive 'switching').

*Goal setting* refers to the processes involved in planned, outcome-driven, forward-thinking, and strategic behaviour (Anderson, 2002). Specifically, this domain encompasses abilities involved in planning or rule-configuration, organization, and problem-solving (including the capacity to conceptualise the problem, develop appropriate plans for action and execute and adjust strategies as required to attain a future goal).

This model has particular merit for adolescent EF research in that it has been confirmed as a useful conceptual framework and valid set of domain groupings for the adolescent period (Anderson et al., 2001). The value of this model also lies in its ability to guide test selection, such that inclusion of particular measures is based on relevant theory. Furthermore, this model is important as it is developmentally staged. That is, use of this model in previous research has indicated that the different EF domains follow different maturational trajectories, developing at different rates, with certain executive skills, such as those involved in attentional control, continuing to develop up until 15 years of age, or even beyond that and into late adolescence (Anderson et al., 2001). Hence, this model allows predictions to be made about how normal, typically-developing adolescents should perform in discrete areas of EF, and how those with AUDs should perform in comparison. Finally, as it allows for a concrete theoretical framework within which to systematically investigate the impact of alcohol use on adolescent EF, such a model is useful in addressing limitations of prior research in this field (e.g., as noted before, the atheoretical approach to EF in previous adolescent studies).

**Specific Aims and Hypotheses**

Previous research regarding the effects of alcohol during adolescence has been further limited in that it has generally focussed on adolescents in treatment who typically have comorbid psychopathology and polysubstance use disorders. The specific effect of alcohol on EF is therefore difficult to isolate. Furthermore, individuals in treatment for AUDs may not be representative of the much larger untreated, alcohol-abusing population living in the general community (Di Sclafani, Finn, & Fein, 2008; Fein & Landman, 2005).

Ferrett et al. (2010) addressed this limitation by investigating the neurocognitive functioning of 26 treatment-naïve adolescents with AD but without comorbid disorders, as compared to that of 26 demographically matched controls. Adolescent AD was significantly associated with poor self-monitoring and inhibition skills, but, interestingly, there were no significant deficits in attention, planning, or problem-solving. Again, however, results of this study with regards to EF have limited value due to its broad nature, silence on conceptual theories of EF, and failure to focus on particular EF domains. Research specifically examining the relations between relatively 'pure' AUDs and executive skills in community-dwelling adolescents is therefore warranted.

The importance of such research is particularly clear when one considers the significant implications for functional impairment associated with an executive system disrupted by alcohol during adolescence, as well as the disproportionately high prevalence of heavy alcohol use amongst local adolescents (Parry et al., 2004). For instance, a survey of high-school students in Cape Town indicated prevalence rates of recent alcohol use of 31% (Flisher, Parry, Evans, Muller, & Lombard, 2003). Consequently, the primary aim of the present study was to investigate and isolate, using a clear theoretical model, the potentially deleterious effects of heavy alcohol use on EF in treatment-naïve adolescents recruited from the local community. This investigation tested the hypothesis that the presence of AUDs in adolescence would impact adversely on certain executive domains. More specifically, although research in this field is not consistent, based on findings in the extant literature reviewed above and using Anderson et al.'s (2001) model, I hypothesized that adolescents with AUDs would demonstrate significantly impaired performance relative to normal, typically-developing controls on the EF domains of Attentional Control and Cognitive Flexibility, but that Goal Setting skills would remain relatively intact.

## Methods

### Research Design and Setting

The study followed a simple cross-sectional two-group case control design in order to compare the performance of AUD adolescents and normal matched controls on various EF measures. A non-randomised convenience sampling procedure was used, and testing involved the once-off administration of an EF test battery. Testing of all participants took place on-site at Tygerberg Hospital.

### Participants

The research team recruited a sample of English- or Afrikaans-speaking adolescents between the ages of 12 and 15 years from 19 schools of differing educational quality in the northern and southern suburbs of Cape Town. All participants had at least 6 years of education. Attempts were made to ensure a heterogeneous sample in terms of sex, ethnicity, language, socioeconomic status (SES), and quality of education. Recruitment of volunteers took place by means of oral presentations at schools and word-of-mouth advertisement. The final selection of participants was informed by a detailed medical history, physical examination and a diagnostic screening interview for past and current psychopathology, the *Schedule for Affective Disorders and Schizophrenia for School-Age Children – Present and Lifetime Version* (K-SADS-PL; Kaufman et al., 1997).

The final sample consisted of 162 participants who were assigned to one of two groups: an AUD group ($n$ = 81), consisting of individuals who met criteria for alcohol dependence or alcohol abuse (see Appendix A) as defined by the fourth edition of the Diagnostic and Statistical Manual of Mental Disorders (DSM-IV; American Psychiatric Association, 1994), and who had consumed a lifetime dosage of more than 100 standard units of alcohol; or a control group ($n$ = 81), consisting of non- or light drinkers (lifetime dosage of less than 60 alcohol units). The groups were matched on all relevant socio-demographic variables, including general intellectual functioning (see Table 1). Exclusion criteria for both groups were stringently applied. Individuals were excluded if they had a history of psychiatric, medical, developmental, or neurologic disorders, or any lifetime DSM-IV Axis I diagnoses other than AUDs for the AUD group (see Ferrett et al., 2010, for a full listing of the exclusion criteria used in the present study). A particularly important eligibility criterion for inclusion in the AUD group was that individuals were treatment-naïve and without comorbid SUDs or psychopathology.

Table 1
*Socio-Demographic Characteristics of the Current Sample*

| Variable | Group: Control ($n$ = 81) | Group: AUD ($n$ = 81) | Test statistic | $p$ |
|---|---|---|---|---|
| Sex | | | | |
| Female:male | 47:34 | 47:34 | … | … |
| Ethnicity | | | | |
| White:Coloured:Black | 1:79:1 | 0:81:0 | 2.025 | .363 |
| Language of test administration | | | | |
| English:Afrikaans | 25:56 | 25:56 | … | … |
| Quality of education | | | | |
| Advantaged:Disadvantaged | 12:69 | 9:71 | 0.451 | .502 |
| Age (in years) | 14.76 (0.78) | 14.92 (0.74) | -1.313 | .191 |
| Years of education | 7.79 (0.85) | 7.85 (0.74) | -0.493 | .623 |
| Socioeconomic status[a] | 28.19 (5.80) | 26.85 (5.93) | 1.438 | .153 |
| WASI PIQ[b] | 80.64 (11.36) | 78.40 (10.71) | 1.295 | .197 |

*Note.* Means are presented with standard deviations in parentheses for all variables not presented as a ratio. Test statistic was either $t$ or chi-square ($\chi^2$), depending on whether the variable under consideration was continuous or categorical.
[a]An SES total score was derived for each participant based on responses on various indicators including: residential information, living conditions (ie; dwelling type, assets possessed, co-habiting arrangements), parental employment, parental education and annual household income. SES is therefore a continuous variable ranging from 0 to 41, where 0 = low SES and 41 = high SES.
[b]Performance IQ (PIQ) was used as a measure of general intellectual ability as it was deemed to be, in this sample, a more reliable intelligence estimate than Verbal or Full Scale IQ, both of which rely more on culturally-specific, learned verbal abilities (Strauss, Sherman, & Spreen, 2006).

**Measures**

A comprehensive neuropsychological test battery was administered for the purposes of an overarching parent study; only those measures applicable to the present research are discussed below. The relevant parts of the larger test battery included measures of various aspects of EF, grouped within the three domains as defined in the applied conceptual model, as well as measures of general intellectual functioning. All these measures are frequently used in clinical practice and research in South Africa and globally. All tests were administered and scored following conventional procedures outlined in the relevant administration manuals.

**Diagnostic assessment.**

***K-SADS-PL***. The K-SADS-PL (Kaufman et al., 1997) is a semi-structured clinical interview conducted with children and their parents. It is used to evaluate current and past psychiatric diagnoses, based on DSM-IV criteria. Level of functioning and symptom severity are assessed on various scales. Kaufman et al. (1997) have reported good test-retest reliability and validity overall for this instrument. The K-SADS-PL was hence used to screen for psychopathology in all participants and to ascertain AUD diagnoses.

***Timeline Followback (TLFB) procedure***. The TLFB procedure (Sobell & Sobell, 1992) is a technique used to assess self-reported lifetime history of specific alcohol use patterns and behaviour. This procedure was used to assess frequency, quantity, and density of alcohol consumption since the first phase of drinking to the present in the AUD group. A standard drink was defined as one beer or wine cooler, one glass of wine, or one 1.5-ounce shot of liquor.

**Socio-demographic questionnaire.** The research team collected information regarding important demographic variables (viz., age, sex, language, SES, and level and quality of education) using a self-report socio-demographic questionnaire administered to participants and their parents at the beginning of the study (see Appendix B). Quality of education was determined based on a school classification code. See note to Table 1 for information regarding how SES was evaluated.

**General intellectual functioning.** The Performance IQ scale of the *Wechsler Abbreviated Scale of Intelligence* (WASI; Psychological Corporation, 1999) was used to assess intellectual ability. The WASI is an abbreviated version of the Wechsler Adult Intelligence Scale that has been standardized for testing with individuals from 6 to 89 years of age. This instrument has excellent test-retest reliability ($r$ = .93 for children) and is a valid estimate of intelligence (Strauss et al., 2006). WASI *Performance IQ* (PIQ) was derived from the *Block Design* subtest, which measures visuospatial abilities, and the *Matrix Reasoning* subtest, which measures nonverbal abstract reasoning (Psychological Corporation, 1999).

**Attentional control**.

***Digit-Span Forwards.*** The DS-Forwards subtest (Wechsler, 2003) is a measure of auditory attention and span of immediate recall from short-term memory (Lezak et al., 2004). Here, it was used specifically to assess attentional capacity. This measure requires participants to repeat a sequence of numbers verbatim as presented verbally by the test administrator. DS-Forwards has moderate to high test-retest reliability, with coefficients ranging from .66 to .89; it also has good construct validity (Lezak et al., 2004; Strauss et al., 2006).

***Digit-Span Backwards***. The DS-Backwards subtest (Wechsler, 2003) is conventionally used as a measure of the ability to hold and mentally manipulate information in working memory (Lezak et al., 2004). Participants are required to repeat a number set of increasing length in the exact reverse order to that presented verbally to them by an examiner. This subtest was therefore included as a measure of complex working memory. DS-Backwards is reportedly a valid and relatively stable measure, with test-retest reliability estimates ranging from .70 to .79 (Strauss et al., 2006).

***Coding***. The Coding subtest (Wechsler, 2003) is frequently used to assess psychomotor performance and was included in this study as a measure of processing speed and sustained attention. This test requires participants to copy a series of nonsense symbols, each of which has been paired with a number, as quickly and accurately as possible within a 2-minute time limit (Wechsler, 2003). Test-retest reliability estimates are high for this measure, ranging from .80 to .89 (Strauss et al., 2006).

***Children's Colour Trails Test-Trial 1 (CCTT)***. The CCTT-Trial 1 (Llorente, Williams, Satz, & D'Elia, 2003) can be used with individuals aged 8 to 16 years. It requires examinees to connect a series of randomly placed encircled numbers, from 1 to 15, in ascending order. This measure assesses speed of attention, mental flexibility, visual search, and motor abilities; here, this trial was used to supplement the Coding subtest as a measure of sustained attention and processing speed (Strauss et al., 2006). The CCTT has been found to have marginal to low test-retest reliability ($r$ = .45-.68) in clinical samples, but reportedly has good diagnostic reliability and moderately strong concurrent validity (.67-.74; Strauss et al., 2006).

**Cognitive flexibility.**

***Children's Colour Trails Test-Trial 2***. The CCTT-Trial 2 (Llorente et al., 2003) was used to tap self-monitoring and cognitive switching abilities. Trial 2 of this measure requires participants to connect a sequence of pink and yellow coloured encircled numbers in numerical order while alternating between the colour of the circles. (See CCTT-Trial 1 above for more details.)

***Stroop Color-Word Test (SCWT)***. The SCWT (Golden, Freshwater, & Golden, 2003) includes three trials. On trials 1 and 2 participants are required to read a list of colour words printed in black ink, and then to name the colour of a series of printed Xs. Trial 3 is an interference trial that ultimately requires participants to read through a sheet of 100 colour words printed in an incongruent colour, naming the ink colour of each word and refraining from reading the word itself. For the purposes of this research, SCWT refers only to this third interference trial. This trial is frequently used as a measure of cognitive control and of the ability to suppress a habitual response (Strauss et al., 2006). Hence, it was used to assess inhibition skills in the current study. Test-retest reliability coefficients range from .89 to .84 to .73 for the different trials, and validity is reportedly moderate to high for this measure (Strauss et al., 2006).

***Verbal Fluency***. Phonemic and semantic verbal fluency tests (McCarthy, 1970) are used in clinical practice and in research to assess spontaneous word production under controlled circumstances (Strauss et al., 2006). Hence, these tasks gave a measure of word-generation ability in this study. Phonemic fluency tasks require participants to generate as many words as possible starting with a specific letter within a specified time limit. Semantic fluency tasks require the production of as many item names as possible in a specific category, such as ‘animal’. Psychometric properties of these tests are good, with test-retest reliability correlations above .70 and similarly high validity coefficients (Strauss et al., 2006).

**Goal setting.**

***Tower of London (TOL)***. The TOL test (Culbertson & Zillmer, 2001), which is typically used as a measure of problem-solving skills and planning capacity, was used to assess these executive abilities in this study. This task requires examinees to rearrange individual coloured beads, one at a time, on a three-stick pegboard. These beads must be reorganised from a particular starting position to match the final goal arrangement as indicated on a separate pegboard by the examiner. Participants must complete the task, which increases in difficulty over 10 problems, as quickly and accurately and in as few moves as possible (Lezak et al., 2004).

Table 2 outlines the various EF measures used in this study, grouped within the domain that they are purported to assess. Details about the specific executive ability tested by each and the respective outcome measures are also provided.

Table 2
*Executive Functioning Test Battery Used in the Present Study*

| Domain/Test name | Ability tested | Outcome measure |
|---|---|---|
| Attentional Control | | |
| DS-Forwards | Attentional capacity | Number of items correct |
| DS-Backwards | Working memory | Number of items correct |
| Coding | Sustained attention and processing speed | Number of items correct |
| CCTT – Trial 1 | | Time to completion (s)[a] |
| Cognitive Flexibility | | |
| CCTT – Trial 2 | Self-monitoring | Time to completion (s)[a] |
| | Cognitive switching | |
| SCWT – Trial 3 | Inhibition | Number of items correct |
| Verbal Fluency - Phonemic | Word generativity | Total words generated |
| Verbal Fluency - Semantic | | Total words generated |
| Goal Setting | | |
| TOL | Problem-solving and planning skills | Total moves score[a] |
| | | Total correct score |

*Note.* DS-Forwards = Digit-Span Forwards; DS-Backwards = Digit-Span Backwards; CCTT = Children's Color Trails Test; SCWT = Stroop Color-Word Test; TOL = Tower of London.
[a]Lower scores indicate better performance on these outcome measures. Higher scores indicate better performance in all other cases.

**Procedure**

Following recruitment, individual pre-screening interviews took place at volunteers' homes and schools in order to determine initial eligibility for the study. We obtained written informed assent (see Appendix C) from participants, reading through the forms with them and offering assistance as necessary. In particular, we ensured that they were assured confidentiality and understood their role in the study and their right to withdraw. Written consent (Appendix C) was also obtained from participants' parents. Self-report socio-demographic questionnaires were completed by participants and their parents at this point.

On a later day, as organised by appointment, participants were transported to the testing site at Tygerberg Hospital where medical history-taking, physical screening, urine analysis, breathalyser testing, and individual psychiatric screening using the K-SADS-PL took place. These were all conducted by a qualified psychiatrist. The TLFB procedure was also used at this time to elicit specific alcohol-related information.

A clinical psychologist or trained, supervised examiner administered the 3-hour neuropsychological test battery individually to participants in their preferred language. The EF test measures formed a component of this once-off battery. Testers provided regular breaks and refreshments for participants during the testing session. Participants received compensatory gift vouchers to the value of R150 once testing was completed. All tests were scored by a licensed clinical psychologist.

Approval for the above study procedures was obtained previously from the Western Cape Education Department and from the Health Research Ethics Committee at Stellenbosch University.

**Statistical Analysis**

All analyses were conducted using the statistical software package SPSS version 18.0 (2010). Analysis of the collected data began with an examination of the descriptive statistics in order to present an initial picture regarding the performance of the two groups across the EF test measures.

**Between-group comparisons.** After checking that all relevant assumptions were met, a series of one-tailed independent samples *t*-tests were conducted in order to provide a preliminary comparison of the performance of the AUD group with that of the matched control group on each of the 10 EF test outcome measures (see Table 2 for description of outcome measures). Non-parametric Mann-Whitney *U* tests were conducted in cases where inspection of P-P plots and results of Kolmogorov-Smirnov tests indicated non-normal distribution of data. Raw scores were used for all these analyses. Effect sizes were calculated for each of these comparisons. As 10 significance tests were conducted, a Bonferroni correction of $\alpha/10 = .005$ was used in order to reduce the overall Type 1 error rate (Field, 2009).

**Primary multiple regression analyses.** In order to reduce the number of variables examined and to confer a more theoretical approach to the study of EF, composite domain scores were computed for the main analysis based on a hybrid method of grouping test measures (described by Medina et al., 2007). This method groups measures into domains based on both theoretical assumptions of association and statistical correlation. Hence, measures were initially grouped, based on what they were assumed to assess, into the domains indicated in the theoretical model proposed by Anderson et al. (2001). Each outcome measure raw score was then converted into a *z*-score based on the control group's scores. *Z*-scores were inverted where necessary to ensure that a higher score indicated better performance for all test measures. Average composite domain *z*-scores were then computed. The internal consistency of each domain was statistically assessed by calculating Cronbach's alpha ($\alpha$ ) coefficients. Where $\alpha$ was too low, the domain was re-examined.

Based on this method, I derived three composite EF domains: (a) Attentional Control; (b) Cognitive Flexibility; and (c) Goal Setting, with Cronbach's alphas ranging from 0.61 to 0.74 (within the acceptable range, according to Finchilescu, 2002). Although the *Coding* and *CCTT-Trial 1* tests theoretically form part of the Attentional Control domain, they were removed from these analyses as they did not correlate highly with other variables or each other, and did not contribute statistically to the model. The measures in each domain are listed in Table 3, along with the relevant Cronbach's alphas.

After checking that all assumptions for regression analyses were upheld, the main analysis then involved conducting a series of hierarchical multiple regression analyses in order to establish whether group status (AUD or control) significantly predicted performance on each EF domain, even after controlling for PIQ and relevant demographic variables (as in Ferrett et al., 2010). Three separate regression analyses were therefore conducted with the EF domain *z*-score as the outcome variable; PIQ entered as a predictor on Step 1; gender, language of test administration, SES, and level of education entered as a 'block' of demographic predictors on Step 2; and group status entered on Step 3. PIQ and the demographic variables were entered first as these are known predictors of general cognitive performance, whereas group status was entered last as it the unknown variable under investigation (as suggested by Field, 2009). Problems of multicollinearity, with strong correlations between SES and quality of education, and between age and level of education, informed the decision to remove quality of education and age as predictors. SES was considered a more reliable variable than quality of education as the total SES score was based on a combination of responses on various indicators. Level of education was retained over participant's age as it is in itself an important predictor but was also assumed to encompass an indirect measure of age due to its high correlation with chronological development.

**Post-hoc regression analyses**. If findings indicated that group status significantly predicted performance on a certain EF domain, post-hoc multiple regression analyses were conducted separately on each of the individual test measures within that domain. The same procedures as for the initial regression analyses were followed, with individual EF measure *z*-scores as the outcome variable. The assumptions for multiple regression analysis were met for all individual measures on which analyses were conducted, except for CCTT-Trial 2 data, which showed negative skew. A successful log transformation was performed on the reverse scores of this measure in order to achieve normality.

Data were missing for four participants on the SES variable. Such missing data were dealt with by excluding these cases listwise from all relevant analyses. For all regression analyses, an alpha level of $p < .05$ was used as the threshold of significance.

Table 3

*Composite Domains and Associated Cronbach's Alpha Coefficients*

| | Cronbach's alpha ($\alpha$) |
|---|---|
| Attentional Control | 0.61 |
| DS-Forwards | |
| DS-Backwards | |
| Cognitive Flexibility | 0.62 |
| CCTT-Trial 2 | |
| SCWT – Trial 3 | |
| Phonemic Fluency | |
| Semantic Fluency | |
| Goal Setting | 0.74 |
| TOL | |
| Total Moves | |
| Total Correct | |

*Note.* DS-Forwards = Digit-Span Forwards; DS-Backwards = Digit-Span Backwards; CCTT = Children's Color Trails Test; SCWT = Stroop Color-Word Test; TOL = Tower of London.

# Results

## Descriptive Statistics

Descriptive statistics for each EF outcome measure, within the AUD and control groups, are presented in Table 4. An inspection of the mean scores appears to indicate that participants in the AUD group showed poorer performance than those in the control group on all 10 EF measures, and hence across all EF domains.

Table 4
*Results of Between-Group Comparisons*

| EF measure | Control group ($n$ = 81) *M (SD)* | AUD group ($n$ = 81) *M (SD)* | Test statistic | $p$ | ESE |
|---|---|---|---|---|---|
| Digit Span | | | | | |
| Forwards | 7.48 (1.79) | 7.44 (1.53) | 0.141 | .444 | 0.02 |
| Backwards | 4.47 (1.61) | 4.07 (1.35) | 1.696 | .046* | 0.27 |
| Coding | 52.40 (11.31) | 48.23 (10.44) | 2.433 | .008** | 0.38 |
| CCTT | | | | | |
| Trial 1[a] | 24.14 (8.09) | 25.86 (9.62) | 3587.5[b] | .152 | 0.19 |
| Trial 2[a] | 46.16 (14.42) | 50.64 (16.94) | 3887.5[b] | .021* | 0.28 |
| SCWT | 34.28 (9.15) | 30.57 (8.63) | 2.658 | .0045** | 0.42 |
| Verbal Fluency | | | | | |
| Phonemic | 28.68 (7.94) | 26.22 (7.74) | 1.995 | .024* | 0.31 |
| Semantic | 15.20 (3.93) | 14.65 (3.27) | 0.956 | .170 | 0.15 |
| TOL | | | | | |
| Total Moves[a] | 26.32 (11.89) | 28.78 (11.88) | 3642[b] | .113 | 0.21 |
| Total Correct | 3.69 (1.71) | 3.58 (1.41) | 3306.5[b] | .465 | 0.07 |

*Note*. The Bonferroni correction was applied here because multiple between-group comparisons were conducted. Specifically, the statistical significance level was set at $p < .005$ because $\alpha /10 = .005$. Data presented are raw scores for individual tests. ESE = effect size estimate; in this case, Cohen's $d$; CCTT = Children's Color Trails Test; SCWT = Stroop Color-Word Test; TOL = Tower of London.
[a]Lower scores indicate better performance on these measures. Higher scores indicate better performance in all other cases. [b]Mann-Whitney $U$ tests conducted due to non-normal distributions. $T$-tests ($df$ = 160) were conducted in all other cases.
*$p < .05$; **$p < .01$, all one-tailed.

## Between-Group Comparisons

Although the AUD group performed more poorly than controls across all measures, after a Bonferroni correction was performed ($\alpha/10 = .005$), between-group comparisons indicated that this difference was statistically significant for only one measure, the SCWT (see Table 4). That is, participants in the AUD group were correct on significantly fewer colour-word items than participants in the control group, suggesting relative impairment in inhibition skills. As seen in Table 4, there were also certain noteworthy trends towards significance ($p < .05$) on the DS-Backwards, Coding, CCTT-Trial 2 and Phonemic Fluency outcome variables, suggesting some decrements for the AUD group in the areas of working memory, sustained attention, processing speed, self-monitoring, cognitive switching, and word generativity. Effect sizes ranged from very small (0.02) to medium (0.42; for the SCWT), indicating varied real-world, practical significance.

**Primary Multiple Regression Analysis: EF Domains**

Results of hierarchical regression analyses indicated that, after controlling for PIQ and relevant demographic variables (viz., sex, language of test administration, SES, and years of education), alcohol group status was statistically significantly associated with impaired performance in only one of the three EF domains, that of Cognitive Flexibility. Details about the overall regression models for all three domains are reported in Table 5. As shown, although beta values ($\beta$) indicate that the AUD group performed more poorly than the control group across all domains, group status alone (step 3) did not significantly predict performance in the domains of Attentional Control and Goal Setting. However, the overall regression model for the domain of Attentional Control was statistically significant (PIQ, language of test administration, and years of education were significant predictors). The domain of Goal Setting did not have a statistically significant model (i.e., none of the predictors accounted for a significant proportion of variability in performance on this domain).

Table 5
*Primary Hierarchical Regression Model Results for each EF Domain*

| | Attentional Control | Cognitive Flexibility | Goal Setting |
|---|---|---|---|
| $\beta$: control vs. AUD | -.06 | -.19 | -.09 |
| Model $F(6,151)$ | 6.98 | 9.36 | 1.58 |
| Model $p$-level | <.001 | <.001 | .156 |
| Step 1 $R^2$ | .09 | .12 | .01 |
| $\Delta R^2$ Step 2 | .13 | .11 | .04 |
| Step 2 $R^2$ | .21 | .23 | .05 |
| $\Delta R^2$ Step 3 | .004 | .04 | .01 |
| Step 3 $R^2$ | .22 | .27 | .06 |
| $\Delta F$ for Step 3 | 0.7 | 7.42 | 1.33 |
| $\Delta F$ $p$-level for Step 3[a] | .404 | .007 | .250 |

[a] *p*-value associated with contribution of group status (control vs. AUD).

As noted earlier, alcohol group status was a significant predictor of performance in the domain of Cognitive Flexibility (see Table 6). In this domain, whereas PIQ and the relevant demographic variables together accounted for 23% of the variability in performance, group status alone explained a further 4% of the variability in the data. This proportion, although seemingly small, is statistically significant. The overall model (with all predictors included) for Cognitive Flexibility was statistically significant (see Table 5), accounting for a total of 27% of the variability in performance. A significant result for group status in this domain suggests a relatively impaired ability in the AUD group to switch efficiently between alternate response categories, inhibit incorrect responses, and spontaneously generate words across various tasks.

Table 6

*Regression Analysis Results for Significant Executive Functioning Domain Score*

| | Cognitive Flexibility | | |
|---|---|---|---|
| | *B* | *t* | *p* |
| Step 1 | | | |
| Constant | | -5.08 | < .001*** |
| Performance IQ | .35 | 4.72 | < .001*** |
| Step 2 | | | |
| Constant | | -5.35 | < .001*** |
| Performance IQ | .32 | 4.37 | < .001*** |
| Sex | .001 | 0.01 | .993 |
| Language | -.15 | -1.78 | .078 |
| Socio-economic status | .07 | 0.85 | .398 |
| Education | .26 | 3.62 | < .001*** |
| Step 3 | | | |
| Constant | | -5.04 | < .001*** |
| Performance IQ | .30 | 4.23 | < .001*** |
| Sex | .01 | 0.07 | .944 |
| Language | -.17 | -2.04 | .044* |
| Socio-economic status | .04 | 0.51 | .611 |
| Education | .27 | 3.84 | < .001*** |
| Group: control vs. AUD | -.19 | -2.72 | .007** |

*Note.* $R^2$ = .12 for Step 1; $\Delta R^2$ = .11 for Step 2; $\Delta R^2$ = .04 for Step 3; $R^2$ = .27 for Step 3; $\Delta F$ = 7.42** for Step 3.

*$p$ < .05; **$p$ < .01; ***$p$ < .001

Furthermore, as shown in Table 6, the results also indicated that, within this domain, certain other variables alone also accounted for a significant proportion of the variance. PIQ, language of test administration, and years of education were all independent significant predictors of performance in this domain (i.e., participants with higher PIQ scores, those tested in English, and those with more years of education obtained higher scores on this composite domain).

Hence, in summary, regression analyses indicated that adolescents in the AUD group displayed generally poorer functioning relative to healthy adolescent controls in the executive domain of Cognitive Flexibility. Alcohol group status did not, however, appear to be significantly associated with poorer functioning in terms of Attentional Control and Goal Setting skills.

**Post-hoc Regression Analysis: Individual Measures in Cognitive Flexibility**

As group status significantly predicted performance on the Cognitive Flexibility domain, post-hoc hierarchical multiple regression analyses were conducted on the four measures (*z*-scores) comprising this domain: CCTT-Trial 2, SCWT, phonemic fluency, and semantic fluency tasks. Details about the overall regression models for these four individual outcome measures are reported in Table 7.

Table 7
*Post-hoc Regression Model Results for each Individual Outcome Measure in the Cognitive Flexibility Domain*

| | CCTT-Trial 2 | SCWT | Phonemic Fluency | Semantic Fluency |
|---|---|---|---|---|
| $\beta$: control vs. AUD | .14 | -.19 | -.15 | -.07 |
| Model $F(6,151)$ | 5.81 | 6.04 | 3.79 | 4.60 |
| Model $p$-level | <.001 | <.001 | .002 | <.001 |
| Step 1 $R^2$ | .10 | .05 | .08 | .03 |
| $\Delta R^2$ Step 2 | .07 | .11 | .03 | .13 |
| Step 2 $R^2$ | .17 | .16 | .11 | .15 |
| $\Delta R^2$ Step 3 | .02 | .04 | .02 | .004 |
| Step 3 $R^2$ | .19 | .19 | .13 | .15 |
| $\Delta F$ for Step 3 | 3.57 | 6.51 | 3.90 | 0.75 |
| $\Delta F$ $p$-level for Step 3[a] | .061 | .012 | .05 | .388 |

*Note.* CCTT-Trial 2 *z*-scores were reversed in order to perform a log transformation (lower score indicates better performance), hence the positive $\beta$ value. CCTT = Children's Color Trails Test; SCWT = Stroop Color-Word Test.
[a]*p*-value associated with contribution of group status (control vs. AUD).

As shown, results indicated that, after controlling for PIQ and the relevant demographic variables, alcohol group status (step 3) was significantly associated with impaired performance on only one of these outcome measures, the SCWT. Group status alone did not significantly predict performance on any of the other three dependent measures. However, the result for group status for the phonemic fluency task ($p = .05$) is noteworthy as it indicates that AUD status was almost statistically significantly associated with relatively deficient performance (fewer words generated across letter categories) on this test measure. Furthermore, CCTT-Trial 2 results ($p = .061$) also show a notable trend towards statistical significance suggesting poorer performance (longer time to completion) in the AUD group on this mental set-shifting task.

As also shown in Table 7, despite a non-significant group status result, the overall regression models were statistically significant for CCTT-Trial 2 (PIQ, and years of education were significant predictors), phonemic fluency (PIQ was a significant predictor), and semantic fluency (sex, language of test administration, and years of education were significant predictors).

As noted, the SCWT was the only dependent measure on which AUD group status significantly predicted poorer performance (see Table 8). This result is consistent with the results of the between-group comparisons. Here (as indicated by the negative beta value) AUD group status predicted significantly fewer correct colour-word items and hence significantly more errors on this task. Whereas PIQ and the relevant demographic variables together accounted for 16% of the variability in performance on this outcome measure, group status alone explained a further significant 4% of the variability in the data. The overall regression model predicting performance on the SCWT was statistically significant (see Table 7), accounting for a total of 19% of the variability in performance.

As shown in Table 8, the results further indicated that PIQ and years of education were also both significant predictors, when all other predictors were held constant, of performance on this outcome measure (i.e., participants with higher PIQ scores and participants with more years of education obtained higher scores on this measure).

Interestingly, across all analyses, whereas PIQ, years of education and language of test administration were common significant predictors, participant sex was associated with performance on only one task, semantic fluency (males outperformed females on this task). Furthermore, SES was not significantly associated with performance on any of the individual outcome measures or on the composite domains.

Table 8
*Post-hoc Regression Analysis Results for Significant Individual Test Outcome Measure in the Cognitive Flexibility Domain*

| | Stroop Color-Word Test | | |
|---|---|---|---|
| | *B* | *t* | *p* |
| Step 1 | | | |
| Constant | | -3.12 | .002** |
| Performance IQ | .22 | 2.77 | .006** |
| Step 2 | | | |
| Constant | | -4.18 | < .001*** |
| Performance IQ | .21 | 2.75 | .007** |
| Sex | -.14 | -1.85 | .066 |
| Language | -.07 | -0.86 | .393 |
| Socio-economic status | .02 | 0.19 | .847 |
| Education | .27 | 3.60 | < .001*** |
| Step 3 | | | |
| Constant | | -3.86 | < .001*** |
| Performance IQ | .20 | 2.59 | .011* |
| Sex | -.14 | -1.83 | .070 |
| Language | -.09 | -1.09 | .280 |
| Socio-economic status | -.01 | -0.13 | .896 |
| Education | .28 | 3.80 | < .001*** |
| Group: control vs. AUD | -.19 | -2.55 | .012* |

*Note.* $R^2 = .05$ for Step 1; $\Delta R^2 = .11$ for Step 2; $\Delta R^2 = .04$ for Step 3; $R^2 = .19$ for Step 3; $\Delta F = 6.51$* for Step 3.
*$p < .05$; **$p < .01$; ***$p < .001$

In summary, post-hoc regression analyses indicated that within the domain of Cognitive Flexibility, AUD group status was statistically significantly associated with poorer functioning on the measure of response inhibition only, although there were trends toward statistical significance on measures of phonemic word generativity, self-monitoring, and cognitive switching.

## Discussion

The present study aimed to systematically investigate the potentially deleterious impact of relatively ‘pure’, heavy alcohol use on executive functioning during adolescence. Untreated, community-dwelling adolescents with alcohol use disorders were compared to demographically-matched controls on performance across a range of EF measures. A domain-specific model of EF, proposed by Anderson et al. (2001), was used to provide a solid theoretical base for the research. Based on previous literature, which has been sparse and fraught with methodological limitations, I hypothesized that excessive alcohol consumption during adolescence would be associated with poorer functioning in the EF domains of Attentional Control and Cognitive Flexibility, but that Goal Setting skills would remain relatively unimpaired. Results of two separate analyses, basic between-group comparisons and more sophisticated regression analyses, were relatively consistent and indicated that this hypothesis was partially confirmed: the AUD group demonstrated relative deficits in the domain of Cognitive Flexibility but not in the domains of Attentional Control or Goal Setting.

Hence, the hypothesis that adolescent alcohol use would predict impaired abilities on tasks involving cognitive flexibility (e.g., tasks that required self-monitoring, mental set shifting, spontaneous word production and response inhibition) was firmly supported by the data. AUD participants in this study exhibited notably poorer performance relative to healthy controls across this composite domain. Therefore, these results suggest that alcohol misuse during this neuro-developmentally vulnerable period may reduce the capacity to respond flexibly and adaptively to complex situational demands. Interestingly, adult studies have frequently reported similar alcohol-related deficits in the area of mental flexibility (Ihara et al., 2000; Ratti et al., 2002). Consequently, one might propose that certain aspects of EF may be impacted by adolescent AUDs in ways that parallel the effects of more chronic alcoholic behaviour that stretches over an extended period.

On post-hoc analysis, statistical trends indicated that the significant finding for the Cognitive Flexibility domain in this study may be partially attributed to subtle deficits in word generation ability and in the capacity to monitor behaviour and to flexibly shift between cognitive sets. Indeed, mental set shifting is an ability commonly noted to be impaired by alcohol in the adult literature (see Thomas & Ferrett, in press, for a review). However, the most prominent finding driving significance in this domain was a notable alcohol-related impairment in inhibitory control. That is, it would appear that heavy alcohol use during adolescence is particularly associated with difficulties in selectively attending to relevant information while simultaneously suppressing habitual, prepotent responses to conflicting, irrelevant information.

In short, adolescent AUDs may predict poor cognitive control and impulsive behaviour. These findings are relatively consistent with those reported in some international and local studies. For instance, the finding by Tarter et al. (1995) that substance abusers are highly distractible and susceptible to impulsive responding to irrelevant stimuli was supported by the present study. Furthermore, and importantly, the present finding appears to confirm the results of local research conducted with a similar adolescent population (Ferrett et al., 2010). As in the current study, those investigators found heavy adolescent alcohol use to be associated with poor self-monitoring and self-regulation abilities and a reduced capacity to inhibit salient responses.

The hypothesis that adolescent AUDs would be associated with impaired performance in the domain of Attentional Control was not supported by the current data. Although the data indicated trends toward mild deficiencies on aspects of attentional functioning, specifically working memory, processing speed, and sustained attention, the overall domain of Attentional Control was unimpaired in the AUD group. These results stand in strong contrast to the findings of previous studies that have consistently demonstrated that adolescent SUDs predict significant attentional difficulties. For instance, Tapert and Brown (1999) and Tapert et al. (2002) found protracted substance use during adolescence to be associated with notable attention and working memory deficits at 4- and 8-year follow-ups. Similarly, Tarter et al. (1995) reported an association between substance abuse and poor performance on tests of sustained attention and perceptual speed.

Although the current study did not replicate the results reported in those previous studies of substance-abusing adolescents, it did, however, confirm the findings of a similar study of treatment-naïve adolescents with relatively 'pure' alcohol dependence conducted by Ferrett et al. (2010). Those researchers also found no attentional deficits in their sample. Hence, the present research suggests that although adolescent alcohol use may confer mild deficits in aspects of attention, these may remain below the threshold of clinical significance, and general attentional control abilities do not appear to be adversely affected in adolescents who abuse alcohol in the absence of other substances.

The current results also confirmed the hypothesis that cognitive abilities in the domain of Goal Setting would not be impaired in the AUD group relative to healthy controls. That is, planning, problem-solving, and rule-configuration skills, and the capacity for strategic behaviour, appeared to remain relatively intact even in adolescents with heavy alcohol use. This finding is consistent with previous adolescent research which has failed to find significant deficits in planning or problem-solving abilities in adolescents with SUDs (Tapert & Brown, 1999) or local, untreated adolescents with alcohol dependence (Ferrett et al., 2010). Such results may reflect the finding that these abilities are relatively mature by the age of 12 years (Anderson et al., 2001), and hence possibly less vulnerable to developmental disruption by alcohol during the adolescent period. Alternatively, the finding in the extant adult literature that chronic alcoholism is associated with inferior planning ability and deficits in ‘everyday’ problem solving skills (e.g., Ihara et al., 2000; Ratti et al., 2002) leads to the tentative suggestion that while these skills are relatively resilient during adolescence, they may become more susceptible to impairment with protracted alcohol use and age. Such conclusions are beyond the scope of the present research, however. Finally, this result may also simply reflect the current reliance on only one task, the TOL, to assess these specific skills. However, the consistency of this finding with previous adolescent research that has used more comprehensive test batteries (e.g., Ferrett et al., 2010; Tapert & Brown, 1999) appears to rule out this possibility.

Results of the current study also indicated interesting associations between certain demographic factors and EF performance. PIQ and level of education were positively associated with performance across most EF domains (with the exception of Goal Setting) and individual measures. This result is expected in light of standard findings in the field which suggest that intellectual ability and educational achievement consistently predict outcomes on a range of EF and cognitive tests (Strauss et al., 2006). Interestingly, the current data suggested that SES did not exert a significant influence on EF abilities; this result stands in contrast to previous findings which suggest that higher SES levels are positively associated with better cognitive performance (e.g., Tarter et al., 1995). However, it is possible that the result reported here simply reflects the limited variability of this demographic factor in the current sample. That is, most participants fell within a relatively narrow SES range, and hence the finding that SES is not a significant predictor may simply be an artefact of sampling characteristics.

Another interesting, unexpected finding of the current study is that participant sex did not impact on performance on most EF measures. This finding is not consistent with previous adolescent research which has found evidence of sex differences in performance across the three EF domains highlighted here (Anderson et al., 2001). Furthermore, extant work in this field has demonstrated that adolescent females appear to be more vulnerable than males to alcohol-related neurocognitive sequelae (Brown & Tapert, 2004; Tarter et al., 1995). Such sex differences in terms of susceptibility to the adverse effects of alcohol, specifically with regards to EF, were not consistently supported by the current data, however. Interestingly, this finding is consistent with those of Ferrett et al. (2010), who recently reported no differences between male and female adolescents with AD on general neuropsychological performance.

The only measure in the present study on which participant sex did significantly predict performance was the semantic fluency task. On that task, males produced significantly more ‘animal’ words than females. This result stands in contrast to most findings in the relevant literature which have generally indicated no gender-specific differences on animal fluency (Strauss et al., 2006). However, a similar male performance advantage on this task has previously been noted by Sliwinski and Buschke (1999). The finding of a sex difference on this task in only these two studies, and not other previous research, may be the consequence of large sample sizes in both which are capable of detecting small effect sizes. Hence, it may potentially reflect a general type II error in the extant literature and should be addressed in future research.

Overall, the value of the present study lies in its ability to make strong, conclusive statements regarding the impact of alcohol on adolescent executive abilities due to its highly theoretical nature, and the exclusive focus on a unique sample of untreated adolescents with ‘pure’ AUDs. That is, possibly due to the myriad of conceptual and measurement difficulties associated with the construct of EF (Zelazo & Müller, 2002), previous research in this field has generally been broad and has lacked an organised theoretical foundation for its study. This is the first study to specifically and systematically investigate the effects of heavy alcohol use on adolescent executive skills using a clear, concrete conceptual framework. The current use of a domain-specific model of EF, which has been previously validated for research with adolescents (Anderson et al., 2001), has allowed the drawing of conclusions that are structured, specific, and theoretically-sound, and that can be considered sufficiently comprehensive. Furthermore, as this model has been found to be developmentally staged, it allows for the present findings to be understood within the context of normal adolescent development.

Another strength of the current study is its use of a sample of adolescents with AUDs but with no other SUDs or comorbid psychopathology. Previous studies in this field have generally relied on samples of adolescents who exhibit polysubstance use disorders (i.e.,a history of abuse of substances other than or in addition to alcohol) and psychiatric comorbidity (e.g., Tapert & Brown, 1999; Tapert et al., 2002; Tarter et al., 1995). The unique impact of alcohol on adolescent functioning has therefore been difficult to establish. The current data, however, are not complicated by the presence of other substances or psychiatric symptoms and the observed effects can be more reliably attributed to the effects of alcohol. Hence, although this study replicates some of the findings of previous research, it does so in a relatively ‘clean’ population and thereby enhances the power of such conclusions.

Furthermore, as noted earlier, certain previous findings, particularly those related to attentional impairment in adolescent substance abuse (Tapert & Brown, 1999; Tapert et al., 2002), were not confirmed by the present data. This pattern of outcomes suggests that the deficits seen in previous studies may not have been attributable to the specific impact of alcohol. In fact, generally the pattern of EF impairment found in the present study was less pervasive than that reported elsewhere: only the domain of cognitive flexibility was impaired, with attentional abilities and goal setting skills remaining intact. This result may indicate that 'pure' alcohol use has a more selective impact on adolescent EF, primarily disrupting those components of PFC functioning underlying the capacity for mental flexibility, self-regulation and inhibitory control.

Finally, the present focus on treatment-naïve adolescents represents an additional advantage of the current study (as in Ferrett et al., 2010). Most previous studies in the adolescent AUD field have based their conclusions on samples of adolescents in treatment. However, individuals in treatment for AUDs typically have significantly higher levels of comorbid psychiatric disorders and more severe patterns of alcohol use than treatment-naïve individuals who abuse alcohol (Di Sclafani et al., 2008; Fein, Klein, & Finn, 2004; Fein, McGillivray, & Finn, 2006). Hence, results of studies that rely on this clinical group cannot be assumed to apply generally to the broader population of untreated AUD individuals (Fein & Landman, 2005). However, considering the finding that a significant number of alcohol-abusing youth are community-dwelling (Flisher et al., 2003), samples representative of this group, such as that in the present study, can be considered an essential aspect of relevant AUD research. That is, the representative nature of the current sample is particularly important as it renders present findings more reflective of the pattern of EF deficits that we may expect to observe in the larger population of community-dwelling adolescents with AUDs.

One important limitation of the present study that warrants discussion is the cross-sectional design employed. Although associations between heavy adolescent alcohol use and certain EF deficits were established, this cross-sectional, correlational design makes it impossible to draw causal links (Brown et al., 2000). Hence, as participants in this study already met diagnostic criteria for AUD, it is not possible to establish whether these deficits arose as a consequence of alcohol use or were, in fact, a precursor to adolescent AUDs, potentially having contributed to their onset (as noted by Tarter et al., 1995).

The nature of impairments found, which particularly emphasize deficits in inhibition skills, compound this problem. That is, executive dysfunction, and more specifically cognitive and behavioural disinhibition/dysregulation, appear to be risk factors for adolescent participation in substance abuse (Clark, Cornelius, Kirisci, & Tarter, 2005; Dawes et al., 2000; Dolan, Bechara, & Nathan, 2008; Tarter et al., 2003). For instance, Nigg et al. (2006) followed a sample of children longitudinally and found deficits in response inhibition skills to strongly predict the onset of problematic drinking patterns in adolescence. Consequently, although the present results suggest that alcohol use contributes to impaired cognitive flexibility and self-regulation skills, there exists the possibility that a reduced capacity to regulate behaviour, and to inhibit inappropriate responses and control impulses, antedates heavy alcohol use during adolescence (Ferrett et al., 2010). Future research should include prospective longitudinal studies which follow individuals in this population from childhood and examine the specific trajectory of alcohol use and EF deficits in order to clarify these issues of directionality.

The possible existence of additional, unconsidered factors that may mediate the observed associations between adolescent AUDs and specific EF impairments might further complicate interpretations. A family history of heavy alcohol use, for instance, has been associated both with a higher risk for the development of adolescent AUDs and with deficits on certain aspects of EF (Brown & Tapert, 2004; Dolan et al., 2008; Monti et al., 2005). Hence, it is possible that in the current sample, impairments are attributable to family history of AUDs rather than, or in addition to, personal alcohol use. Future research in this field should perhaps take this pre-existing factor into consideration in order to refine conclusions about the relationship between active alcohol abuse during adolescence and EF difficulties. Similarly, the presence of externalizing psychopathology, such as conduct disorder or attention deficit hyperactivity disorder, which is associated both with AUDs and poor executive control, may also function as a potentially mediating factor (Dawes et al., 2000; Finn et al., 2009). However, as adolescents with these disorders were excluded from the present study, this possibility may be ruled out for the current data.

Another limitation of the present study is that although the method of statistical analysis controlled for the influence of demographic variables, the effects of those variables on the currently observed associations cannot be entirely ruled out (see Tapert & Brown, 1999, for a discussion of this general point). That is, findings may reflect the complex interaction between adolescent AUDs and other socio-demographic factors, such as education level and language (Ferrett et al., 2010). Although such investigation is beyond the scope of this study, future research could perhaps examine in more detail the effects of sex, SES, language, and level of education on adolescent EF abilities. Such research may be particularly pertinent locally considering the educational, economic, and sociocultural diversity of the South African population.

An additional drawback of the current cross-sectional design is that it is consequently not possible to establish whether the alcohol-related EF impairments exhibited are temporary or reflect long-term damage. Urine analysis and breathalyser screening prior to testing ensured that impairments cannot be attributed to alcohol intoxication at the time of testing. However, it is not clear whether the observed deficits are primarily associated with the effects of active, ongoing alcohol use, or are relatively permanent. Future longitudinal follow-up studies would be needed to clarify this issue. Findings of such research could shed light on whether the developing nature of the adolescent brain renders capacities that are adversely affected by alcohol more recoverable, or more likely to be permanently disrupted (Brown & Tapert, 2004).

Importantly, the present results, which indicate alcohol-related impairments in the EF domain of cognitive flexibility, are relatively consistent with findings of reduced PFC volumes in adolescents with AUDs (De Bellis et al., 2005). Hence, they appear to support the notion that heavy alcohol use during this vulnerable developmental period may in fact selectively disrupt certain aspects of PFC neuromaturation (Monti et al., 2005). However, such conclusions cannot be reliably drawn based purely on the results of a neuropsychological study. Rather, confirmation of such findings awaits future prospective structural and functional MRI studies of similar adolescent populations (Ferrett et al., 2010).

Regardless of issues of directionality discussed above, the association between adolescent AUDs and reduced mental flexibility and inhibitory skills established herein have important implications for treatment outcomes and for long-term functioning in these individuals. That is, baseline deficits in the ability of adolescents with AUDs to inhibit habitual responses, control impulses, and regulate behaviour flexibly may result in a feed-forward cycle that exacerbates heavy alcohol use, encourages further participation in high-risk activities, and limits the success of rehabilitation efforts (Dolan et al., 2008; Ihara et al., 2000; Tarter et al., 1995). Intervention aimed at enhancing abstinence and reducing relapse rates should therefore perhaps target such executive skills.

Furthermore, adolescence represents an important period of transition into adulthood responsibilities when individuals are required to acquire various life skills and to meet multiple, complex demands in the interpersonal, academic, and vocational realm (Monti et al., 2005; Paus, 2005). Such psychosocial developments set the stage for future effective adult functioning. Consequently, a reduced capacity for flexible, adaptive thought and behaviour during this developmental period may have important implications for limiting adolescents' ability to reach optimal potential in a number of critical life areas. That is, even transient alcohol-related impairment in the EF domain of cognitive flexibility during adolescence may contribute to significant and far-reaching deficits in social, educational, and occupational functioning. Considering that alcohol is the most popular substance of abuse amongst South African adolescents (Flisher et al., 2003; Parry et al., 2004), this situation may result in considerable costs for society and should be regarded as an urgent matter of public health concern.